Assessment of investment system for rural resources and water quality management: multi-objective optimisation of interregional sustainable development

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Abstract: This study intends to develop a decision making model that gives a solution of social problems such as widening economic gap between rural and urban regions and the corresponding environmental pollution. To revitalise regions that confront rural collapse, a framework of interregional management should be sought. A household investment system is taken up as a watershed-based management approach that enables to improve the water quality and realise sustainable agricultural activities. Multi-objective optimisation problems regarding regional long-term utilities are solved with a water pollutant emission model and an investment behavioural model. The proposed investment system is assessed in terms of interregional economic growth and environmental conservation. As a result, the investment system works well on an additional rural economic development and the watershed water quality conservation without interrupting regional economic growth.

Keywords: interregional management system; investment model; rural resources; multi-objective optimisation; water pollutant.

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1 Introduction

A sufficient economic growth in commerce and industry triggers a flow of population from agricultural areas to cities and a rapid aging in rural regions. As a result, Japan incurs a collapse of rural communities. Some farmers are forced to withdraw from agricultural production activities and then abandoned farmlands are increasing. Ironically, it has been recognised that agricultural production base such as farmlands could have a potential of water quality improvement and mitigation of flood or global warming if the agricultural production base was maintained properly. Regional crisis management in decreasing both farmer activities and the corresponding environmental benefits is an urgent subject. This kind of social problem would be a common subject in developing and developed countries. Therefore, an effective method that can achieve a cross-regional sustainable development and environmental resources management should be sought.

An integrated policy making of inter-regional environmental and economic aspects would be needed to address the above social problem. In the existing market principle that agriculture is becoming a small industry, it is important to build up a rational system that other regions except rural regions are involved with sustainable rural management. This is probably a common management method so that rural regions can perform agricultural capital formation for sustainable production activity. In fact, it is suggested that the concept of social common capital becomes important in order to maintain a secure resource that would be lost easily under the market principle (McCay and Acheson, 1987). However, an additional discharge of environmental pollutant incurred by the economic development should be avoided. Above all, to make an interregional common management system, a proper model that enables to assess multi-regional economic growth and environmental impact with a certain policy should be developed.

In the previous research works, Dasgupta and Heal (1974) developed an inter-temporal general equilibrium model from the Ramsey model (1928) in order to investigate the accumulation-depletion process of environmental resource. Dasgupta (1993) and Barbier (2004) investigated the social issues of economic development of poor countries with economic models. Agrarian model was proposed by Uzawa (2005), who examined the conditions that agricultural social common capital and privately owned scare resources could develop with sustainability. Much research has been performed for regional, national economical development and environmental resources sustainability (Olli and Jari, 1991; Barbier, 1999; Poul, 2000; Andreas and Jacoby, 2005). Kiyama (2010) developed an integrated one-country model consisting of optimal economic growth, water pollutant emission and agricultural subsidy policy. The effect of subsidy policy on the optimal economic growth under environmental regulation was examined. However, most research works addresses a problem of a single region or a single country. Therefore, these policy analyses that address interrelated problems of regional economic gap and environmental conservation have not been performed sufficiently due to the complex numerical calculations with non-linear and multi-objective problems.

When an interregional management of the rural region is dealt with, it may be difficult to build an intimate relationship between rural and urban inhabitants with the subsidy policy. The subsidy policy does not give a chance of direct involvement among those inhabitants and is affected by all-farmer behaviour. Therefore, a different approach would be required to establish an interregional management, e.g., an investment system in something that watershed inhabitants could feel to be actively involved in rural management. The water is a vital resource for mankind and the prevention of water pollution with agricultural economic growth will be significant not only for rural inhabitants but also for the downstream, urban inhabitants. Chemical oxygen demand (COD) is a major index of eutrophication. Kiyama (2007) denotes that the agricultural sector has a greatest COD emission per unit production. The environmentally conscious farming is indeed more costly and a heavier work, but it can lead to have a higher income and a lower environmental burden of chemical fertilisers and pesticides. Therefore, it is likely that farmer's water quality improvement is an object of watershed household investment. This investment is also more attractive for farmers who can take up environmentally conscious farming more easily.

The purpose of this study is to develop a multi-regional decision making model with an investment system and to provide information that policy makers can seek regional sustainable agricultural development, improvement of regional economic gap and regional water quality conservation. Consequently, one country model (Kiyama, 2010) is extended to a two-country model consisting of rural and urban regions in the same watershed. The presented model has three sub-models: a dynamic computable general equilibrium model, an input-output based water pollutant emission model and an agricultural subsidy model. Furthermore, the investment system in farmer's water quality improvement is coupled with the proposed agricultural subsidy policy model of environmentally conscious rice farming (Kiyama, 2010).

This study describes the two-country model formulation and the numerical calculation method of Pareto optimisation problem with two regional utilities. The coupling methodology of investment system and subsidy policy model is subsequently mentioned. It is assumed that watershed household decides investment according to the marginal willingness to pay (MWTP) for water quality improvement. A series of policy scenario analysis is performed to investigate a long-term economic growth and environmental burden by region. The investment effect on inter-regional sustainable development, economic gap and the resultant water pollutant emission is discussed.

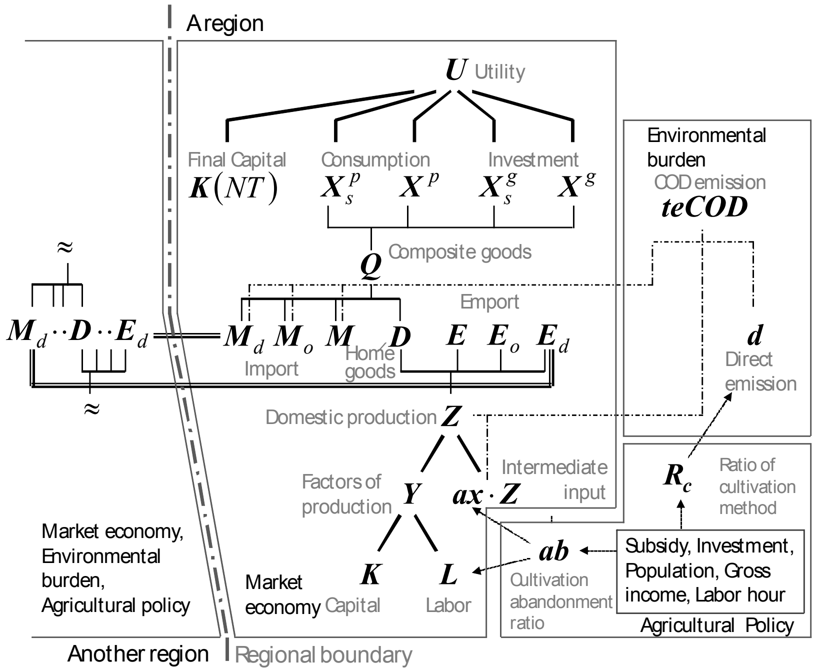
2 Methodology

An integrated model consisting of economic utility, environment burden and policy device is formulated. A genetic algorithm is applied in order to solve multi-objective problems regarding two regional utility functions. The corresponding explanation is described as follows.

2.1 A two-country model

A two-country model has been previously developed by Bianconi (2003) and Nishimura and Shimomura (2006). Let us consider two countries as a rural region and an urban region, which are located in the same watershed and are in physically-intimate in terms of the water cycle system. Each country, i.e., each region has a separate household, separate multi-sector firms and a separate government. Based on the conventional multi-sector dynamic model (e.g., Hosoe, 2001) and the corresponding watershed model (Kiyama 2010), Pareto optimisation problem of two regional long-term utilities is numerically solved with additional four profit maximising problems regarding the following: the composite goods production, the domestic goods production, the factors of production and the input of intermediate goods and factors of production. A series of profit maximisation problems are described as follows. Figure 1 illustrates a schematic diagram of the two-country model.

Figure 1 Schematic diagram of a two-country model



For a region denoted by i, a regional long-term utility during a finite time period is defined as the Cobb-Douglas type function consisting of consumption and final capital stock, $U(i)$.

$$U(i)=\sum_{k=0}^{NT-1}\sum_{l=1}^{NB}\left\{ \alpha_p(i,l)\ln X^p(i,l,k)+\alpha_g(i,l)\ln X^g(i,l,k)\right\}\frac{pop(k)}{(1+\rho)^k} + b\sum_{j=1}^{NB}\alpha_k(i,j)\ln K(i,j,NT)\frac{pop(k)}{(1+\rho)^{NT}}, \tag{1}$$

where j and l: sector, k: time period, X^p: household consumption, X^g: government consumption, K: capital stock, pop: population, ρ: the social discount rate, NT: the number of time periods, NB: the number of sectors. A parameter b denotes the contribution ratio of capital stock. Parameters α_p, α_g, α_k are determined from the sectoral composition ratio of X_p, X_g, K in the initial year, respectively. Pareto optimisation problem of two regions is also solved with the following budget constraint and capital accumulation constraint.

Household budget constraint:

$$\sum_{l=1}^{NB}p_l^q(l,k)\left\{ X^p(i,l,k)+X_s^p(i,l,k)\right\} =\left\{1-\tau_p(i)\right\}\sum_{l=1}^{NB}\left\{ p^k(l,k)K(i,l,k)+p^l(l,k)L(i,l,k)\right\}, \tag{2}$$

Government budget constraint:

$$\begin{aligned}\sum_{l=1}^{NB} p_l^q(l,k)\{X^g(i,l,k)+X_s^g(i,l,k)\} &= Tax(i,k)-\sum_{l=1}^{NB} sub(i,l,k),\\ Tax(i,k) &= \sum_{l=1}^{NB}\Big[\{\tau_p(i)+\tau_k(i,l)\}p^k(l,k)K(i,l,k)\\ &+\{\tau_p(i)+\tau_l(i,l)\}p^l(l,k)L(i,l,k)+\tau_m(i,l)p^m(l,k)M(i,l,k)\Big],\end{aligned} \tag{3}$$

Capital accumulation constraint:

$$K(i,j,k+1)=\{1-\delta(j)-n_p(i,k)\}K(i,j,k)+X_s^p(i,j,k)+X_s^g(i,j,k), \tag{4}$$

where X_s^p: the household investment, X_s^g: the government investment, p^q: the composite goods price, p^k and p^l: the price of production factors: capital and labour, p^m: the imported goods price, *Tax*: the total tax, τ_p: the income tax rate, τ_k and τ_l: the production tax rate of capital and labour, τ_m: the tariff rate, *sub*: the amount of subsidy, δ: the depreciation rate and n_p: the rate of population increase.

Furthermore, firms would produce their commodities to maximise their own profits regarding production factors: capital and labour, regarding these production factors and intermediate goods, regarding domestic goods and exported goods and regarding domestically produced goods and imported goods. The profit maximisation problem of domestic production process, the input share of production factors and the intermediate goods can be written by the following two-step structures.

Step 1 profit maximisation problem in inputting production factors:

$$\begin{aligned}\max \pi^y(i,j,k) &= p^y(j,k)Y(i,j,k)\\ &-\{1+\tau_k(i,j)\}p^k(j,k)K(i,j,k)\\ &-\{1+\tau_l(i,j)\}p^l(j,k)L(i,j,k),\end{aligned} \tag{5}$$

subject to

$$Y(i,j,k)=a(i,j)K(i,j,k)^{\alpha(i,j)}L(i,j,k)^{1-\alpha(i,j)}, \tag{6}$$

where p^y: the price of composite production factors and Y: the production function. The Cobb-Douglas type of production function is used for production factors. Parameters a, α denote the scale parameter of the production function and the parameter regarding input relationship between the capital and the labour, respectively.

Step 2 profit maximisation in inputting intermediate goods and production factors:

$$\begin{aligned}\max \pi^z(i,j,k) &= p^z(j,k)Z(i,j,k)\\ &-p^y(j,k)Y(i,j,k)-\sum_{l=1}^{NB} p^q(l,k)XX(l,j,k),\end{aligned} \tag{7}$$

subject to

$$Z(i,j,k)=\min\left\{\frac{XX(l,j,k)}{ax(l,j)},\frac{Y(l,j,k)}{ay(l,j)}\right\}, \tag{8}$$

where Z: the domestic production defined by the Leontief type (Leontief, 1953), XX: the intermediate input, ax: the intermediate input coefficient, ay: the input coefficient of composite production factors and p^z: the price of domestic goods.

Subsequently, domestically produced goods become four types of commodities: the domestic goods D, the exported goods to foreign E, exported goods to domestic regions outside the watershed E_o and exported goods to domestic regions inside the watershed E_d. These goods are assumed to be imperfect substitutes and have the relation of a constant elasticity of transformation. The corresponding profit maximisation problem can be described as:

$$\max \pi^z(i,j,k) = p^e(j,k)\,E(i,j,k) + p^d(j,k)\left\{D(i,j,k) + E_o(i,j,k) + E_d(i,j,k)\right\} - p^z(j,k)\,Z(i,j,k), \tag{9}$$

subject to

$$Z(i,j,k) = \vartheta(i,j)\Big\{\xi e_1(i,j)\,E(i,j,k)^{\varphi(i,j)} + \xi e_2(i,j)\,D(i,j,k)^{\varphi(i,j)} + \xi e_3(i,j)\,E_o(i,j,k)^{\varphi(i,j)} + \xi e_4(i,j)\,E_d(i,j,k)^{\varphi(i,j)}\Big\}^{\varphi(i,j)^{-1}}, \tag{10}$$

where p^e: the export price and p^d: the domestic price. The output transformation is assumed as the constant elasticity of transformation function with the scale parameter ϑ and the export share parameter ξe_m, $\xi e_1 + \xi e_2 + \xi e_3 + \xi e_4 = 1$; the elasticity of transformation is given by $1/(\varphi(i,j)-1)$.

Finally this study considers the profit maximisation problem for composite goods Q, which consists of domestic goods D and imported goods M, import goods from domestic regions outside the watershed M_o and import goods from domestic regions inside the watershed M_d. The Armington assumption is applied. This problem can be written by:

$$\max \pi^q(i,j,k) = p^q(j,k)\,Q(i,j,k) - \{1+\tau_m(i,j)\}\,p^m(j,k)\,M(i,j,k) - p^d(j,k)\left\{D(i,j,k) + M_o(i,j,k) + M_d(i,j,k)\right\}, \tag{11}$$

subject to

$$Q(i,j,k) = r(i,j)\Big\{\delta m_1(i,j)\,M(i,j,k)^{\eta(i,j)} + \delta m_2(i,j)\,D(i,j,k)^{\eta(i,j)} + \delta m_3(i,j)\,M_o(i,j,k)^{\eta(i,j)} + \delta m_4(i,j)\,M_d(i,j,k)^{\eta(i,j)}\Big\}^{\eta(i,j)^{-1}} \tag{12}$$

A constant elasticity of substitution function describing composite goods is given by equation (12) with the scale parameter r and the import share $\delta m(i,j)$, $\delta m_1 + \delta m_2 + \delta m_3 + \delta m_4 = 1$; the elasticity of substitution is given by $1/(\eta(i,j)-1)$.

Two regions inside the watershed, i.e., the rural region with $i = 1$ and the urban region with $i = 2$, should have the following condition of trade balance.

$$p^d(j,k)\,E_d(1,j,k) = p^d(j,k)\,M_d(2,j,k), \tag{13}$$

$$p^d(j,k)E_d(2,j,k) = p^d(j,k)M_d(1,j,k). \tag{14}$$

Furthermore, additional market equilibrium and a balance of international payment condition should be considered to solve the computable general equilibrium model.

$$\begin{aligned} Q(i,j,k) = {} & X^p(i,j,k) + X^g(i,j,k) + X_s^p(i,j,k) + X_s^g(i,j,k) \\ & + \sum_{l=1}^{NB} \{ ax(i,j,l)\, Z(i,l,k) + \lambda_l X_f(i,k) \}, \end{aligned} \tag{15}$$

$$\sum_{l=1}^{NB} p^{We}(i,l,k)\, E(i,l,k) + X_f(i,k) = \sum_{l=1}^{NB} p^{Wm}(i,l,k)\, M(i,l,k), \tag{16}$$

where X_f: the current-account deficit, λ: the sectoral current-account rate and p^{We} and p^{Wm}: the price of exported and imported goods in the foreign currency, respectively.

2.2 Numerical calculation

Pareto optimisation problem of two objective functions that correspond to regional long-term utility has to be solved. This study applies the α constrained genetic algorithm (α GA) to solve multi-objective optimisation problems with some constraint equations, i.e., equations (2)–(16). The GA combines the genetic algorithm and α constrained method as a direct search method. This method was proposed by Takahama and Sakai (2004) and then Kiyama (2010) utilised this calculation method to solve one-country dynamic optimal growth problem.

However, an extension of the retrospective method should be needed to solve Pareto optimisation problem. In place of conventional ranking method, Pareto-ranking method is employed to rank individuals that have two objective function values. New individuals are generated step by step so as to come close to Pareto solution while tightening a satisfaction level of constraint equations gradually.

A α level, which is denoted by $\breve{\alpha}$, is defined as a monotonically increasing function with the domain [0, 1]. This is used as a threshold value to check a satisfaction level of constrained equations.

$$\breve{\alpha}(t_g) = \begin{cases} -(1-\breve{\alpha}(0))(1-ct_g/T_g)^2 + 1, & 0 \le t_g < T_g/c \\ 1, & T_g/c \le t_g \end{cases}, \tag{17}$$

where c: a parameter that controls the threshold value of satisfaction level, t_g: a generation number, T_g: the total number of generations and $\breve{\alpha}(0)$: a mean value of initial residual sum of constraint equations of all individuals

A satisfaction level μ_h is also defined as an error sum of squares of constraint equations.

$$\mu_h(x_{ig}^{kg}) = \begin{cases} 1 - \sum_{jg} h_{jg}(x_{ig}^{kg})^2 / d_g, & \sum_{jg} h_{jg}(x_{ig}^{kg})^2 \le d_g \\ 0, & otherwise \end{cases} \tag{18}$$

where x_{ig}^{kg} : the *ig*th variable of individual number *kg*, h_{jg}: the residual error of constraint equation number *jg*, d_g: a parameter to regulate permissible range of residual error. A satisfaction level becomes 1 when the residual error of constraint equation becomes 0. Finally, a representative satisfaction level $\bar{\mu}_h$ is defined as the minimum satisfaction level among all individuals.

As a generation t_g is updated, individuals are well-adapted to have a higher representative satisfaction level. Then, individuals that have a higher ranking are selected by Pareto-ranking method when a representative satisfaction level is satisfied with a α level.

$$\min \sum_{jg} h_{jg} \left(x_{ig}^{kg} \right)^2, \quad when \quad \bar{\mu}_h < \breve{\alpha}, \tag{19}$$

$$\max U(i=1), U(i=2), \quad when \quad \bar{\mu}_h \geq \breve{\alpha}. \tag{20}$$

where *U*: regional long-term utility function value. The entire calculation process of modified α GA is described as follows.

Step 1 Set initial individuals.

Step 2 Calculate satisfaction level. Compared with $\bar{\mu}_h$ and $\breve{\alpha}$ and define either minimisation problem of residual error of constraint equations or Pareto optimisation problem of regional utility.

Step 3 When the error sum of squares of constraint equation is allowable, the calculation is terminated.

Step 4 Perform ranking selection.

Step 5 Perform simplex crossover (SPX).

Step 6 Perform mutation-crossover and then return to step 2.

The current study assumes the following condition: the number of individuals = 70, mutation rate = 0.5, simplex crossover rate = 0.2, bit length per variable = 12 and the number of generation = 200.

2.3 COD emission model

Industrial production could incur pollutant discharge. Leontief (1970) originally estimated the discharge amount of environmental pollutant and waste material with input-output tables. Since then Nansai et al. (2002) formulated the national input-output–based GHG emission model, Kiyama (2007) developed multi-regional COD emission model for the water pollution problem. This study applies the multi-regional COD emission model.

The water pollutant source migrates among multi-industrial sectors depending on the input condition of intermediate goods. For a region, the total COD discharged from a sector can be given as the sum of direct emission amount by itself and the indirect emission amount with the exception of import. Therefore, the following mass balance equation with respect to water pollutant COD per unit production can be written:

$$d\left(i,j,k\right)+e\left(i,j,k\right)\left\{\ ax\left(i,j,k\right)-M'\left(i,j,l\right)ax\left(i,l,k\right)\ \right\}=e\left(i,j,k\right), \tag{21}$$

where *d*: the measurable direct COD burden per unit production, *e*: the COD burden per unit production, i.e., the embodied COD emission intensity, and M': the diagonal block matrix of import coefficient. After solving the embodied COD emission intensity *e* from equation (21), the sectoral COD emission, *COD*, can be calculated as the product of the COD emission intensity and the value of production.

$$COD\left(i,j,k\right)=e\left(i,j,k\right)Z\left(i,j,k\right)p^{z}\left(j,k\right), \tag{22}$$

For a region *i*, the corresponding total COD emission, *teCOD*, is given as the sum of sectoral COD emission.

$$teCOD\left(i,k\right)=\sum_{l=1}^{NB}COD\left(i,l,k\right), \tag{23}$$

Figure 1 illustrates that the COD emission model is related to the general equilibrium model with economic variables of the import amount and the value of production. Especially for the agricultural industry, the direct COD burden per unit production *d*, the input of intermediate goods and the amount of production factors change depending on the policy regime such as the subsidy and the household investment.

2.4 Investment model

2.4.1 Model concept

This study develops a household investment behavioural model regarding the environmentally conscious rice farming. Households could gain an additional environmental benefit from the water quality improvement by farmers. Rice farmers could produce higher value-added commodities while reducing the amount of water pollutant discharge with a shift to environmentally conscious rice cultivation. Therefore, there could be a chance that both rural and urban inhabitants have a more benefits from the investment system. Unlike the delivery of subsidies depending on farmer's one-sided proposal, the investment could build good interrelationship between watershed households and rice farmers. The households will require their own benefits from the water quality that farmers should improve and also the farmers will provide maximal effort to perform the environmentally conscious rice cultivation.

A shift to environmentally conscious cultivation is performed on a farmland basis that is a smaller unit than a rural region. Therefore, the investment judgement should be conducted by a certain farmland size. This study considers a farmland with a square of 100 m on a side. This is the same condition of the agricultural subsidy policy model that judges whether the agricultural subsidy is paid to farmers or not (Kiyama, 2010). Thus, a farmland is collected as a GIS polygon that has a set of data, i.e., the cultivation abandonment ratio, the composition of environmentally conscious rice farming, subsidy amount, investment amount, population, population by industry, land elevation and angle of land gradient etc. The regional investment amount, which is also used for the two-country economic model, is calculated as a sum of all polygons that receive the investment in the corresponding region.

2.4.2 Extended subsidy model

The proposed investment model is formulated as the extended earlier agricultural subsidy model for environmentally conscious rice farming (Kiyama, 2010). The earlier model is introduced and then its extension methodology for the investment model is described.

The earlier model is a multiple regression model and estimates the composition ratio of rice cultivation methods. This model considers three types of cultivation methods: the conventional cultivation (type-*mc* = 1), organic cultivation (type-*mc* = 2) and cultivation by low chemical input (i.e., at least 50% less pesticide and chemical fertiliser) (type-*mc* = 3). The composition ratio of cultivation type-*mc* of polygon number *j*, year *k* can be given as:

$$Rc(mc, j, k) = \frac{\exp\left(\sum_{ic=1}^{NK} \kappa_{ic,mc} y_{ic,mc,j}\right)}{\sum_{mc'=1}^{3} \exp\left(\sum_{ic'=1}^{NK} \kappa_{ic',mc'} y_{ic',mc',j}\right)}, \tag{24}$$

where *NK*: the number of explaining variables, *y*: the explaining variable, $\kappa_{ic,mc}$: the parameter regarding *ic* th explaining variable of cultivation type-*mc*, *ic* = 1: the gross income ratio of cultivation type-*mc* to the conventional cultivation, *ic* = 2: the labour cost ratio of cultivation type-*mc* to the conventional cultivation and *ic* = 3: the amount of subsidy per cultivation area. The existing Japanese subsidy payment amount is given as 4,000 JPY/1,000 m^2 on average for environmentally conscious cultivation. Assuming that the conventional cultivation is normalised ($\kappa_{ic,1} = 0$), the previous study reasonably estimated the model parameters: $\kappa_{1,2} = 0.447$, $\kappa_{2,2} = -3.477$, $\kappa_{3,2} = 3.268$, $\kappa_{1,3} = 0.927$, $\kappa_{2,3} = 2.608$, $\kappa_{3,3} = 3.268$ (Kiyama, 2010).

A sum of products of the composition ratio *Rc* and the corresponding direct COD discharge amount is calculated as the representative value of COD amount discharged from a paddy field polygon. The direct COD discharge amount by cultivation method is type-1 (19.7 kg/1000m^2); type-2 (69.5 kg/1000m^2); type-3 (2.1 kg/1000m^2) (Kiyama, 2007).

A GIS polygon that represents a paddy field is explored as investment destination. When a *Xj* of investment amount is carried out in a polygon number *j*, the corresponding COD reduction amount *Rj* can be determined from the earlier model, in which an explaining variable of subsidy amount is replaced with a sum of subsidy amount and investment amount, $y_{3,mc\neq 1,j} = sub_j + X_j$. The conventional rice cultivation gives a condition of $y_{3,mc\text{-}1,j} = 0$.

Investment decision making depends on the magnitude of benefit from the water quality improvement. The ratio of investment amount to COD emissions reduction, *Xj*/*Rj*, is applicable to investment decision making in the comparison of the MWTP regarding COD discharge reduction, *MWTP*. Households make investment decisions when an investment amount per COD discharge reduction *Xj*/*Rj* is smaller than *MWTP*. Otherwise a household does not make investment decisions.

To determine *MWTP*, this study utilises a resultant value of *MWTP* given from a conjoint analysis for the environmental valuation of a dam lake in the same watershed (Kiyama, 2006). The MWTP for a 1 mg/L of COD improvement (*MWTP*) was estimated as 786 JPN in this dam lake. This study assumes that the estimated *MWTP* is applicable to *MWTP* in paddy fields as the water quality problem of the same watershed.

2.4.3 Coupled problem

Variables determined by the investment model are utilised for economic and environmental models. Regional investment amount reflects the two-country model variables; the labour and the input coefficient of intermediate goods (see Figure 1). The proposed two-country model uses the normalised labour. The agriculture industry consists of two production sections of rice and other agricultural commodities. The agricultural labour becomes a sum of these two sectional labours. Assuming that the labour of rice production is proportion to both the rate of paddy field acreage *Rp* and the rate of gross incomes regarding rice cultivation method *Ra*, the normalised labour *L* can be written as the following relation

$$L(i,j,k) = L^*(i,j,k) \Big/ \sum_{l=1}^{NB} L^*(i,l,k), \tag{25}$$

$$L^*(i,j,k) = \begin{cases} L1(i,k-1)\,Rp(k)\,Ra(k) + L2(i,k=0) & j=1 \\ L(i,j,k=0) & j \neq 1 \end{cases},$$
$$Ra(k) = \frac{\sum_{kc=1}^{Ns} \sum_{mc=1}^{3} Rc(mc,kc,k)\,rl(mc)}{\sum_{kc'=1}^{Ns} \sum_{mc'=1}^{3} Rc(mc',kc',0)\,rl(mc')}, \tag{26}$$

where L^*: the labour before the normalisation, $L1$: the labour of the rice farming per regional production, $L2$: the labour of the other agricultural production per regional production, *Ns*: the number of samples, *rl*: the ratio of labour cost of the cultivation type-*mc* to the conventional cultivation. The rate of paddy field acreage is estimated from the agricultural subsidy model regarding cultivation abandonment (Kiyama, 2010). Pre-normalised labour of industries except agriculture assumes to be constant.

The input coefficient of intermediate goods in agricultural sector is given as a sum of products of the intermediate input coefficient and the composition ratio of rice production and other agricultural production.

$$ax(i,j,1) = p_a\, ax1(i,j,1) + (1-p_a)\, ax2(i,j,1),$$
$$ax1(i,j,1) = \frac{1}{Ns} \sum_{kc=1}^{Ns} \sum_{mc=1}^{3} Rc(mc,kc)\, ax1mc(i,j,1), \tag{27}$$

where p_a: the composition ratio of the rice production to total agricultural production, $ax1$, $ax2$: the intermediate input coefficients of rice production and the other agricultural production, respectively and $ax1mc$: the intermediate input coefficient of rice farming type-*mc*.

The investment behaviour also affects the water quality or the COD emissions (see Figure 1). When households make investment decisions for the water quality improvement with the environmentally conscious rice cultivation, the direct COD burden per unit production is given as a sum of the products of the composition ratio of rice cultivation methods and the corresponding direct COD burden per unit production.

$$d1(i,k) = \sum_{kc=1}^{Ns} \sum_{mc=1}^{3} dr(mc,kc)\, Rc(mc,kc,k),$$

The direct COD burden per unit production can be written as a sum of the rice production part and the other agricultural production part.

$$d(i,1,k) = p_a\, d1(i,k) + (1-p_a)\, d2(i,k), \quad (28)$$

where $d1$: direct COD burden with rice production, $d2$: direct COD burden with other agricultural productions, dr: direct COD burden of rice cultivations type-*mc*.

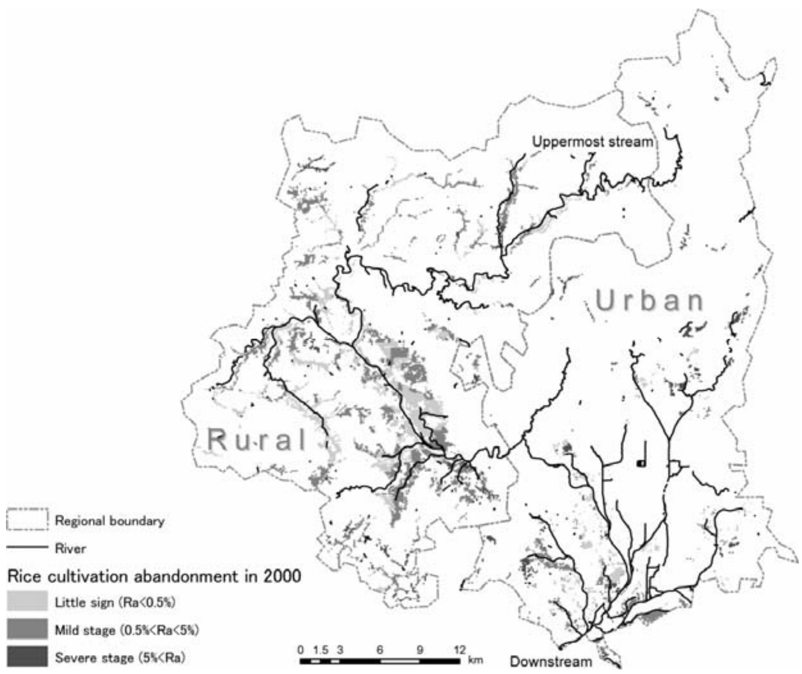
3 Surveyed region

A target watershed is introduced as a Japanese case study and a series of initial condition of the subsequent numerical analysis for regional optimal economic growth is determined.

3.1 Watershed

The Katsura River Basin, which is located in the Kyoto Prefecture, has a catchment area of 1,361 km^2 and 1.74 million inhabitants in 2000. This watershed is divided into two regions; a rural region and an urban region (see Figure 2). According to the National Institute of Population and Social Security Research in Japan (2004), it is predicted that projected populations of rural and urban regions in 2030 fall by 18.7% and 8.9% of a 2000 level, respectively.

Figure 2 Katsura River Basin and cultivation abandonment status in 2000



Paddy field acreage of this watershed amounts to 5,378 ha in 2000. The corresponding cultivation abandonment ratio is 2.54 %. However, agricultural subsidy policy model suggests that the 2030 cultivation abandonment state worsens by an 8.10% of cultivation abandonment ratio unless the proper agricultural policy is performed (Kiyama, 2010).

From the Kyoto Prefecture input-output tables in 2000, social accounting matrices of rural and urban regions were separately prepared with four industrial sectors: the agriculture, forestry and fisheries industry (sector 1); the manufacturing industry (sector 2); the construction, electricity, gas and heat supply, water supply and waste management industry (sector 3) and the other service industries such as commerce, finance, transport, medicine and social security (sector 4). A non-survey technique, the RAS method, is applied to estimate these input-output tables (Stone and Brown, 1962). From regional social accounting matrices, initial variables and parameters of two-country model are determined to satisfy equations (1)–(16). However, it is assumed that parameters of production functions, $\eta(i, j) = 0.5$ and $\phi(i, j) = 1.5$ are equal among all sectors, that the income tax rate τ_p is 0.3 and the social discount ratio ρ is 0.03. Each sectoral depreciation rate can be taken from the census; $\delta(1) = 0.032$, $\delta(2) = 0.100$, $\delta(3) = 0.066$ and $\delta(4) = 0.050$.

3.2 COD emission intensity

Table 1 illustrates the 2000 of embodied COD emission intensity *e* that varies by region due to a different wastewater treatment system. The urban manufacturing industry (sector 2) has a minimum COD emission intensity due to sufficient effluent treatment facilities and recycled water usage. On the other hand, the agricultural industry (sector 1) has the highest value. Indeed, although the agricultural industry has a tiny share of production value, an excessive environmental burden associated with agricultural economic growth should be avoided. Therefore, a shift from the conventional cultivation to the environmentally conscious cultivation should be needed.

Table 1 Embodied COD emission intensity in 2000

Region	*Sector 1*	*Sector 2*	*Sector 3*	*Sector 4*
Rural	16.7714	0.5130	2.0945	0.2459
Urban	2.4498	0.1522	2.2556	0.1991

Note: ton/1,000 million JPY

4 Discussion

Defining the scenario analysis with investment system, the implementation status of environmentally conscious rice farming is described. Then, regional economic growth and resultant COD emissions and economic gap problems are examined when the proposed investment system is provided.

4.1 Scenario setting

To assess the proposed household investment system, three types of policy scenarios are prepared; the baseline scenario, the subsidy scenario and the investment scenario. The baseline scenario denotes a scenario without any policy measures such as agricultural subsidy and other investment system for sustainable cultivation and environmentally conscious rice farming.

The subsidy scenario deals with a subsidy plan for a long-term sustainability of rice cultivation and the existing flat rate subsidy plan for environmentally conscious rice farming. The former subsidy plan was proposed so that the rice cultivation abandonment ratio in 2030 can remain below a 2000 level with the minimum cost. The details of these subsidy plans are described in a separate literature (Kiyama, 2010). Compared to the baseline scenario with the subsidy scenario, the subsidy effect can be examined.

The investment scenario means a combinational policy of these subsidies and household investment for water quality improvement in rice production. Therefore, the proposed investment effect can be estimated by comparison of the investment scenario and the subsidy scenario. For a series of scenario analysis, it is assumed that the subsidy and the investment start in 2005. Multi-objective optimisation problems for 30 years are solved every five years.

4.2 Environmentally conscious rice farming

A long-term behaviour of environmentally conscious rice farming performed is examined. Figure 3 illustrates that the amount of household investment is smaller than the subsidy amount. However, the decline of investment amount is smaller compared with the subsidy amount. Figure 4 shows the watershed composition ratio of environmentally conscious rice farming. The baseline scenario shows a monotonous decrease of the corresponding composition ratio. Either scenario shows a decreasing trend of the corresponding ratio in the latter stage due to the decrease of agricultural labour supply. The investment scenario has the highest composition ratio of environmentally conscious farming during the whole period. Therefore, it is suggested that the investment system is more stable than the subsidy in terms of a sustainable future rice production activity and the resultant water quality improvement. The investment system is feasible since the investment amount is nominal to the watershed production value (e.g., 12,272,527 million JPN in 2000).

Figure 3 Regional amounts of subsidy and investment for environmentally conscious rice farming

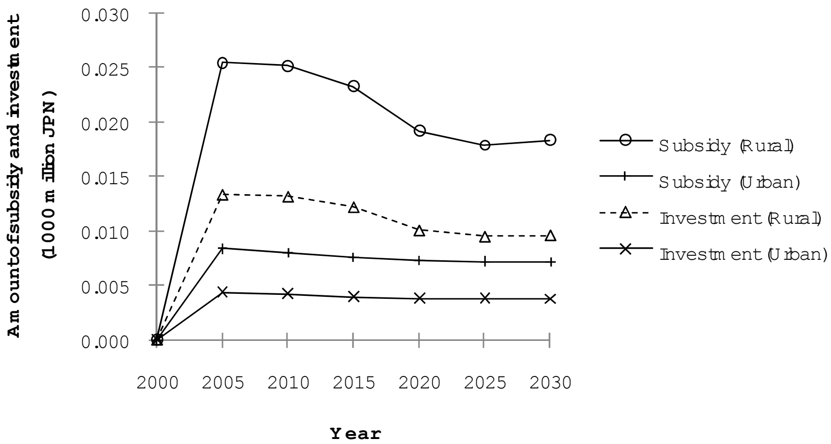
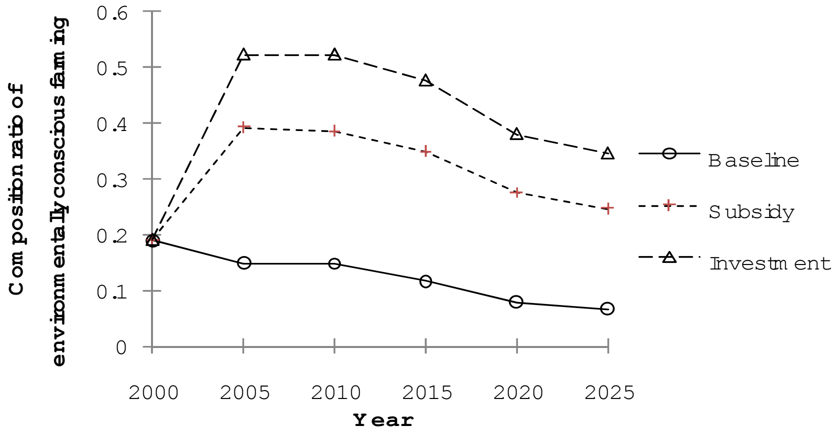


Figure 4 Composition ratio of environmentally conscious rice farming in watershed (see online version for colours)



4.3 Economic growth

Figure 5 illustrates Pareto optimal solution set of rural and urban utility values given by equation (1). The number of Pareto optimal solution set is four or five in any scenario. The utility values have a negative sign because consumption and capital per unit wages are utilised. The household's investment gives a higher utility in both regions compared with the single agricultural subsidy scenario. It would be suggested that a favourable economic growth in rural and urban regions could be expected with the proposed investment system.

Figure 5 Pareto optimum solutions of regional utilities

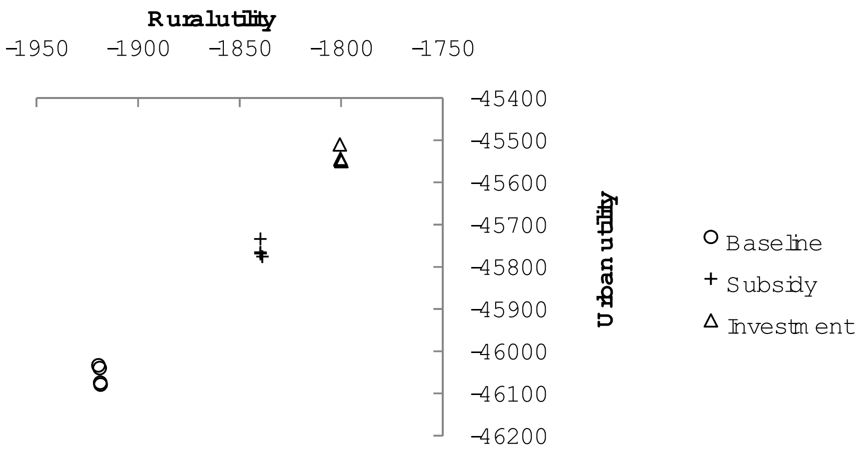
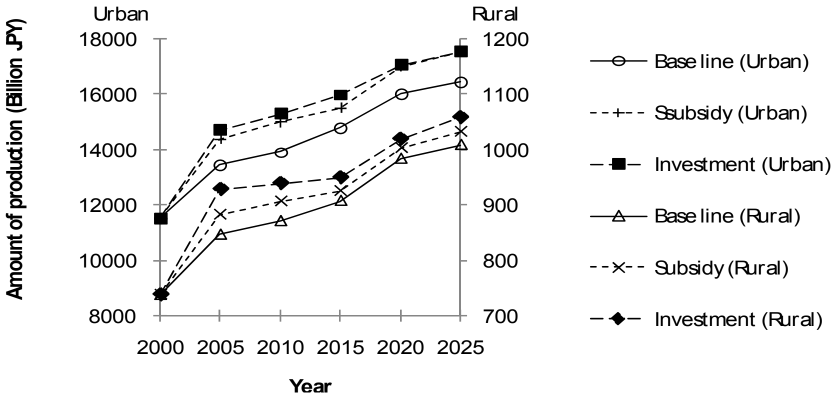


Figure 6 shows a long-term behaviour of production value in rural and urban regions. The subsequent results are described as the average value of individuals regarding Pareto optimal solution set. The subsidy policy remarkably increases rural and urban production values at the early stage and achieves a more production value during the whole period.

The household investment policy with subsidy successfully can attain a maximum rural production value during the whole period. However, in the late stage, the urban production value of the investment scenario slightly exceeds the production value of the subsidy scenario. It is suggested that the early stage investment is particularly helpful for rural and urban economic growths.

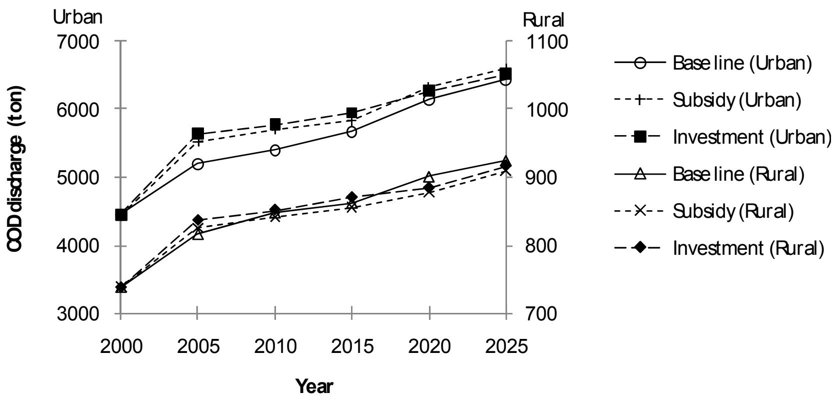
Figure 6 Regional production value



4.4 COD discharge

Figure 7 illustrates a long-term behaviour of total discharge amount of COD by region. For the urban region, the policy of subsidy or investment allows additional COD discharge associated with Pareto optimum economic growth, even though the environmentally conscious rice farming is promoted. As a result, the investment scenario has a maximum COD discharge amount in the watershed while achieving a maximum economic growth. The rural region also temporarily allows a more COD discharge in the early stage with subsidy and investment policies. However, in the subsequent stage, the rural COD discharge incurred by the subsidy and investment policies remains below the COD discharge of the baseline scenario.

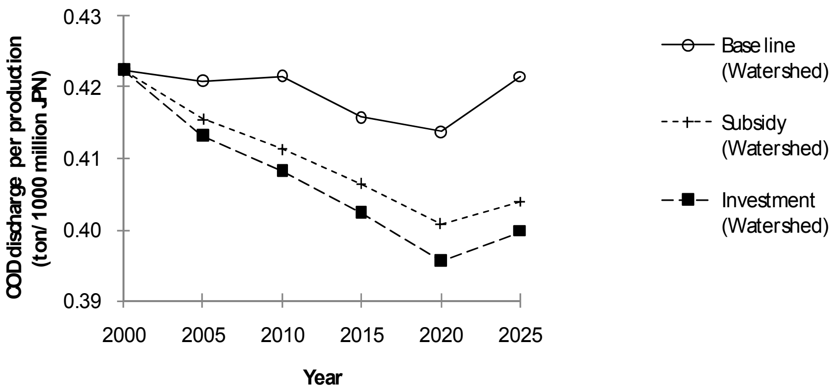
Figure 7 Regional COD discharge (ton/year)



These phenomena could be explained as follows. Immediately after the subsidy and investment policies, farmers would like to switch to a higher value-added, environmentally conscious rice production with a larger cultivation area. Moreover, a further agricultural development incurs an additional COD discharge in other industries as an economic spill over effect. As a result, the COD discharge amount exceeds the COD discharge amount of baseline scenario regardless of the lower input cultivation of chemical fertiliser and agricultural pesticides.

Figure 8 illustrates a long-term behaviour of watershed COD discharge per unit production (COD emission rate). This emission rate has a minimum value in the investment scenario and therefore the household investment system is helpful in terms of the production value based emission improvement rate. However, there remain problems that either agricultural policy allows an additional water pollutant emission incurred by the further economic growth and what should be utilised as an index of sustainable development and environmental conservation.

Figure 8 Watershed COD discharge per production



4.5 Economic gap

Figures 9 and 10 illustrate rural and urban sectoral economic growth rates for 25 years, respectively. For the rural region, any sector can achieve an additional economic growth with the agricultural subsidy and the investment system. Especially for the investment scenario, the maximum economic growth is expected. The maximum difference of sectoral economic growth rate is the baseline scenario (17.8%); the subsidy scenario (9.8%); the investment scenario (8.8%), which suggests that the investment scenario could narrow the rural sectoral economic gap.

For the urban region, the addition of investment system might cut some sectoral production growths (sectors 3 and 4). However, the economic growth rates of total sector shows a maximum value when the investment scenario is carried out. This means that the investment system could be performed without diminishing urban utility. Furthermore, the sectoral maximum difference is the baseline scenario (15.8%); the subsidy scenario (16.4%); the investment scenario (12.6%). Therefore, the sectoral economic gap is improved at a maximum by the investment system.

Figure 9 Rural economic growth rate: 2025y/2000y

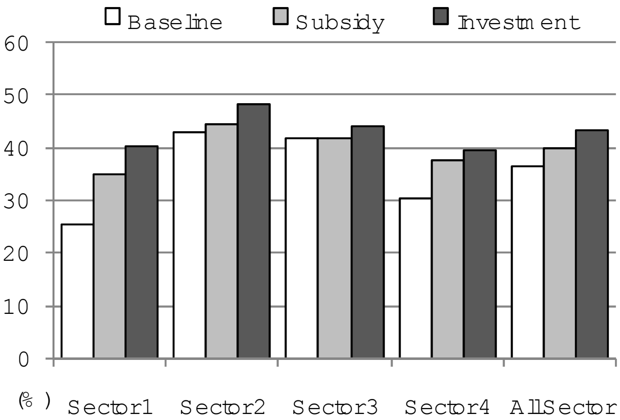
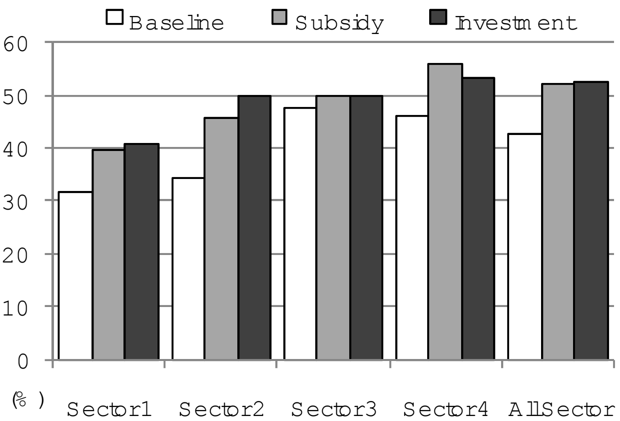


Figure 10 Urban economic growth rate: 2025y/2000y



The difference of total sectoral economic growth rate between rural and urban regions by scenario is the baseline scenario (6.2%); the subsidy scenario (12.3%); the investment scenario (9.0%). Therefore, there is a possibility that the subsidy policy enables rural development but urban development accelerates to widen regional economic gap. However, it is significant that the investment system redresses regional economic gap.

5 Conclusions

For rural regions, it is difficult to achieve a sustainable development by itself. This study was performed to discover a good way of sustainable rural development and watershed environmental conservation with the framework of the interregional cooperation. Therefore, a two-country model coupled with other water pollutant emission model and household investment model was developed in order to share the meaning of a household investment system with policy makers.

The proposed investment system has a condition that rice farmers can perform water quality improvement that households containing the urban region request. Furthermore, target farmers can perform the environmentally conscious farming to have a higher added-value of production, which means that the investment contributes to rural sustainable development. This kind of investment system would be helpful as a management system that other regions can provide support for the sustainable development of impoverished region economically, socially and environmentally.

For a feasible interregional cooperation, this study notes a unit of watershed that typically consists of rural and urban regions. The proposed investment system has a potential that rural and urban regions can advance their own economic growth maximally with the minimum COD emission rate and without losing their economic benefits. Furthermore, the investment is an effective method that narrows the economic gap between rural and urban regions compared with the single subsidy policy.

However, the agricultural policy for environmentally conscious farming is not sufficient when the total COD discharge amount should be reduced. The economic spill over effect with the policy incurs an additional COD discharge from all industrial sectors. Therefore, a sectoral COD emission program would be necessary when the reduction of total COD discharge is requested. Meanwhile, it is also important to elucidate what should be defined as an index of sustainable development and environmental conservation. In either case, the proposed methodology would be helpful to support the decision making process to arrange stakes regarding economic and environmental aspects across regions and nations.

Economic, environmental and social problems that this study covers would be no longer limited to Japan and be a common problem in foreign countries that face the rural poverty and collapse. The proposed concept of investment and analytical methodology is also applicable to a global cooperation problem between developing and developed countries.

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