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General Equilibrium Approach consistent with Travel Cost Method for Economic Evaluation of Beach Erosion by Climate Change *

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Abstract

Numerous attempts have been made to evaluate economic impacts by climate change, and the evaluation method can be classified into two approaches. One is a partial equilibrium approach and the other is a general equilibrium approach. The former method includes a travel cost method (TCM) and a contingent valuation method. On the other hand, the latter method has a computable general equilibrium (CGE) analysis. Considerable studies on economic evaluation of climate change have separately analyzed by two approaches. Therefore, by explicit linkage between a partial equilibrium approach and a general equilibrium approach, comprehensive assessments in a general equilibrium framework are needed. To measure economic impacts of the changes in environmental quality by climate change, this study develops a theoretical framework of a CGE model that integrates the utility function that has environmental quality as the independent variable derived from a recreation demand function in a TCM, confirms the validity of our CGE model through some numerical experiments using the beach erosion scenarios, and demonstrates that our CGE model is applicable for empirical analysis of climate change.

JEL Classification: C68, D58, Q26, Q51, Q54

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1 Introduction

Numerous attempts have been made to evaluate economic impacts by climate change, and the evaluation method can be classified into two approaches. One is a partial equilibrium approach and the other is a general equilibrium approach. The former method includes a travel cost method (TCM) and a contingent valuation method (CVM). These methods have been applied in some studies to quantify economic value of natural environment and ecosystem and value of statistical life. As these methods are partial equilibrium approaches for each case, however, economic impacts of changes in natural environment by climate change and environmental conservation policies on the whole economy cannot be captured. On the other hand, the latter method has a computable general equilibrium (CGE) analysis. As a computable general equilibrium model explicitly formulates an objective function in economic agent, direct impacts of climate change on economic activities of agent can be captured. Also, as a CGE model treats all markets in the economy, indirect impacts of climate change on the whole economy through change in the behavior of agent can be captured. By using a CGE model, however, to measure economic impacts of climate change on natural environment and ecosystem, formulation of impacts on them and estimation of their parameters in a model are needed. As mentioned above, considerable studies on economic evaluation of climate change have separately analyzed by two approaches. Therefore, by explicit linkage between a partial equilibrium approach and a general equilibrium approach, comprehensive assessments in a general equilibrium framework are needed.

Seung *et al.* (2000) attempted to apply a recreation demand function into a general equilibrium model for the water reallocation issues in Nevada, the United States. Seung *et al.* (2000) reported that impacts of the water reallocation issues on not some recreation sectors but agriculture sector could be analyzed by their method. As a recreation demand function used in their study, however, does not account for the generalized transportation cost, it is not consistent with a utility function. Ciscar *et al.* (2011) comprehensively evaluated economic and physical impacts of climate change on natural environment, ecosystem and human society in Europe. Ciscar *et al.* (2011) treated four sectors, which are agriculture, coastal zone, flood, and tourism, as physical impact term. Though their study calculated estimates of each physical impact from projected climate data under condition of socio-economic scenarios, and evaluated the projected economic impacts by economic model, it does not have a theoretical consistency between estimates of physical impact term and economic

model. On the other hand, in a general equilibrium analysis of the waste problem in Japan, Miyata (1995) derived a utility function consistent with a pre-formulated demand function from solving the integrability problem, and integrated an externality like waste into CGE model.

To measure impacts of damage in natural environment by climate change on the whole economy, the purpose in this study is to develop a theoretical framework of a general equilibrium model that integrates the utility function that has environmental quality variables as the independent variable derived from a recreation demand function in a travel cost method. Specifically, for tidal flats all over Japan, by solving the integrability problem from recreation demand function for shellfish gathering, utility function that has composite consumption goods, visit frequency to tidal flat and the area of tidal flat as the independent variables is derived, and that utility function is applied to a computable general equilibrium model. By developing utility function including in the area of tidal flat as the independent variable, this study can quantitatively measure how economic activities are affected by a loss of tidal flat due to climate change. In addition, this study extends the way of solving the integrability problem, as with Miyata (1995), to derive a utility function from a recreation demand function.

The structure of this study is the following. Chapter 2 explains estimation method of a recreation demand function in this model. Chapter 3 derives utility function from recreation demand function estimated in Chapter 2, by solving the integrability problem. Chapter 4 integrates utility function derived in Chapter 3 into a CGE model, and performs simplified numerical analyses. Finally, Chapter 5 presents concluding remarks and topics for future study.

2 Derivation of Utility Function

2.1 Utility Function Consistent with Recreation Demand Function

This study develops the expression for a utility function from a recreation demand function estimated by the zone travel cost method, and applies it to a computable general equilibrium model.

First, we assume that some regions are divided into N zones and each zone has natural environment which is a sandy beach in our study. Also, a recreation demand function from zone a to zone b is estimated by regression analysis as below. For elimination of negative

estimation of visiting rate and treatment of heteroskedasticity due to difference of population among each zone, we employ a semi-logarithmic function. For the details, see Cooper and Loomis (1993).

$$\ln \left(\frac{z_{ab}}{n_a} \right) = \hat{\gamma}_0 + \hat{\gamma}_1 p_{ab} + \hat{\gamma}_2 q_b + \hat{\varepsilon}_{ab}, \quad \forall a, b \quad (1)$$

$$p_{ab} \equiv \frac{p_2^Y g_{ab} + p_3^Y c_{ab} + w t_{ab}}{p^{NH}}, \quad \forall a, b \quad (2)$$

In Eq.(1) and Eq.(2), z_{ab} denotes the frequency of visit from zone a to zone b and n_a represents population in zone a . Therefore, (z_{ab}/n_a) signifies visiting rate from zone a to zone b . The price index p_{ab} is represented as travel cost per one visit that is needed to make a round trip zone a to zone b , and is defined as a relative price of composite goods price p^{NH} in Eq.(2). The price index p_{ab} is equivalent to p_{ba} . Then, p_2^Y , p_3^Y and w denote price of the petroleum and coal products sector, price of goods and services supplied by the transport sector, and value of time, respectively, as mentioned below. Also, g_{ab} , c_{ab} and t_{ab} represent amount of gasoline per one visit, expressway use per one visit and time per one visit, respectively. Furthermore, q_b signifies the environmental quality in zone b , which is treated as a sandy beach in this study. By formulating the environmental quality as the explanatory variable explicitly, we can make computable general equilibrium analyses by changes in environmental quality. In Eq.(1), $\hat{\gamma}_0$, $\hat{\gamma}_1$ and $\hat{\gamma}_2$ are estimated parameters and they are $\hat{\gamma}_1 < 0$ and $\hat{\gamma}_2 > 0$, and $\hat{\varepsilon}_{ab}$ is residual.

A travel cost method measures the consumer surplus CS from Eq.(1) to economically evaluate the environmental quality. The consumer surplus is shown to be proportional to the sum of the frequency of visit as below. In addition, $\mathbf{p}^Y = (p_1^Y, p_2^Y, p_3^Y)$ is a price vector and $\mathbf{q} = (q_1, \dots, q_n)$ is an environmental quality vector.

$$\begin{aligned} CS(\mathbf{p}^Y, \mathbf{q}) &\equiv \sum_a \sum_b \int_{p_2^Y g_{ab} + p_3^Y c_{ab} + w t_{ab}}^{\infty} n_a \exp \left\{ \hat{\gamma}_0 + \hat{\gamma}_1 \left(\frac{l}{p^{NH}} \right) + \hat{\gamma}_2 q_b + \hat{\varepsilon}_{ab} \right\} dl \\ &= -\frac{p^{NH}}{\hat{\gamma}_1} \sum_a \sum_b z_{ab} \end{aligned} \quad (3)$$

In general, when the environmental quality changes in $\mathbf{q}^0 \rightarrow \mathbf{q}^1$ in a travel cost method, from $\Delta CS = CS(\mathbf{p}^{Y_0}, \mathbf{q}^1) - CS(\mathbf{p}^{Y_0}, \mathbf{q}^0)$, the change in the environmental quality is evaluated by the price vector \mathbf{p}^{Y_0} fixed in initial period. Although this evaluation method is a simple process, without fixing a price vector, benefit by changing in the environmental quality

should be measured by considering the changes in a price vector. Our study aims at benefit measurement taking into account the changes in price and income.

As a demand function is derived from solving a utility maximization problem of household, there exists utility function corresponding to its demand function. And, it is known as the integrability problem. For the details on the integrability problem, see Varian (1992), Mas-Colell *et al.* (1995) and Jehle and Reny (2000). By solving the integrability problem, a utility function with Eq.(1) as a recreation demand function and a budget constraint are derived as below. For the details of these derivations, see the appendices.

$$u_a = x_a + \frac{1}{\hat{\gamma}_1} \sum_b z_{ab} (\ln z_{ab} - \ln \Gamma_{ab} - 1), \quad \forall a \quad (4)$$

$$p^{NH} x_a + \sum_b (p_2^Y g_{ab} + p_3^Y c_{ab}) z_{ab} = M_a, \quad \forall a \quad (5)$$

$$\Gamma_{ab} \equiv n_a \exp \left\{ \hat{\gamma}_0 + \hat{\gamma}_1 \left(\frac{wt_{ab}}{p^{NH}} \right) + \hat{\gamma}_2 q_b + \hat{\varepsilon}_{ab} \right\}, \quad \forall a, b \quad (6)$$

where u_a denotes a household utility in zone a , x_a represents consumption of composite goods in zone a and M_a is household income in zone a , respectively. Also, Γ_{ab} signifies the number of visitors from zone a to zone b , when price of gasoline and toll fees between zone a and zone b equal zero $p_2^Y = p_3^Y = 0$. If $\hat{\gamma}_1 < 0$, it is $z_{ab} \leq \Gamma_{ab}$ in subjective equilibrium of household and the second term of the right-hand side in Eq.(4) is non-negative. For simplification, as this study is assumed that there exists one household in this model, a utility function and a budget constraint are formulated by the summation of each variable with respect to zone in Eq.(4) and Eq.(5) as below.

$$U = NH + \frac{1}{\hat{\gamma}_1} \sum_a \sum_b z_{ab} (\ln z_{ab} - \ln \Gamma_{ab} - 1) \quad (7)$$

$$p^{NH} NH + \sum_a \sum_b (p_2^Y g_{ab} + p_3^Y c_{ab}) z_{ab} = M \quad (8)$$

where U is a utility ($= \sum_a u_a$), NH is consumption of composite goods ($= \sum_a x_a$) and M is income ($= \sum_a M_a$), respectively, in household.

2.2 Corresponding to the Social Account Matrix

Let $x_{2,ab}$ be consumption of gasoline and $x_{3,ab}$ be use of expressway needed to visit between zone a and zone b . Also, the frequency of visit between them is denoted by z_{ab} in independent variable of utility function. The relationships among them can be expressed as below.

$$x_{2,ab} = g_{ab}z_{ab}, \quad \forall a, b \quad (9)$$

$$x_{3,ab} = c_{ab}z_{ab}, \quad \forall a, b \quad (10)$$

Eq.(9) and Eq.(10) can be shown as optimal solution in cost minimization problem based on a production function with the Leontief technology as below.

$$z_{ab} = \min \left\{ \frac{x_{2,ab}}{g_{ab}}, \frac{x_{3,ab}}{c_{ab}} \right\}, \quad \forall a, b \quad (11)$$

From Eq.(11), it can be seen that household *produces* visit for a recreation site, and that Eq.(11) is a part of utility function. It is shown as UZ_{ab} in **Figure.1**.

Secondly, consumption of gasoline and use of expressway in household are aggregated with respect to all zones, respectively, as Eq.(12) and Eq.(13).

$$X_{2H} = \sum_a \sum_b x_{2,ab} \quad (12)$$

$$X_{3H} = \sum_a \sum_b x_{3,ab} \quad (13)$$

According to MIC (2009), gasoline is produced in the "petroleum refinery" sector and use of expressway is produced in the "travel agency and other services relating to transport" sector, in the input-output table for Japan composed of 190 sectors. This study is assumed that hypothetical sectors produce gasoline and expressway to visit a sandy beach.

This study estimates parameters in a recreation demand function by using travel cost data in Japan and annual traffic data among all prefectures. Therefore, by use of these data, annual consumption of gasoline and use of expressway to visit a sandy beach can be measured in money metric. Annual consumption of gasoline for visiting a sandy beach is divided from household consumption of the petroleum refinery products in the input-output table. Also, intermediate inputs and factor inputs in the petroleum refinery sector are divided at the same rate as household consumption. In a similar way, annual use of expressway for visiting a sandy beach is treated. Other production sectors are aggregated as the composite goods sector. In summary, our model has three goods and sectors that include consumption of gasoline for visiting a sandy beach, use of expressway for visiting a sandy beach and composite goods.

3 Outline of Model and Scenarios

3.1 Structure of CGE Model

Our CGE model consists of one household sector and three production sectors that produce the composite goods, the petroleum and coal products, and transport. **Figure.1** shows the consumption structure of household in our CGE model, where index R is used as household consumption for visiting a sandy beach and index H is used as household consumption excluding that for visiting a sandy beach. The set of all affordable bundles that satisfy consumer's budget constraint is derived from solving the basic problem of utility maximization. Then, consumption of the petroleum and coal products and transportation for visiting a sandy beach depends on a recreation demand function that has travel cost (the price of the petroleum and coal products, the price of goods and services supplied by the transport sector, and value of time) and the area of sandy beach. On the other hand, **Figure.2** shows the structure of production sectors. For the details of formulations of each economic agent, see the appendix.

3.2 Setting of Parameters

Parameters of a recreation demand function are estimated by function form shown in Eq.(1). Ohno (2009) created data set with travel cost and amount of traffic for visiting a sandy beach, from MLIT (2000) and MAFF (2004) database, and estimated parameters of a recreation demand function. Also, environmental quality data is created as logarithmic value of the area of sandy beach by prefecture estimated by Mimura (1994). Then, we employ the same data set as Ohno (2009) and the environmental quality data and estimate parameters of our recreation demand function by the least-square method. **Table.1** shows the estimated parameters. As regression coefficients of travel cost are estimated as negative and coefficient of environmental quality is positive, sign condition is satisfied. Also, all variables are significant. It can be seen that coefficient of environmental quality is less than 1, and that the frequency of visit decreases gradually as the area of sandy beach decreases. On the other hand, Ohno (2009) assumed that changing the area of sandy beach changes proportionally the frequency of visit.

Next, for the numerical experiment by using our CGE model constructed above, we need to create the social account matrix as the baseline data set. The input-output table by MIC (2009) is used for our baseline data set. By using this baseline data, all parameters in

our CGE model are estimated by calibration. Also, parameters of elasticity in the constant elasticity of substitution function σ are assumed as 2.0 exogenously. In addition, all estimated parameters in the production function are shown in **Table.2**.

3.3 Setting of Scenarios

The purpose of the numerical experiment in this study is to verify the model validity that we construct the CGE model consistent with a recreation demand function, by welfare measurement through changes in household behavior by environmental quality changes. Therefore, by assuming environmental quality change as the beach erosion, our scenario changes the erosion ratio from 10% to 90% by 10%. Our scenarios are called the beach erosion scenario.

3.4 Definition of Benefit

It is assumed that benefit in this study is defined by the equivalent variation (EV). As the indirect utility function converts the sum of the factor income and the consumer surplus into the composite goods term, it can be shown as below.

$$V(\mathbf{p}^Y, M, \mathbf{q}) = \frac{M + CS(\mathbf{p}^Y, \mathbf{q})}{p^{NH}} \quad (14)$$

As the expenditure function is inverse function of the indirect utility function with respect to income, it can be derived from solving for M , where V is the level of utility.

$$E(\mathbf{p}^Y, V, \mathbf{q}) = p^{NH}V - CS(\mathbf{p}^Y, \mathbf{q}) \quad (15)$$

We assume that the beach erosion causes the changes in the area of sandy beach from \mathbf{q}^0 to \mathbf{q}^1 . From the viewpoint of the general equilibrium analysis, such a change in the exogenous variable makes impacts on prices and factor income. With this beach erosion, it is assumed that price system changes from \mathbf{p}^{Y_0} to \mathbf{p}^{Y_1} , and factor income changes from M^0 to M^1 . Then, the equivalent variation is shown as below.

$$\begin{aligned} EV &= E(\mathbf{p}^{Y_0}, V(\mathbf{p}^{Y_1}, M^1, \mathbf{q}^1), \mathbf{q}^0) - E(\mathbf{p}^{Y_0}, V(\mathbf{p}^{Y_0}, M^0, \mathbf{q}^0), \mathbf{q}^0) \\ &= p^{NH_0} \cdot \left[\frac{M^1 + CS(\mathbf{p}^{Y_1}, \mathbf{q}^1)}{p^{NH_1}} - \frac{M^0 + CS(\mathbf{p}^{Y_0}, \mathbf{q}^0)}{p^{NH_0}} \right] \end{aligned} \quad (16)$$

The travel cost method based on the partial equilibrium analysis is often to measure benefit without considering the changes in price and factor income. If the utility function is quasi-linear, as shown below, the equivalent variation by the change in only the area of sandy

beach is equal to the differences in consumer surplus ΔCS , where this equivalent variation shows EV' .

$$\begin{aligned}
EV &= E(\mathbf{p}^{Y_0}, V(\mathbf{p}^{Y_0}, M^0, \mathbf{q}^1), \mathbf{q}^0) - E(\mathbf{p}^{Y_0}, V(\mathbf{p}^{Y_0}, M^0, \mathbf{q}^0), \mathbf{q}^0) \\
&= p^{NH_0} \cdot \left[\frac{M^0 + CS(\mathbf{p}^{Y_0}, \mathbf{q}^1)}{p^{NH_0}} - \frac{M^0 + CS(\mathbf{p}^{Y_0}, \mathbf{q}^0)}{p^{NH_0}} \right] \\
&= CS(\mathbf{p}^{Y_0}, \mathbf{q}^1) - CS(\mathbf{p}^{Y_0}, \mathbf{q}^0) = \Delta CS
\end{aligned} \tag{17}$$

From the differences between EV and EV' , it can be seen as below.

$$\begin{aligned}
EV - EV' &= p^{NH_0} \cdot \left[\frac{M^1 + CS(\mathbf{p}^{Y_1}, \mathbf{q}^1)}{p^{NH_1}} - \frac{M^0 + CS(\mathbf{p}^{Y_0}, \mathbf{q}^1)}{p^{NH_0}} \right] \\
&= p^{NH_0} \cdot \left[\left\{ \frac{M^1}{p^{NH_1}} - \frac{M^0}{p^{NH_0}} \right\} - \frac{1}{\hat{\gamma}_1} \sum_a \sum_b \{z_{ab}(\mathbf{p}^{Y_1}, q_b^1) - z_{ab}(\mathbf{p}^{Y_0}, q_b^1)\} \right] \tag{18}
\end{aligned}$$

Therefore, both cannot be equivalent theoretically. From the second term of the second equation in Eq.(18), if a recreation demand varies significantly according to price change through the change in environmental quality, it can be seen that there is large differences between EV and EV' . Also, the income change evaluated in the composite goods term makes impact on the differences between EV and EV' . In our numerical experiments, the equivalent variation calculated by our CGE model is compared with the differences in consumer surplus $\Delta CS(= EV')$ calculated from the estimation of recreation demand function.

4 Results from Numerical Experiments

First, **Figure.3** and **Figure.4** show that both the equivalent variation (EV) and the differences in the consumer surplus (ΔCS) run from about 3.5 billion yen per year to about 55 billion yen per year in economic damages, as the rate of the beach erosion increases, with decline of a recreation demand. Also, it can be seen that EV and ΔCS are close to the same in any scenario. This is likely to result from the slight differences in price change and income change in Eq.(16), as **Figure.5** and **Figure.6** indicate that the rates of change of price and income in each scenario are close to zero. However, though the difference between EV and ΔCS is very close, there exists the difference and both are not equivalent. In the definition of the equivalent variation in Eq.(16), it is clear that our CGE model reflects price change and income change that are not taken into account in the definition of the consumer surplus derived from the partial equilibrium approach.

Secondly, in any beach erosion scenarios, **Figure.6** shows that the prices of the petroleum and coal products and the transportation rise, and **Figure.7** indicates that the outputs of them decrease. On the other hand, in any scenarios, **Figure.8** shows that household consumptions of the petroleum and coal products and the transportation increase, and **Figure.9** indicates that household consumptions for visiting the sandy beach, consumption of gasoline and use of expressway, decrease. This is likely that, as a recreation demand decreases due to the beach erosion, consumption of gasoline and use of expressway for visiting the sandy beach decrease and household consumptions excluding the consumption for visiting the beach, consumption of the petroleum and coal products and the transportation, increase respectively.

It follows from our numerically experimental results by the beach erosion scenarios that our CGE model incorporating a recreation demand function is confirmed appropriate and valid, as the behaviors of calculated variables, that are price, income, demand, and output, can be explained in economics.

5 Concluding Remarks

To measure economic impacts of the changes in environmental quality by climate change, this study developed a theoretical framework of a computable general equilibrium model that integrates the utility function that has environmental quality factors as the independent variable derived from a recreation demand function in a travel cost method, and confirmed the validity of our CGE model through some numerical experiments using the beach erosion scenarios. The findings in this study are shown below.

1. By solving the integrability problem in the consumer's behavior theory, we derived the utility function that has composite goods, visit frequency to recreation sites and environmental quality in the site as the independent variable from the estimation of a recreation demand function in a travel cost method, and developed the theoretical framework of computable general equilibrium model consistent with the utility function derived in this study.
2. Through some numerical experiments by the beach erosion scenarios, we revealed that our CGE model can evaluated the changes in price and income that are not taken into account in the definition of the consumer surplus derived from the partial equilibrium approach.

3. By testing the economic validity of numerically experimental results, we demonstrated that our CGE model is applicable for empirical analysis of climate change.

Further consideration must be made of the environmental valuation that is not discussed herein. In the environmental economic valuation, it is of significant importance not only to measure the use value, but to measure non-use value. In a general equilibrium analysis, we need the consistent measurement of non-use value.

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A Figures and Talbles

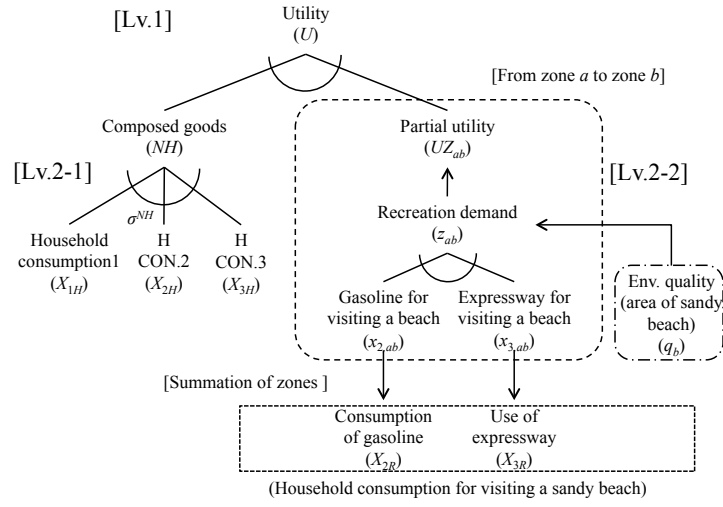


Figure 1: Consumption structure of household

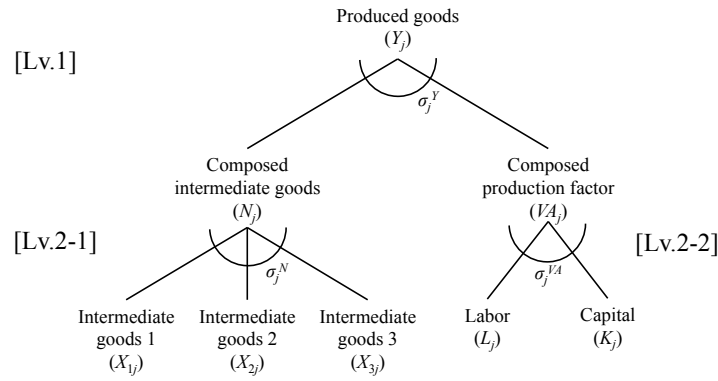


Figure 2: Structure of production sectors

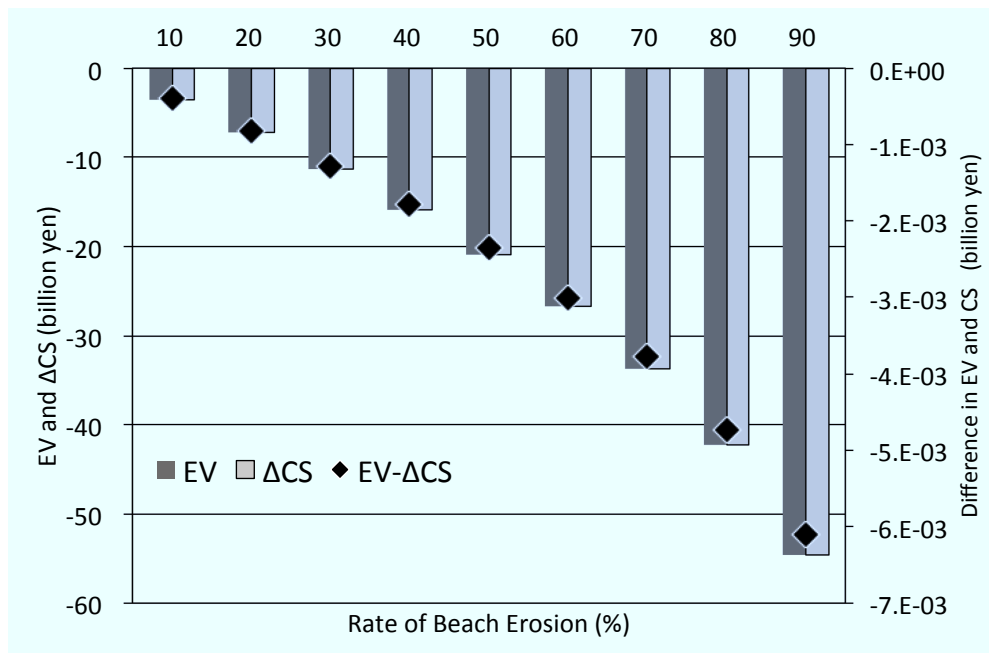


Figure 3: Equivalent variation and consumer surplus in each scenario

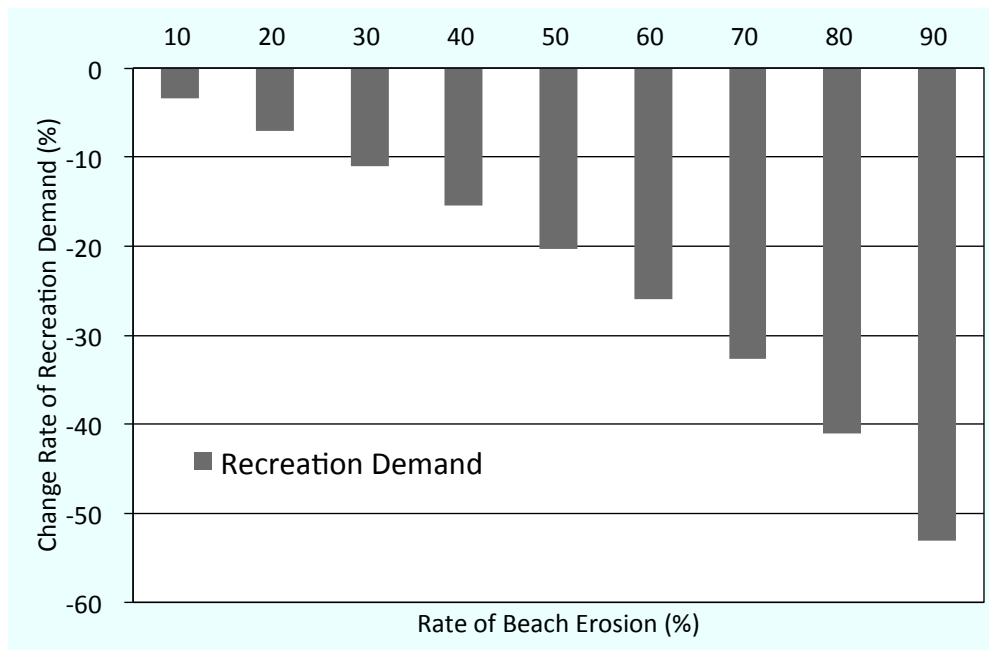


Figure 4: Change rate of recreation demand

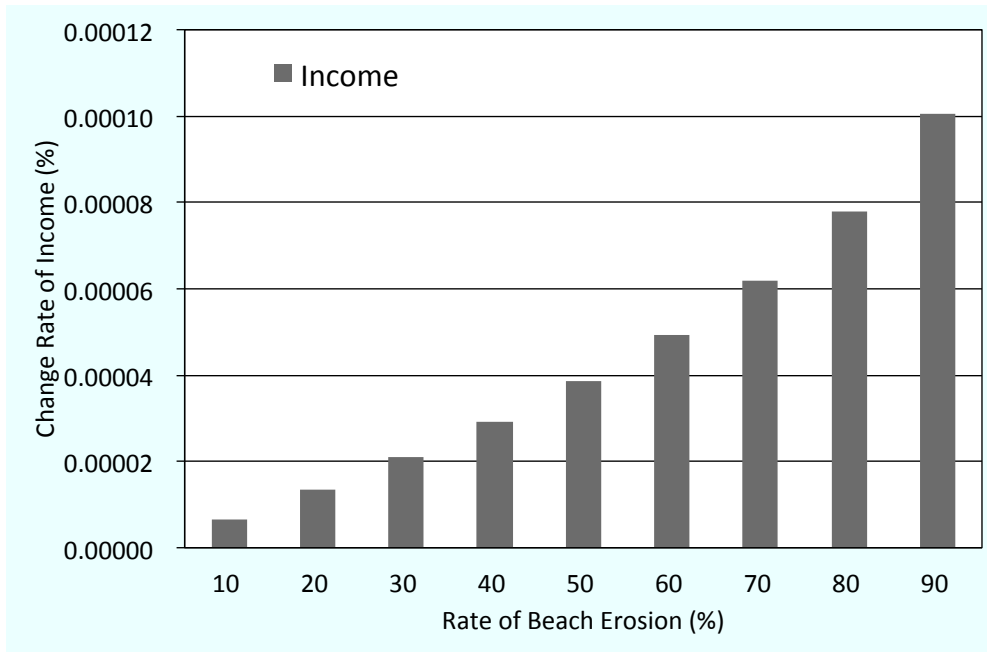


Figure 5: Change rate of household income

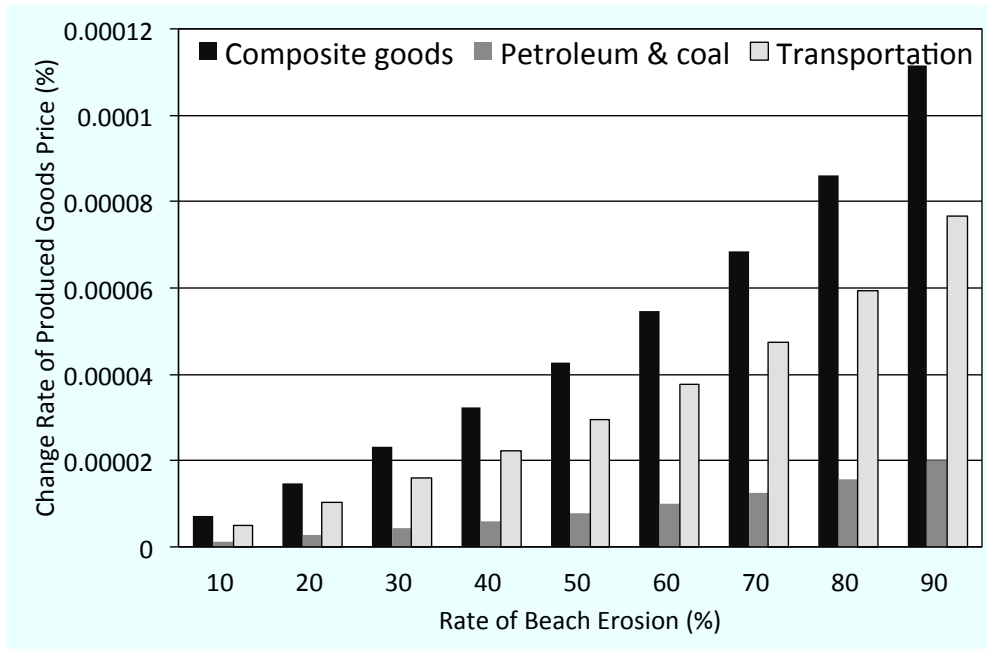


Figure 6: Change rate of output price produced by each production sector

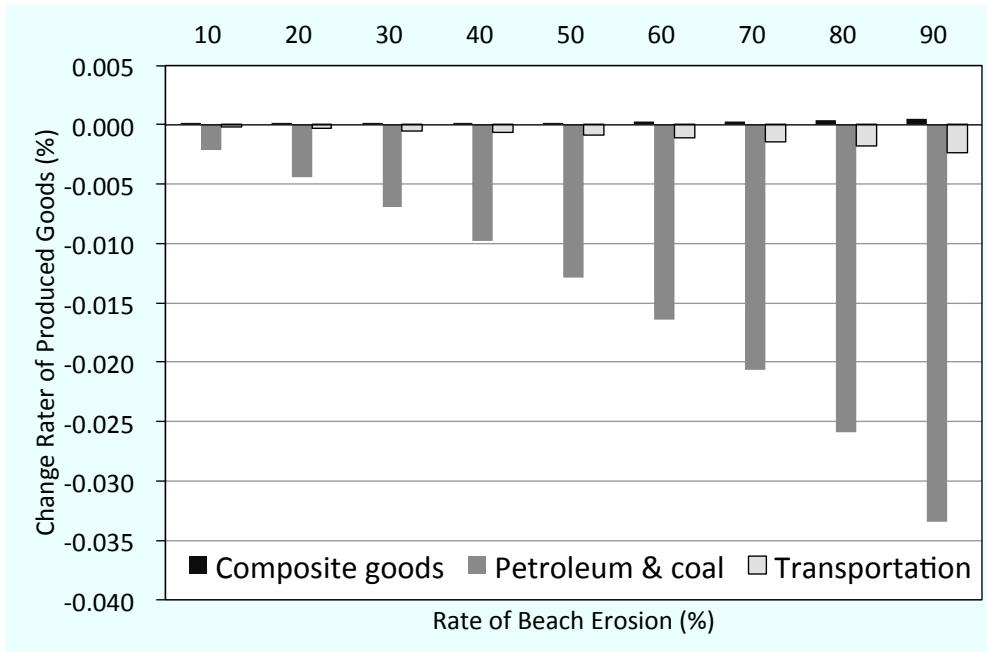


Figure 7: Change rate of output produced by each production sector

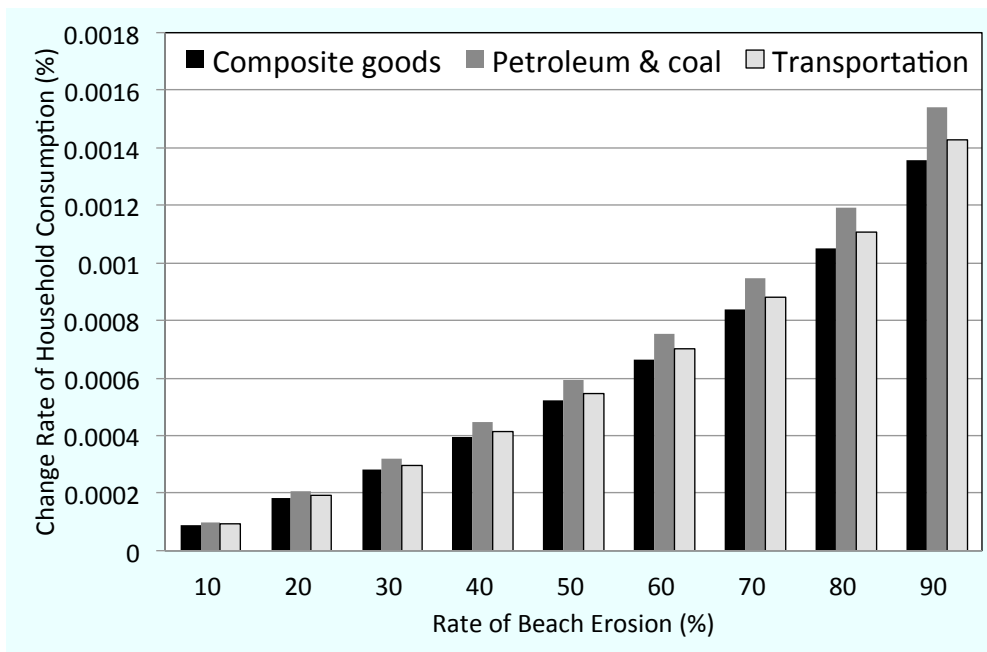


Figure 8: Change rate of household consumption (excluding consumption for visiting beach)

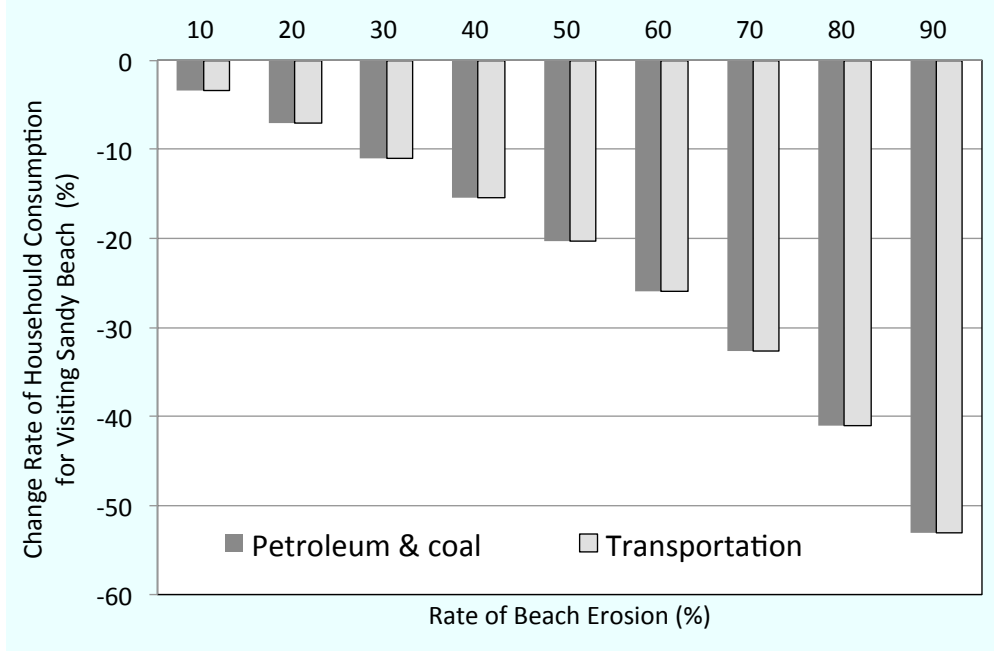


Figure 9: Change rate of household consumption for visiting sandy beach

Table 1: Estimated parameters in the utility function

coefficient	estimated value	t-value
$\hat{\gamma}_0$	-4.604	-7.575
$\hat{\gamma}_1$	-4.110×10^{-4}	-14.029
$\hat{\gamma}_2$	0.329	3.178
\hat{R}^2	0.477	
N. of observations	227	

Table 2: Estimated parameters in the production function

	1.composite	2. gasoline	3.expressway	–
α_j^Y	0.495	0.607	0.519	–
α_j^{VA}	0.545	0.779	0.613	–
α_{1j}^N	0.720	0.687	0.460	–
α_{2j}^N	0.096	0.170	0.261	–
α_{3j}^N	0.184	0.143	0.279	–
α_j^{NH}	0.778	0.070	0.151	–
ϕ_j^Y	2.000	1.912	1.997	–
ϕ_j^{VA}	1.984	1.526	1.903	–
ϕ_j^N	1.778	1.917	2.796	–
ϕ^{NH}	–	–	–	1.579

B Market Clearance Conditions

About the market clearance conditions, the goods market can be shown as Eq.(19), the labor market as Eq.(20), and the capital market as Eq.(21), respectively. Also, \bar{L} and \bar{K} are represented as initial labor and capital that household has as the initial endowment.

$$Y_i = \sum_j X_{ij} + X_{iH} + X_{iR} \quad \forall i \quad (19)$$

$$\bar{L} = \sum_j L_j \quad (20)$$

$$\bar{K} = \sum_j K_j \quad (21)$$

C Formulation of Household's and Producer's Behavior

In our model, **Table.3** shows the formulation of household's behavior, and **Table.4** shows the formulation of producer's behavior, respectively.

Table 3: Formulation of Household's Behavior

Level	Optimal problem
[1]	$\max_{NH, z_{ab}} U = NH + \frac{1}{\hat{\gamma}_1} \sum_a \sum_b z_{ab} (\ln z_{ab} - \ln \Gamma_{ab} - 1)$ $\text{s.t. } p^{NH} NH + \sum_a \sum_b (p_2^Y g_{ab} + p_3^Y c_{ab}) z_{ab} = M$
	Demand function
	$z_{ab} = n_a \exp(\hat{\gamma}_0 + \hat{\gamma}_1 p_{ab} + \hat{\gamma}_2 q_b + \hat{\varepsilon}_{ab}) \quad \forall a, b$ $NH = \frac{1}{p^{NH}} \left[M - \sum_a \sum_b (p_2^Y g_{ab} + p_3^Y c_{ab}) z_{ab} \right]$
[2-1]	Optimal problem
	$p^{NH} NH = \min_{X_{1H}, X_{2H}, X_{3H}} \sum_i p_i^Y X_{iH}$ $\text{s.t. } NH = \phi^{NH} \left[\sum_i \alpha_{iH}^{NH} (X_{iH})^{\rho^{NH}} \right]^{\frac{1}{\rho^{NH}}},$ $\text{where } \rho^{NH} = \frac{\sigma^{NH} - 1}{\sigma^{NH}}, \sum_i \alpha_{iH}^{NH} = 1 \quad (i = 1, 2, 3)$
	Demand function
	$X_{iH} = \frac{NH}{\phi^{NH}} \frac{(\alpha_{iH}^{NH})^{\frac{1}{1-\rho^{NH}}}}{(\Delta^{NH})^{\frac{1}{\rho^{NH}}}} (p^{NH})^{\frac{1}{\rho^{NH}-1}} \quad \forall i,$ $\text{where } \Delta^{NH} = \sum_i (\alpha_{iH}^{NH})^{\frac{1}{1-\rho^{NH}}} (p_i^Y)^{\frac{\rho^{NH}}{\rho^{NH}-1}}$
	Price
	$p^{NH} = \frac{(\Delta^{NH})^{\frac{\rho^{NH}-1}{\rho^{NH}}}}{\phi^{NH}} \quad \forall i$
	X_{iH} : consumption of i-th goods excluding for visiting sandy beach, $\alpha_{iH}^{NH}, \phi^{NH}$: parameters in the CES utility function ($0 \leq \alpha_{iH}^{NH} \leq 1$), σ^{NH} : elasticity of substitution
[2-2]	Optimal problem
	$\min_{x_{2,ab}, x_{3,ab}} p_2^Y x_{2,ab} + p_3^Y x_{3,ab}$ $\text{s.t. } z_{ab} = \min \left\{ \frac{x_{2,ab}}{g_{ab}}, \frac{x_{3,ab}}{c_{ab}} \right\} \quad \forall a, b$
	Demand function
	$x_{2,ab} = g_{ab} z_{ab}, \quad x_{3,ab} = c_{ab} z_{ab} \quad \forall a, b$ $X_{2H} = \sum_a \sum_b g_{ab} z_{ab}, \quad X_{3H} = \sum_a \sum_b c_{ab} z_{ab}$
	Expenditure function
	$e_{ab} = (p_2^Y g_{ab} + p_3^Y c_{ab}) z_{ab} \quad \forall a, b$

Table 4: Formulation of Producer's Behavior

Level	Optimal problem
[1]	$p_j^Y Y_j = \min_{N_j, VA_j} p_j^N N_j + p_j^{VA} VA_j$ $\text{s.t. } Y_j = \phi_j^Y \left[\alpha_j^Y N_j^{\rho_j^Y} + (1 - \alpha_j^Y) VA_j^{\rho_j^Y} \right]^{\frac{1}{\rho_j^Y}}, \text{ where } \rho_j^Y = \frac{\sigma_j^Y - 1}{\sigma_j^Y}$
	Demand function $N_j = \frac{Y_j (\alpha_j^Y)^{\frac{1}{1-\rho_j^Y}} (p_j^N)^{\frac{1}{\rho_j^Y-1}}}{\phi_j^Y (\Delta_j^Y)^{\frac{1}{\rho_j^Y}}}, \quad VA_j = \frac{Y_j (1 - \alpha_j^Y)^{\frac{1}{1-\rho_j^Y}} (p_j^{VA})^{\frac{1}{\rho_j^Y-1}}}{\phi_j^Y (\Delta_j^Y)^{\frac{1}{\rho_j^Y}}},$ $\text{where } \Delta_j^Y = (\alpha_j^Y)^{\frac{1}{1-\rho_j^Y}} (p_j^N)^{\frac{\rho_j^Y}{\rho_j^Y-1}} + (1 - \alpha_j^Y)^{\frac{1}{1-\rho_j^Y}} (p_j^{VA})^{\frac{\rho_j^Y}{\rho_j^Y-1}}$
	Price $p_j^Y = \frac{(\Delta_j^Y)^{\frac{\rho_j^Y-1}{\rho_j^Y}}}{\phi_j^Y}$
	p_j^Y : price of the j-th output, p_j^N : price of the j-th composite intermediate goods, p_j^{VA} : price of the j-th composite factor, Y_j : output by the j-th firm, N_j : composite intermediate goods, produced in the level [2-1] and used in the level [1], VA_j : composite factor, produced in the level [2-2] and used in the level [1], α_j^Y, ϕ_j^Y : parameters in the CES production function ($0 \leq \alpha_j^Y \leq 1$), σ_j^Y : elasticity of substitution in the CES production function
[2-1]	Optimal problem $p_j^N N_j = \min_{X_{1j}, X_{2j}, X_{3j}} \sum_{i=1}^3 p_i^Y X_{ij}$ $\text{s.t. } N_j = \phi_j^N \left[\sum_i \alpha_{ij}^N X_{ij}^{\rho_j^N} \right]^{\frac{1}{\rho_j^N}}, \text{ where } \rho_j^N = \frac{\sigma_j^N - 1}{\sigma_j^N}, \sum_i \alpha_{ij}^N = 1, (i = 1, 2, 3)$
	Demand function $X_{ij} = \frac{N_j (\alpha_{ij}^N)^{\frac{1}{1-\rho_j^N}} (p_i^N)^{\frac{1}{\rho_j^N-1}}}{\phi_j^N (\Delta_j^N)^{\frac{1}{\rho_j^N}}} \quad \forall i, \text{ where } \Delta_j^N = \sum_i (\alpha_{ij}^N)^{\frac{1}{1-\rho_j^N}} (p_i^N)^{\frac{\rho_j^N}{\rho_j^N-1}}$
	Price $p_j^N = \frac{(\Delta_j^N)^{\frac{\rho_j^N-1}{\rho_j^N}}}{\phi_j^N} \quad \forall i$

	X_{ij} : intermediate input of the i-th good used by the j-th firm, α_{ij}^N, ϕ_j^N : parameters in the CES production function ($0 \leq \alpha_{ij}^N \leq 1$), σ_j^N : elasticity of substitution
[2-2]	<div>Optimal problem</div> $p_j^{VA} V A_j = \min_{L_j, K_j} p^L L_j + p^K K_j$ $\text{s.t. } V A_j = \phi_j^{VA} \left[\alpha_j^{VA} L_j^{\rho_j^{VA}} + (1 - \alpha_j^{VA}) K_j^{\rho_j^{VA}} \right]^{\frac{1}{\rho_j^{VA}}}, \text{ where } \rho_j^{VA} = \frac{\sigma_j^{VA} - 1}{\sigma_j^{VA}}$ <div>Demand function</div> $L_j = \frac{V A_j}{\phi_j^{VA}} \frac{(\alpha_j^{VA})^{\frac{1}{1-\rho_j^{VA}}} (p^L)^{\frac{1}{\rho_j^{VA}-1}}}{(\Delta_j^{VA})^{\frac{1}{\rho_j^{VA}}}}, \quad K_j = \frac{V A_j}{\phi_j^{VA}} \frac{(1 - \alpha_j^{VA})^{\frac{1}{1-\rho_j^{VA}}} (p^K)^{\frac{1}{\rho_j^{VA}-1}}}{(\Delta_j^{VA})^{\frac{1}{\rho_j^{VA}}}},$ $\text{where } \Delta_j^{VA} = (\alpha_j^{VA})^{\frac{1}{1-\rho_j^{VA}}} (p^L)^{\frac{\rho_j^{VA}}{\rho_j^{VA}-1}} + (1 - \alpha_j^{VA})^{\frac{1}{1-\rho_j^{VA}}} (p^K)^{\frac{\rho_j^{VA}}{\rho_j^{VA}-1}}$ <div>Price</div> $p_j^{VA} = \frac{(\Delta_j^{VA})^{\frac{\rho_j^{VA}-1}{\rho_j^{VA}}}}{\phi_j^{VA}}$ $p^L: \text{ labor price, } p^K: \text{ capital price,}$ $L_j: \text{ labor used by the j-th firm, } K_j: \text{ capital stock used by the j-th firm,}$ $\alpha_j^{VA}, \phi_j^{VA}: \text{ parameters in the CES production function } (0 \leq \alpha_j^{VA} \leq 1),$ $\sigma_j^{VA}: \text{ elasticity of substitution}$

D The Integrability Problem

From a recreation demand function identified in Eq.(1), in accordance with Varian (1992), we derive a utility function that has it as an optimal solution in the utility maximization problem. This is known as the integrability problem. For the details of this problem, see Varian (1992).

First of all, the budget constraint that a consumer faces in zone a is shown as follows.

$$x_a + \sum_b p_{ab} z_{ab} = m_a \quad (22)$$

$$m_a \equiv \frac{M_a}{p} \quad (23)$$

For simplicity, Eq.(22) is rewritten as follows.

$$z_{ab} = \exp(\hat{\gamma}_{ab} + \hat{\gamma}_1 p_{ab}), \quad \forall b \quad (24)$$

$$\hat{\gamma}_{ab} \equiv \hat{\gamma}_0 + \hat{\gamma}_2 q_b + \hat{\varepsilon}_{ab} + \ln n_a, \quad \forall b \quad (25)$$

Since Eq.(24) is independent of income, it means the Marshallian demand function as well as the Hicksian demand function. Also, if such an expenditure function exists, it is known that it certainly must satisfy the system of partial differential equations given by Eq.(26) and the boundary condition in Eq.(27).

$$\frac{\partial e(\mathbf{p}_a, v(\bar{\mathbf{p}}_a, \bar{m}_a))}{\partial p_{ab}} = \exp(\hat{\gamma}_{ab} + \hat{\gamma}_1 p_{ab}), \quad \forall b \quad (26)$$

$$e(\bar{\mathbf{p}}_a, v(\bar{\mathbf{p}}_a, \bar{m}_a)) = \bar{m}_a \quad (27)$$

where $\mathbf{p}_a = (1, p_{a1}, \dots, p_{aN})$, $\bar{\mathbf{p}}_a = (1, \bar{p}_{a1}, \dots, \bar{p}_{aN})$, $e(\cdot)$ is an expenditure function, and $v(\cdot)$ is an indirect utility function. The solution to this partial differential equation is derived as follows.

$$\begin{aligned} e(\bar{\mathbf{p}}_a, v(\bar{\mathbf{p}}_a, \bar{m}_a)) &= \sum_b \int_{\bar{p}_{ab}}^{p_{ab}} \exp(\hat{\gamma}_{ab} + \hat{\gamma}_1 t) dt + C \\ &= \frac{1}{\hat{\gamma}_1} \sum_b \{\exp(\hat{\gamma}_{ab} + \hat{\gamma}_1 p_{ab}) - \exp(\hat{\gamma}_{ab} + \hat{\gamma}_1 \bar{p}_{ab})\} + C \end{aligned} \quad (28)$$

where C denotes the constant of integration, and it yields $C = m_a$ from the boundary condition. Therefore, an indirect utility function is shown as below.

$$v(\mathbf{p}_a, m_a) = \frac{1}{\hat{\gamma}_1} \sum_b \exp(\hat{\gamma}_{ab} + \hat{\gamma}_1 p_{ab}) + m_a \quad (29)$$

Recalling that both travel cost and income are in real terms of composite goods price, the minimization problem to derive a utility function is written as follows.

$$\min_{p, p_{a1}, \dots, p_{aN}} \frac{1}{\hat{\gamma}_1} \sum_b \exp \left\{ \hat{\gamma}_{ab} + \hat{\gamma}_1 \left(\frac{p_{ab}}{p} \right) \right\} + \frac{M_a}{p} \quad (30)$$

$$\text{s.t. } x_a + \sum_b \frac{p_{ab} z_{ab}}{p} = \frac{M_a}{p} \quad (31)$$

$$p_{ab} = p_2 g_{ab} + p_3 c_{ab} + w t_{ab} \quad (32)$$

The optimum value function by solving this problem means a utility function, and it is shown as follows.

$$U_a = x_a + \sum_b \left\{ \frac{z_{ab} \ln z_{ab} - (1 + \hat{\gamma}_{ab}) z_{ab}}{\hat{\gamma}_1} \right\} \quad (33)$$

The recreation demand function in Eq.(1) is derived from maximizing a utility function in Eq.(33) under a budget constraint in Eq.(22). However, a budget constraint equation in Eq.(22) includes the value of time $w t_{ab} z_{ab}$. Then, by focusing on that a utility function is quasi-linear, we have incorporated time needed visiting a recreation site into a utility function as disutility.

$$U_a = x_a + \sum_b \left\{ \frac{z_{ab} \ln z_{ab} - (1 + \hat{\gamma}_{ab}) z_{ab}}{\hat{\gamma}_1} - \frac{w t_{ab} z_{ab}}{p} \right\} \quad (34)$$

Rearranging Eq.(34), we have Eq.(4). Also, considering incorporation of time needed to visit a recreation site into a utility function, a budget constraint is rewritten in Eq.(5).