Relationships between Agricultural policies and Environmental Effects in Japan: An Environmental-Economic Integrated Model Approach

Hiroki Sasaki

OECD Trade and Agriculture Directorate, France,
e-mail: hiroki.sasaki@oecd.org

Paper prepared for presentation at the 120th EAAE Seminar "External Cost of Farming Activities: Economic Evaluation, Environmental Repercussions and Regulatory Framework", Chania, Crete, Greece, date as in: September 2 - 4, 2010

Relationships between Agricultural Policies and Environmental Effects in Japan: An Environmental-Economic Integrated Model Approach

Hiroki SASAKI
OECD Trade and Agriculture Directorate, France
E-mail: hiroki.sasaki@oecd.org

Abstract. This study investigates the optimal agricultural land use allocation and nitrogen application to a representative Japanese farm. The site-specific nature of numerous agri-environmental issues necessitates analysis at a disaggregated level in order to capture the underlying heterogeneity of agricultural productivity and environmental sensitivity across different parcels of land. This study adopts an integrated approach—a decision-making economic model for representative farms is combined with a stylized site-specific biophysical model, which quantifies the impact of different policy instruments on agricultural production practices and on multiple environmental effects. This model estimates the government budget outlays and social welfare, which require monetary valuation of environmental effects as well as of crop production. In addition to several agri-environmental policy scenarios, this study investigates the impact of the rice production adjustment policy, wherein a rice production quota is allocated to each region on the basis of the sales records for the previous two years. According to the simulation results, there is greater increase in social welfare when farmers are paid in order to reduce chemical fertilizer applications rather than by levying a nitrogen tax. Regarding carbon sequestration, the modelling exercise indicates that an agri-environmental payment depending on the level of application of organic fertilizer (manure) is preferable; however, the social welfare derived by payments on the basis of the application of a minimum organic matter, which may avoid increasing the fiscal budget burden (on account of the increased application of organic matter on paddy fields), is higher than that derived by unit payments depending on the level of application of organic matter. The relaxation of the rice production quota results in an increase in social welfare. This integrated model approach is subject to limitations with respect to the data, model parameters, as well as economic and biophysical relationships. However, this approach is a valuable tool for enabling policy makers to design and implement effective and efficient policies.

Keywords: integrate model, agri-environmental policy, paddy field, production quota

1. Introduction

Japan has recently adopted market-oriented agricultural policy reforms and has been accelerating the implementation of agri-environmental policies even though they continue to constitute a rather small portion of the overall policy package. The transition to environmentally-friendly farming is being encouraged. *The Agricultural Environmental Code,* which was endorsed in 2005, necessitates farmers to adopt production practices that facilitate environmental conservation. Further, this code initiated cross compliance measures, which focused on environmentally-friendly farming practices. For environmentally-friendly farming practices to be effective and extend beyond the "reference level," the government provides additional support to farmers in the form of incentives. "Eco-farmers," are encouraged to adopt agricultural practices by means of concessionary loans. Moreover, based on the *Law for Promoting Organic Farming,* which was enacted in 2006, direct payments for pioneering environmental farming are being made and organic farming is being promoted. In addition to promoting agri-environmental farming, recent policies for strengthening agri-environmental programmes, such as promoting the production of bio-energy derived from non-food materials, mitigation and adaptation to global warming, and biodiversity conservation, have been adopted.

In Japan, although farm nitrogen and phosphorus surpluses declined over this decade (1990–92 to 2002–04), the absolute levels per hectare remained among the highest across all OECD countries. On the other hand, agriculture may provide certain ecosystem services depending on the management of the agricultural land; rice paddy fields provide higher levels of ecosystem services (for example, owing to their water-retaining capacity) as compared to other agricultural land utilization alternatives. However, a reduction in the agricultural area has affected the provision of ecosystem services, wild species diversity, and value of landscape (OECD 2008).

Currently, a lack of monitoring data is negatively influencing the evaluation of agri-environmental performance. In addition, there exists limited information regarding the relative costs and benefits of employing different agricultural land utilization alternatives, especially rice paddy fields, for providing ecosystem services (OECD 2008). However, micro level policy analysis modelling is considered to be useful for capturing cause-effect linkages. This paper investigates the optimal agricultural land use allocation and nitrogen utilization for a representative Japanese farm. Owing to the site-specific nature of numerous agri-environmental issues, analysis at a disaggregated level is necessary in order to capture the underlying heterogeneity of agricultural productivity and environmental sensitivity across different parcels of agricultural land. This study adopts an integrated approach—a decision-making economic model for representative farms is combined with a stylized site-specific biophysical model, which quantifies the impact of different policy instruments on agricultural production practices as well as on multiple environmental issues. The integrated model estimates the government budget outlays and social welfare, which entails a monetary valuation of environmental issues as well as crop production.

This overall structure of this paper is organised in the following manner: Section 2 provides the theoretical framework. Section 3 introduces the empirical specifications. Section 4 reports the policy simulations including the agri-environmental policy and relaxation of rice production quota policy scenario. Finally, Section 5 presents the conclusion and policy implications.

2. Theoretical framework

2.1 Land use allocation

Following Lankoski and Ollikainen (2003), land is divided into rectangular parcels of equivalent size; although the land quality of each parcel is homogeneous (productivity: q), the land quality amongst parcels is heterogeneous. It is assumed that each parcel is 10 a[1] and the total cultivated land is 6 ha (60 parcels). In order to estimate the profit function, the national statistics data has been applied on a sample farm size of 5−7 ha, although the average Japanese farm size is approximately 1.36 ha. This assumption will not create a significant difference in terms of social welfare estimation because the impact of the input-related externality (for example, Nitrogen (N) runoff) is constant with the sample farm size in this model.

In this study, the land use allocation is assumed to include rice paddy, upland crop, and abandonment (Figure 1). The upland crop area, which was formerly a part of the rice paddy area, is assumed to be increasing in the model. Paddy fields equivalent to 740 thousand ha have been temporarily converted into upland fields by draining water; this area previously accounted for 30% of cultivated paddy. There is some trade-off between paddy fields and upland crops in terms of environmental externalities. For example, although methane emissions from upland fields amount to zero, the N_2O emissions are higher (Nishimura *et al*. 2004). Consequently, it is beneficial to analyze both rice paddy and the upland crop cultivation in a continuous analytical framework by formulating their main characteristics from both economic and environmental perspectives. In this paper, wheat is assumed to be the upland crop.

It is assumed that land reforms in paddy fields (drainage canal and subsurface drainage) have already been initiated. This implies that a farmer may allocate land only on the basis of the profit generated from each parcel; therefore, it is not necessary to incorporate "the land conversion cost" exogenously.

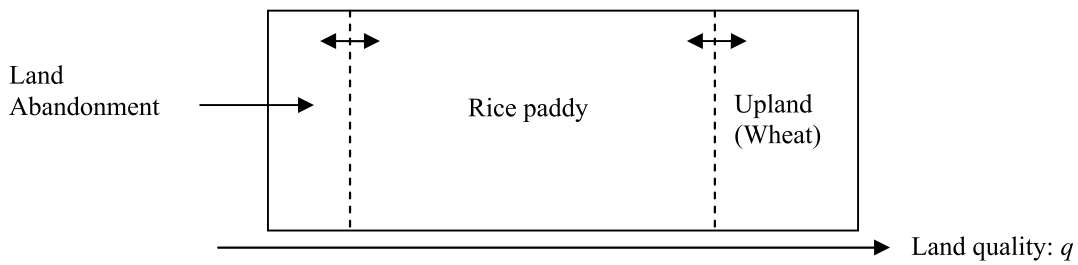

Figure 1. Spatial characteristics in the model

Lichtenberg (1989, 2002), Lankoski and Ollikainen (2003), Lankoski *et al*. (2004), Ollikainen and Lankoski (2005), and Lankoski *et al*. (2006) developed a framework for analyzing the joint production of commodity and environmental outputs as well as negative externalities under heterogeneous land quality; this is the point of departure for this modelling exercise.

[1] 100 a = 1 ha

Following Lankoski and Ollikainen (2003), let $G(q)$ denote the cumulative distribution of q (acreage possessing quality q , $0 \le q \le 1$) and $g(q)$ denote the density of q, where it is assumed that $g(q)$ is continuous and differentiable. The total amount of land in the region is given by

$$G = \int_0^1 g(q)dq. \tag{1}$$

It is assumed that only rice paddy and wheat are cultivated in this region, $i = 1,2$. Both these crops are produced under constant returns to scale. The output of each crop per unit of land area is denoted by y_i and yield is a function of land quality, q as well as fertilizer application, x_i . The applied amount of fertilizer, x_i is the combination of chemical fertilizer, x_{ci} , and organic fertilizer, x_{oi} ; therefore, the production function is given as $y_i = f^i(x_i;q)$. This production function is increasing and concave in fertilizer and land quality. It is assumed that the arable land may be allocated to either paddy rice or wheat. The share of paddy rice, L_1 and wheat, L_2 , is given by the following equations:

$$L_1 = \int_0^{q_1} g(q)dq = G(q_1) \text{ and} \tag{2}$$

$$L_2 = \int_{q_2}^{1} g(q)dq = G(1) - G(q_1) \text{, respectively.} \tag{3}$$

For the sake of simplicity, land abandonment has not been considered in the theoretical discussion of this paper. Two environmental effects have been assumed in this study: impact on water quality owing to chemical fertilizer runoff and green house gas (GHG) emissions through chemical and organic fertilizer applications.

2.2. Profit function

The profit from agricultural production is expressed as

$$\pi^i = p_i f^i(x_i;q) - cx_i,\ i = 1,2 \tag{4}$$

Here, p_i refers to the price of crops and c refers to the fertilizer price, which are both given. Organic fertilizers possess a yield-increase effect, which depends on the amount of application: $\Phi^i(x_{oi})$, defined as $1 < \Phi^i(x_{oi})$ with $\Phi^i_x > 0$ and $\Phi^i_{xx} < 0$. Simultaneously, the additional cost of organic fertilizer collection, transportation, and spreading are incorporated into the profit function. In the presence of the yield-increase effect and additional cost of organic application, the profit function is modified in the following manner:

$$\pi^i = p_i f^i(x_{ci}, x_{oi}, q)\Phi^i(x_{oi}) - c^i(x_{ci}, x_{oi}),\ i = 1,2 \tag{5}$$

2.3. Nitrogen (N) runoff and purification function

Aggregate N runoff is a function of the use of chemical fertilizers. It is assumed that the N content in organic fertilisers is not included in the N runoff function; this is because N in organic fertilizers could become a serious issue only when a substantial amount of fertilizer has been used. In this model, the maximum application of organic fertilizer is approximately 1.5t/10a owing to economic factors (high additional cost). The runoff of nutrients (kg) from each parcel is expressed as a function of the chemical fertilizer, x_{ci} , that has been used and is given by

$$z_i = v_i\left[x_{ci}(q)\right] \quad for\ i = 1,2 , \tag{6}$$

where $v_x > 0, v_{xx} > 0$. Therefore, the runoff function is convex in fertilizer application. It is an established fact that paddy fields effectively improve water quality by removing nitrogen through the denitrification and absorption processes. When the total nitrogen inflow in the paddy field water exceeds the total nitrogen outflow, then paddy field operates as a nitrogen removal site, which implies that z_1 is negative. Therefore, the total amount of runoff from the land area allocated to rice paddy and wheat is given as

$$z = \int_0^1 \left\{v_1\left[x_{c1}(q)\right]L_1 + v_2\left[x_{c2}(q)\right](1 - L_1)\right\}g(q)dq. \tag{7}$$

The monetary valuation of the damage caused by runoff (purification benefit), is defined by a valuation function, $D(z)$, which is assumed to be convex ($D(\square)_x > 0, D(\square)_{xx} < 0$).

2.3. GHG emission and sequestration

With respect to GHG emissions, agriculture is an important anthropogenic source of CH_4 and N_2O. Moreover, agricultural soil operates as a carbon sink. The impact of organic fertilizers on CH_4 emissions is critical (Yan *et al*., 2005); the volume of fertilizer applied and CH_4 emissions may be described using a response curve. Methane generation is not possible if soil is not maintained in an anaerobic state. Upland soils are normally oxidative and in aerobic condition; therefore, they do not produce CH_4. CH_4 emission is denoted as

$$CH_4 = \int_0^1 \left\{ m\left[x_{o1}(q)\right] L_1 \right\} g(q) dq, \tag{8}$$

where $m_x > 0, m_{xx} < 0$. Thus, the runoff function is concave in the organic fertilizer application (Yan *et al*. 2005, IPCC 2006).

Following the guideline by the Intergovernmental Panel on Climate Change (IPCC), if the N_2O emission is a combination of direct emissions (denitrification) and indirect emissions (associated with atmospheric deposition and nitrogen runoff), i.e.,

$$N_2O = \int_0^1 \left\{ \left[n_1(x_{c1}(q), x_{o1}(q), z_1)\right] L_1 + \left[n_2(x_{c2}(q), x_{o2}(q), z_2)\right](1-L_1) \right\} g(q) dq, \tag{9}$$

where $n_x > 0, n_{xx} < 0$, then the emission function is concave in fertilizer application.

Soil carbon stock is heavily influenced by fertilizer management as well as by CH_4 and N_2O emissions from agricultural land. Appropriate amounts of organic fertilizer could increase the soil carbon content and reduce of the total GHG emission. The carbon sequestration function is given as

$$Seq = \int_0^1 \left\{ s_1\left[x_{o2}(q)\right] L_1 + s_2\left[x_{o2}(q)\right](1-L_1) \right\} g(q) dq, \tag{10}$$

where $s_x > 0, s_{xx} < 0$. Thus, the sequestration function is concave in the organic fertilizer application. Consequently, the net GHG emission is expressed in the following manner:

$$\begin{aligned} e = & \int_0^1 \left\{ m\left[x_{o1}(q)\right] L_1 \right\} g(q) dq \\ & + \int_0^1 \left\{ \left[n_1(x_{c1}(q), x_{o1}(q), z_1)\right] L_1 + \left[n_2(x_{c2}(q), x_{o2}(q), z_2)\right](1-L_1) \right\} g(q) dq \\ & - \int_0^1 \left\{ s_1\left[x_{o2}(q)\right] L_1 + s_2\left[x_{o2}(q)\right](1-L_1) \right\} g(q) dq. \end{aligned} \tag{11}$$

The monetary valuation of emission damages (sequestration benefits), defines the valuation function, $GW(e)$, which is assumed to be convex ($GW(\square)_x > 0, GW(\square)_{xx} < 0$).

2.4. Social welfare function

Chemical fertilizers influence both crop yield and environmental externalities. Moreover, although organic fertilizers may aid in preserving soil fertility (yield-increase effect) and increasing carbon sequestration, they could increase CH_4 emissions and be a source of water quality problems. The social welfare maximization problem may now be expressed as

$$SW = \int_0^1 \sum_{i=1}^{2} \left[pf^i(x_i(q), q)\Phi_i(x_i(q)) - cx_i(q) \right] g(q) dq + D(z) + GW\left[e(m,n,s)\right]. \tag{12}$$

The social planner selects the inputs (chemical and organic fertilizers) to be applied to each parcel under the heterogeneous productivity of land The first-best optimum is solved recursively and expressed in the following manner:.

$$SW_{x_{ci}}^{i} = p_i f_{x_c}^{i} - c_{x_c}^{i} + D'(z)\frac{\partial v_i}{\partial x_{ci}} + G'(e)\frac{\partial n_i}{\partial x_{ci}} = 0 \tag{13}$$

$$SW_{x_{oi}}^{i} = p_i f_{x_o}^{i}\Phi_{x_o}^{i} - c_{x_{oi}}^{i} + D'(z)\frac{\partial v_i}{\partial x_{oi}} + G'(e)\left[\frac{\partial m_i}{\partial x_{oi}} + \frac{\partial n_i}{\partial x_{oi}} + \frac{\partial s_i}{\partial x_{oi}}\right] = 0 \tag{14}$$

On the basis of the optimal utilization of inputs and subsequent profits generated by each crop from a given quality of land, the land is allocated to the crop with the highest social return in each parcel. The unique value of switching land quality, q_1, is defined as

$$\pi_1^* + D'(\cdot)v_1 + GW'(\cdot)e_1 = \pi_2^* + D'(\cdot)v_2 + GW'(\cdot)e_2 \tag{15}$$

Consequently, land is allocated among crops by considering profits as well as the impact of land allocation on N runoff and GHG emission.

The private optimum may readily be extracted from equations (12) to (15). Under the private optimum, the farmer disregards the impact of environmental externalities. Once the marginal damage (benefit) to is set at zero, $\pi_1^* = \pi_2^*$ is obtained.

3. Empirical framework

3.1. Profit function

A farmer's profits from production in the absence of government intervention is given by

$$\pi^i = p_i y_i - cx_i - w_i n_i - o_i \quad for\ i = 1,2\,, \qquad ,(16)$$

where p_i refers to the price of crops, y_i refers to the yield/10a, c refers to the fertilizer (nitrogen) price, w_i refers to the wage rate per hour, and o_i refers to other cost. The model employs a quadratic nitrogen response function, $y_i = a_i + \alpha_i x_i + \beta_i x_i^2$,where x_i refers to the volume of N application (kg/10a). x_i has been estimated for crops 1 (rice) and 2 (wheat).When famers consider using organic fertilizers, x_{oi}, in addition to (instead of) chemical N fertilizers, x_{ci}, the total amount of application of N to the agricultural field is equal to the summation of N fertilizer and N content of organic fertilizer. Although there exists a recommended threshold quantity that indicates the ideal quantity of organic matter that should to be applied to different crops (for example, 1.0−1.5t/10a for paddy field), it has not been implemented effectively (88kg/10a) due to the following barriers: difficulty in understanding the impact of using manure from farmers' perspectives due to the diversity in manure quality, the quantity of manure needed to be applied is significantly higher than chemical fertilizers (high spreading cost of manure), and a lack of collaboration between crop and livestock farming (resulting in high transportation cost of manure).

Several surveys conducted in the past indicate that the impact of organic matter application on yield is statistically positive. According to Shibahara *et al.* (1999), continuous application of organic matter retrenches the total N application for a particular proportion of the yield owing to the high N absorption of organic matter. In fact, the answers to the mail survey conducted by Livestock Environmental Improvement Organization in 2003 indicated that farmers favoured the application of organic matter since they believed that it preserved the fertility and softness of the soil and activated the soil microbes and consequently improved the quality of the products and stabilized production.

The Okayama prefectural agricultural centre (2008, originally from MAFF) has set the average N content in organic fertilizer (cow manure) at 0.7%; therefore, the total amount of N application is expressed as

$$x_i = x_{ci} + 1000 \bullet x_{oi} \bullet 0.007\,, \tag{17}$$

where, 1000 implies the conversion of unit from tonne to kg.
Generally, N requirement × substitution rate (%) = the quantity of organic fertilizer (kg/10a) × N content rate (%) × Fertilizer efficiency (%), where fertilizer efficiency is 30% (Okayama prefectural agricultural centre (2008, originally in Nishio, 2007)).

It is assumed that the positive impact of using 1t of organic matter on yield is expressed as $\Phi_i(x_{oi})$, on paddy it is assumed to be 5%, and on wheat it is assumed to be 10%; this is based on the data from several field surveys (for example, Miyazaki prefecture1999, Shibahara *et al.*, 1999). Considering the additional cost for organic matter application, the profit function is expressed in the following manner:

$$\pi^i = p_i(a_i + \alpha_i x_i + \beta_i x_i^2)\Phi_i(x_{oi}) - cx_{ci} - (c_{op} + c_{ot} + c_{os})x_{oi} - w_i n_i - o_i \quad for\ i = 1,2\,, \tag{18}$$

where c_{op} refers to the price of organic matter (JPY/tonne), c_{ot} refers to transportation cost (JPY/tonne), and c_{os} refers to the spreading cost (JPY/tonne).

3.2. Nitrogen response function

3.2.1. Rice paddy

The data from over 50 sample field surveys, which was collected by Toriyama (2000), was used for estimating the quadratic nitrogen response function of rice paddy, which is presented as

$$y_1 = 368.6 + 31.7x_1 - 1.4x_1^2 (R^2 = 0.61)\,. \tag{19}$$

Even in the absence of fertilizers, nutrients present in the irrigation water impacts yield. It is generally believed that the soil in paddy fields is rather fertile[2]; and the use of fertilizer enhances the yield of paddy by only 20%. In order to reflect the actual yield in paddy fields, a_i has been assigned a fixed value in order to discount the impact of the nutrients present in irrigation water, and subsequently, the land quality, *q,* is incorporated into the response function. The response function is expressed as

$$y_1 = 368.6 + (e_0 + e_1 q)x_1 - (\mu_0 + \mu_1 q)x_1^2 \quad . \tag{20}$$

According to data in Toriyama (2000), the spread of yield is approximately 30% below the average N application amount. Consequently, the parameter ranges have been set as $22.19 \le e_0 + e_1 q \le 41.21$ *and* $0.98 \le \mu_0 + \mu_1 q \le 1.82$. When q is uniformly distributed between 1 to 60, parameters e_0, e_1, μ_0 and μ_1 are estimated in the following manner:

$e_0 = 22.868$, $e_1 = 0.322$, $\mu_0 = 0.994$, and $\mu_1 = 0.014$

3.2.2. Wheat

The quadratic nitrogen response function of wheat (converted from rice paddy cultivation) was estimated using the data sets from the National Agricultural Centre (1989):

$$y_2 = 214.9 + 45.6x_2 - 1.2x_2^2 (R^2 = 0.99) \tag{21}$$

However, this survey had been conducted in order to collect the highest yield data. Therefore, function (21) cannot effectively represent the average response function. Owing to a lack of data for reflecting the land quality variety, the average and lowest yield response functions have been estimated on the basis of the assumption that the spread of yield is approximately 40%. This figure is based on the target yield under the average N application, which was determined in *The Nitrogen Application Standard* by each local government.

The wheat response function to nitrogen is expressed as

$$y_2 = 214.9 + (h_0 + h_1 q)x_2 + (\eta_0 + \eta_1 q)x_2^2 \quad , \tag{22}$$

where $19.54 \le h_0 + h_1 q \le 45.6$ *and* $0.51 \le \eta_0 + \eta_1 q \le 1.2$.

Subsequently, each parameter is obtained in the following manner: $h_0 = 19.101$, $h_1 = 0.442$, $\eta_0 = 0.526$, and $\eta_1 = 0.012$

As indicated in the theoretical framework, farmers consider the total quantity of N, the combination rate of chemical fertilizers, x_{ci} , as well as the organic fertilizer application, x_{oi} . The total amount of N application to the agricultural field is computed as the sum of N fertilizer and N content of organic matter. According to discussion of the Ministry of Agriculture, Forestry, and Fisheries of Japan (MAFF), although a threshold quantity for organic matter application has been recommended (e.g., 1.0−1.5t/10a for paddy fields), it is not being followed (88kg/10a) owing to several difficulties. In this model, the trade-off between the positive impact of organic matter application on yield and the high costs of spreading and transporting organic matter necessitate careful consideration. In general, as compared to

[2] The following indicate the primary functions of irrigation water in paddy fields: 1) natural supply of nutrients, 2) nitrogen fixation, 3) accumulation of organic matter, which is easily-absorbed, and 4) reduction of soil erosion.

paddy rice, the yield of wheat is more responsive to nitrogen applications. z_1 refers to the quantity of runoff of N from paddy and x_1 refers to the quantity of application of N in paddy.

3.3. Nitrogen runoff and purification function

3.3.1. Rice paddy

It is difficult to formulate the relationship between the quantity of N applied and its impact in a straightforward manner because the volume of N runoff from irrigation and meteoric water may impact the N balance in the paddy field. Generally, the N runoff from paddy is explained in the following manner:

[N runoff (surface runoff   subsurface flow)]   [The impact of irrigation water-load]   [The impact of meteoric water-load] + [The impact of N application]

In this regard, Kunimatsu and Muraoka (1989) proposed that the polluting load L is given by $L = \alpha C_{i1}Q_{i1} + \beta C_{i2}Q_{i2} + \lambda X$, where C_{i1} and C_{i2} represent the concentrations of irrigated water and meteoric water, respectively and Q_{i1} and Q_{i2} denote the volumes of irrigated water and meteoric water, respectively. X is the amount of fertilizer application. α, β, and γ are all coefficients. Moreover, they indicated that the volume of N existing in the agricultural land on account of application of fertilizers significantly exceeds the volume of N runoff on account of irrigation and meteoric water. Disregarding the impact of two terms $\alpha C_{i1}Q_{i1}$ and $\beta C_{i2}Q_{i2}$, the relational expression is $L = \lambda F$. Considering the significant impact of fertilizer application as stated in Kunimatsu and Muraoka (1989) and the convenience of economic optimization, the Secretariat attempted to estimate the relationship between the application and runoff of N using the exponential form (for example, Tabuchi and Takamura 1985, pp70) as

$$z_i = \chi_i \exp(\delta_i x_i), \tag{23}$$

where z_i refers to the quantity of runoff of N (surface and subsurface) and x_i refers to the quantity of application of N.

Paddy fields could either serve as N removal or pollution sites depending on the agricultural activities and nitrogen concentration of the irrigation water. It is an established fact that paddy fields and wetlands effectively improve the water quality by removing nitrogen through denitrification and absorption, which is effective only when irrigation water has a strong concentration. Although the concept of nitrogen movement in paddy is not straightforward, the relationship was estimated using Kunimatsu and Muraoka (1989) and data from a recent field survey, which was conducted by the Shiga prefecture during the paddy cultivation period. An exponential relationship was found between the quantity of application and runoff of N.

$$z_1 = 0.0062e^{0.465x_1} - 1.14 (R^2 = 0.54). \tag{24}$$

3.3.2. Wheat

In particular, various factors including soil conditions, crops, cropping seasons, and methodological conditions influence the volume of N runoff; in Japanese conditions, on an average, approximately 30% of the applied N may runoff (Kunimatusu 1989, Takeda 1997, and Shiratani 2004). However, the linear function is not appropriate for optimization. Consequently, the exponential form was estimated on the basis of Japanese field data, which was organized by the National Institute for Ago-Environmental Science (NIAES),

$$z_2 = 1.129e^{0.114x_2} (R^2 = 0.19), \tag{25}$$

where z_2 refers to the quantity of runoff of N and x_2 refers to the quantity of application of N.

Owing to a lack of adequate observations (there is no information on slopes), R^2 is not sufficiently high. In order to validate the robustness of the estimated exponential curve, the linear functions and general nitrogen runoff ratios were compared. Assuming that the average quantity of application of N is lower than 20kg/10a, the other estimation results, which are indicated in Figure 2, are consistent

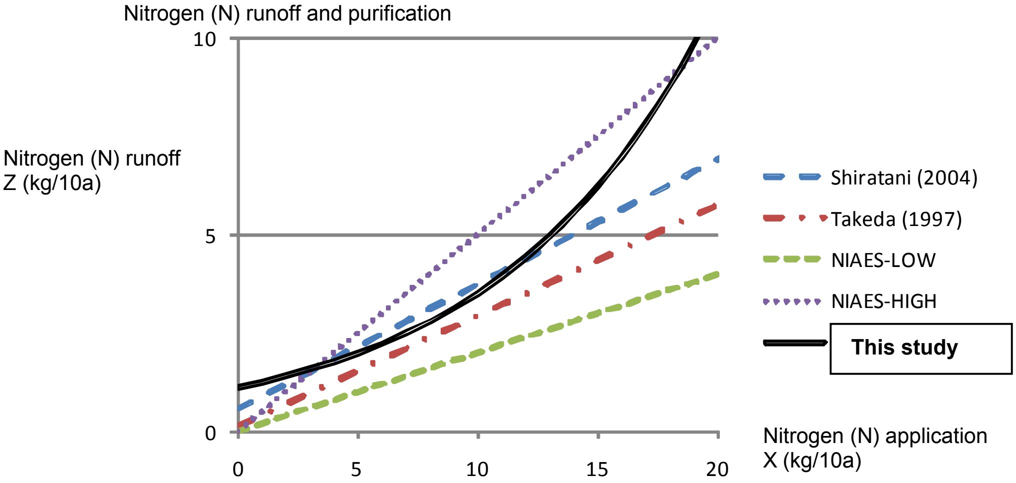

Figure 2. Variations in the estimated nitrogen runoff function from upland fields

3.4. GHG emission and sequestration function

Although agriculture does not significantly contribute to the total GHG emissions in Japan[3], it is an important anthropogenic source of CH_4 and N_2O emissions. 80% of the total GHG emissions from agricultural land (IPCC's 4C category rice cultivation and 4D category agricultural soils) are derived from chemical and organic fertilizer applications. Therefore, in this analysis, the fertilizer application volumes could be considered as a control variable. Rice cultivation is the foremost anthropogenic source of CH_4 (methane) emissions. Application of fertilizer and ploughing of organic soil release ammonium ions inside the soil and N_2O is subsequently emitted. The denitrification process also releases N_2O.

Since the amount of fertilizer application is a control variable in the profit function (nitrogen response function), it is possible to incorporate CH_4, N_2O, and CO_2 emissions (sequestration) into the economic optimization model. Therefore, the net GHG emission (CO_2 equivalent) is expressed by the following equation[4]:

$$GHG(CO_2eq) = 21 \bullet CH_4 + 310 \bullet N_2O + CO_2. \tag{26}$$

The subsequent step individually considers the details regarding each emission category on the basis of the IPCC (2006), Ministry of the Environment (MOE) (2008), and field survey data for country specific coefficients.

3.4.1. CH_4 emission

It is an established fact that rice cultivation is a primary anthropogenic source of CH_4 emissions. According to the IPCC (2006), several rice cultivation characteristics must be considered while calculating CH_4 emissions: regional differences in rice cropping practices, multiple crops, water regime, ecosystem type, flooding pattern, etc. In addition to these factors, organic amendments significantly impact CH_4 emissions; the amount of the fertilizer applied and CH_4 emission may be described with the help of a response curve. Yan *et al*. (2005) concluded that organic amendment and water regime in the rice-growing season were the two most important control variables, and climate was the least important variable.

The water regime in the rice growing season was classified as continuous flooding, single drainage, multiple drainage, wet season rain fed, dry season rain fed, deepwater, or unknown. In Japan, a majority of the paddy fields (98%) are intermittently flooded. There exist scaling factors for water regimes during the cultivation period relative to continuous flooded fields; however, the characteristics of the

---

3 Emissions from both IPCC categories 4C (rice cultivation) and 4D (agricultural soils) accounted for only 1% of the total emissions.

4 CO_2 is released by the use of agricultural machinery and has not been considered owing to a lack of data.

intermittently flooded (multi aeration) water regime in the IPCC category is different from that of the intermittently flooded paddy field (single aeration) concept as per the IPCC Guideline[5]. IPCC (2006) established a default seasonal CH_4 emission factor for rice *under the continuous flooding conditions and in the absence of application of organic matter*. Scaling factors (SF) are used for estimating the CH_4 emissions from rice fields in order to indicate the situation of each country in terms of water regimes or organic matters. However, the IPCC (2006) suggested that country-specific emission factors and scaling factors can indicate appropriate conditions only if they are based on well-researched and documented measurement data (IPCC 2006). A default emission factor is 1.30 kg CH_4/ha/day (23.4kg/10a/180days).

The basic equation for estimating CH_4 emissions from rice cultivation per 10a is defined in equation (15), which has been converted from IPCC (2006).

$$CH_4 = EF_c \bullet SF_w \bullet SF_p \bullet SF_o\,, \tag{27}$$

where CH_4 (t CH_4/10a/yr) is the annual CH_4 emissions from rice cultivation, *EFc* is the baseline emission factor for continuously flooded fields without any organic amendments, *SFw* is the scaling factor to account for the differences in water regime during the cultivation period, *SFp* is the scaling factor to account for the differences in water regime in the pre-season, i.e., the season before the cultivation period, and *SFo* is the scaling factor to account for the differences in both the type and amount of organic fertilizer applied.

There exist country-specific emission factors for intermittently flooded paddy (single aeration) in Japan, which has been estimated as 12.96 gCH_4/m^2/yr (0.001296 tCH4/10a/yr) in MOE (2008). This data reflects both Japanese specific emission factors as well as water regimes.

The scaling factor for organic fertilizers is defined in the following manner (IPCC 2006):

$$SF_0 = \left(1 + \sum_j x_{oj} \bullet CF_j \bullet 10\right)^{0.59}\,,^{6} \tag{28}$$

where x_{oj} (t /10a) is the application amount of organic fertilizer *j* in dry weight for straw and fresh weight for others, CF_j is the conversion factor for organic fertilizer *j* (in terms of its relative impact with respect to straw that is applied shortly before cultivation).

The impact of organic fertilizer on yield varies significantly depending on the type and quantity of organic fertilizer applied. Currently in Japan, rice straw is applied in 60% of the agricultural land, other manure is applied in another 20% of the agricultural land, and no fertilizer is applied in the remaining 20% of the agricultural land (MOE, 2008). MAFF strongly promotes the application of manure from the perspective of reducing (net) GHG and maintaining the fertility of the soil. Therefore, the conversion factor of farm yard manure has been employed in this modelling. It is important to select this control variable at the policy simulation stage because the application of manure entails additional effort in terms of manure collection and spreading (Japan Soil Association, 2009).

Using this country-specific data, CH_4 emission (t CH_4/10a/yr) equations (15) are re-written in the following manner:

$$CH_4 = 0.001296 \bullet \left(1 + x_o \bullet 0.14\right)^{0.59}. \tag{29}$$

The Guidelines for Enhancement Fertility of Soil recommend that the normal manure application amount for paddy is 1.0–1.5t/10a; however, the actual application has been decreasing from 451kg/10a (1970) to only 88kg/10a (2005) owing to the decoupling of crop and livestock farming and the aging of farm labor forces.

Unless soil is maintained in an anaerobic state, methane is not generated. Upland soils are usually oxidative and in aerobic condition; therefore, CH_4 is not produced.

5 See also Ministry of the Environment Greenhouse Gas Inventory Office of Japan (GIO), CGER, and NIES (2008) for detailed information. (http://www-gio.nies.go.jp/aboutghg/nir/2008/NIR_JPN_2008_v4.0_E.pdf).

6 The exponent in this equation is provided by the uncertainty range of 0.54–0.64.

3.4.2. N_2O emission

The application of fertilizer and ploughing of organic soil releases ammonium ions inside the soil, and N_2O is subsequently emitted in the process of oxidizing the ammonium ions into nitrate-nitrogen under aerobic conditions. In addition, the denitrification process releases N_2O. The emission factors (EFs) for N_2O, which is associated with the application of chemical fertilizers to farmland soil, were established on the basis of actual data collected from the agricultural fields in Japan; the same EFs were also used for organic fertilizers. Owing to the fact that there was no the significant differences between the EFs of synthetic fertilizers and that of organic fertilizers, the data on N_2O emissions from Japanese agricultural fields were considered. Akiyama *et al*. (2006) estimated the EFs of Japanese rice paddy fields and upland fields as **0.31**% (±0.31%) and **0.62%** (±0.48%), respectively. The emission of N_2O owing to the application of fertilizer is given by

$$N_2O_{direct\_i} = \frac{1}{1000} \bullet EF_{di} \bullet (x_{ci} + x_{oi} \bullet 0.007 \bullet 1000) \bullet \frac{44}{28}, \tag{30}$$

where N_2O_{di} refers to direct emission of N_2O on account of the application of fertilizer in land use i (t N_2O), EF_{di} refers to emission factors (kgN_2O-N/kgN) (for paddy: 0.0031 and for upland crop: 0.0062), x_{ci} refers to the amount of chemical fertilizer application (kgN), x_{oi} refers to the amount of organic fertilizer applied (tonnes/10a) and 44/28 implies the conversion of N_2O-N emission to N_2O emission.

In the subsequent step, the estimation methods of indirect emission have been considered. When E_{ad} denotes N_2O emissions associated with atmospheric deposition (kgN_2O) and E_l denotes the emissions associated with nitrogen leaching and runoff (kgN_2O), then indirect emission is expressed in the following manner:

$$N_2O_{indirect\_i} = E_{adi} + E_{li}. \tag{31}$$

Emissions from atmospheric deposition may be expressed as

$$E_{adi} = EF_{ad} \bullet (x_i \bullet Frac_{GASF} + N_D \bullet Frac_{GASM}) \bullet \frac{44}{28}, \tag{32}$$

where E_{ad} refers to N_2O emissions from atmospheric deposition, EF_{ad} refers to emission factors (kgN_2O-N/kgN), xc_i refers to the amount of nitrogen fertilizer, $Frac_{GASC}$ (0.1) refers to the rate of chemical fertilizer deposition (kgNH_3-N + NOx-Nkg), x_{oi} refers to the amount of N in the organic fertilizer applied, $Frac_{GASO}$ (0.2) is the rate of organic fertilizer deposition (kgNH_3-N + NOx-Nkg). Therefore,

$$E_{adi} = \frac{1}{1000} \bullet 0.01 \bullet (x_{oi} \bullet 0.1 + x_{ci} \bullet 0.007 \bullet 1000 \bullet 0.2) \bullet \frac{44}{28}. \tag{33}$$

Emissions from nitrogen leaching and runoff (E_{li}) is defined as

$$E_{li} = \frac{1}{1000} \bullet EF_l \bullet z_i \bullet \frac{44}{28}, \tag{34}$$

where EF_l refers to the N_2O EF from nitrogen leaching and runoff (kgN_2O) and z_i refers to the runoff amount (kgN). Although the proportion of N runoff against the application of fertilizer is set at 30% in the MOE (2008), equations (13) and (14), which were estimated in this SAPIM analysis, have been used for determining the leaching and runoff amount.

$$E_{li} = \frac{1}{1000} \bullet 0.0124 \bullet Z_i(x_i) \bullet \frac{44}{28}. \tag{35}$$

3.4.3. Carbon sequestration

In addition to the CH_4 and N_2O emissions, agriculture can significantly reduce the risk of climate change by sequestering the atmospheric CO_2 and depositing it in the soil. Currently, only four countries (Canada, Denmark, Portugal, and Spain) have elected to include “Cropland Management and Grazing Land Management (the key activities relevant to agricultural industries)” in their accounts for the first commitment period (2008−12) of the Kyoto protocol. There is no information regarding this category in Japan’s GHG Inventory (MOE, 2008).

It is doubtful that adopting no-tillage for suppressing carbon release from arable soils, which is strongly recommended in the USA, would be an effective technique for Japan; this is because Japan’s climatic conditions are characterized by high-humidity as well as high-temperature (vigorous weed growth is a serious encumbrance). Given the weather conditions, an appropriate amount of organic input increases soil carbon content and stimulates reductions in the total GHG emissions.

There are limited studies regarding comprehensive carbon dynamics in paddy fields. However, Nishimura *et al*. (2008) studied the impact of change in land utilization from paddy rice cultivation to upland crop cultivation in the Soil Carbon Budget (SCB); this is estimated by integrating the net carbon supply quantities, removing CO_2 and CH4, and draining of the paddy fields for upland crop cultivation, which causes significant carbon loss from the soil.

Japan has access to country specific continuous survey data; these surveys are being conducted in 52 areas for paddy and 26 areas for upland crops. Overall, the average data reveals that organic matter applications increase the amount of carbon sequestration: 1t/10a manure application causes 40.6−77.4kgC/10a sequestration in paddy fields and 1.5t/10a manure results in 37.3−170.9kgC/10 sequestration in uplands. The amount of carbon sequestration as a result of the application of organic matter differs from one soil type to another. In this analysis, gray lowland soils and gley soils for rice paddy and andosols for upland crops have been used for curve estimation because both these soil types are widely present in Japan. In addition, using a type of soil that is predominantly present in Japan could permit greater extrapolation at a spatially aggregate level.

The amount of carbon sequestration is expressed in the following manner:

$$C_i = \sum Seq_i \bullet \frac{44}{12} \tag{36}$$

Regarding the specification of the function form, since there is an upper limit on the carbon sequestration capacity, polynominal functions are estimatd using data from MAFF, which includes the amount of application per year and the increased amount of soil carbon in each soil type. Subsequently, (37) and (38) represent the estimated carbon sequestration capacities for paddy and upland fields, respectively.

$$Seq_1 = -0.0062 x_o^{\,2} + 0.052 x_o \ (R^2 = 0.80) \tag{37}$$

$$Seq_2 = -0.0013 x_o^{\,2} + 0.022 x_o . \ (R^2 = 0.69) \tag{38}$$

3.5. Social welfare function

The monetary valuation of each environmental effect is aggregated in order to consider the collective impact of environmental effects, which is subsequently combined with the profit function. These valuation estimates are based on published valuation studies. First, the N runoff and purification (per kg) are monetarily valued. It is difficult to apply the stated preference method (contingent valuation method and choice experiment) directly owing to the lack of information regarding nitrogen runoff and purification, which may lead to inappropriate valuation (Hanley *et al*. 1997). Additionally, there is no precise calculation technique for the monetary valuation of environmental impact in Japan.

On the other hand, a number of estimations were conducted using the replacement cost method. However, it is difficult to employ this method for estimating water purification in cultivated lands since the degree of water purification varies depending on the natural conditions and farming practices. Shiratani *et al*. (2004, 2008) overcame this difficulty by employing a newly developed method, which replaces the N removal rate of paddy fields and N runoff rate of upland fields by a sum of the maintenance and depreciation costs (instead of construction cost) of the water quality improvement facilities. These facilities possess the same characteristics as paddy fields, i.e., the amount of removal of N is proportionate to the concentration of N. Although the cost of removal of N is significant, the associated costs of water quality improvement facilities remain unchanged. Consequently, the relative cost per kg of the removal of N decreases in proportion to the volume removed. Shiratani *et al*. (2004, 2008) estimated the monetary values of N purification (paddy) and N runoff (upland) as 0.3 JPY/m^2/d and −0.08 JPY/m^2/d, respectively. It is essential that all values be presented in terms of per parcel (10a) as well as per year. Therefore, the monetary values of N purification (paddy) and N runoff (upland) were 42,000 JPY/10a/y[7] and −29,200 JPY/10a/y, respectively. The specificity of the replacement cost method creates a difference between the benefit and damage values.

[7] Paddy cultivation period is assumed to be 140 days.

Regarding paddy, N purification is effective only when the nitrogen concentration of the irrigation water is above 2.5mg/l; such paddy fields account for 10% of total paddy fields (Shiratani *et al*. 2004). In addition, the characteristics of this analysis, which describe the cause-effect linkages in a representative farm level model and extrapolate them for providing greater insights at spatially aggregate levels, must be taken into consideration. Consequently, the monetary valuation of the purification of N as 1/10 must be replaced with the result obtained, i.e., 4,200 JPY/10a/y.

With respect to upland crops, the estimated runoff function is derived by surveying the upland-catchment basins. However, land use linkages strongly influence the amount of N runoff from uplands to rivers. According to the N outflow model developed by Tabuchi (1998a) and Tabuchi (1998b), approximately 65%–75% of the N in water is naturally lost on account of denitrification under anaerobic conditions when the water flows from the uplands to paddy fields (lowland) as well as due to absorption by rice crops. In this analysis, an average figure of 70% was quoted on the basis of the observations in Tabuchi (1998a, 1998b), and the monetary valuation obtained is –8,760 JPY/10a/y.

The average volumes of net purification and runoff have been set at 0.64 kg/10a/y (under the average N application: 8.9 kg/10a/y (Nishio 2001)) and 4.94 kg/10a/y (under the average N application: 13 kg/10a/y (estimated by the National Agriculture Research Centre)), respectively; therefore, the monetary value (per kg) of net purification and net runoff is given by 6,563 JPY/kg and 674 JPY/kg, respectively. The per kg value of purification is much larger than that of runoff damage; as mentioned previously, this is owing to the characteristics of the replaced water quality improvement facilities and the relatively small purification volume as compared to the total runoff volume.

GHG valuations have been considered in the subsequent step. One of the alternatives amongst the various studies is to employ the price of emission allowances as a proxy (CO2 equivalent emissions). In the emissions trading theory, the marginal abatement cost equals the allowance price. However, there exist a few difficulties: The European Union Emissions Trading Scheme (EU ETS) is the world's first large-scale GHG trading programme, which includes approximately 12,000 installations in 25 countries and 6 major industrial sectors; however, the average marginal abatement cost of GHG in Japan is much higher than that of the EU[8]. In addition, since Japan's ETS has been launched recently, no data is currently available.

The social cost of carbon (SCC) is estimated as the economic value of the additional (or marginal) impact caused by the emission of one more tonne of carbon (in the form of carbon dioxide) at any point of time. This may also be interpreted as the marginal benefit of reducing carbon emissions by one tonne (Yohe *et al*. 2007). As per the *Contribution of Working Group II to the Fourth Assessment Report of the IPCC, the average SCC has been estimated at 12 US$*. However, since this figure corresponds to the overall world average SCC, it is inappropriate to consider that this figure indicates the SCC in Japan.

Baker *et al*. (2007) (originally, in Viguier *et al.* 2003) provided a comparison of four model estimates of the costs of meeting Kyoto targets with domestic emission trading and without international trading. Two of these four results are available for Japan; the domestic carbon price for Japan was estimated at 59.8 (2,000 US$/t$CO_2$) by the EPPA model and 70.8 (2,000 US$/t$CO_2$) by the POLES model (average: 65.3 US$/t$CO_2$).

Considering the pros and cons of each method, it is feasible to use a modelling estimation of the domestic carbon price in order to aggregate the environmental effects in SAPIM. Employing the average exchange rate from the year 2000—1USD equals 107.8 JPY—**7**039 JPY/Ct is obtained.

8 In the IPCC third assessment report, marginal abatement costs for the USA, Japan, OECD-Europe, and the rest of the OECD (CANZ) have been compared using 13 world models. "*Despite the wide discrepancies in results across models, the robust information is that, in most models, marginal abatement costs appear to be higher in Japan than in the OECD-Europe"*.
(http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg3/341.htm)

Using the above monetary value estimation, the social welfare function can be expressed as

$$SW = \int_0^1 \sum \pi^i + \alpha z_1 + \beta z_2 + \gamma GHG \quad for\ i = 1,2$$
$$where \quad \alpha = \begin{cases} -674 & if\ z_1 > 0 \\ -6563 & if\ z_1 < 0 \end{cases} \quad , \tag{39}$$
$$\beta = -674$$
$$\gamma = 7039$$

where π^i refers to the farmer's profit function, z refers to the amount of nitrogen runoff (purification), and GHG refers to the total emission of global warming gases.

4. Policy simulations and results

4.1. Setting

The model estimated the government budget outlays, social welfare, crop production, nitrogen runoff, and GHG emission under the various scenarios. Estimating the absolute level of environmental effects is often difficult, and the optimal utilization of land may change depending on the relationship among the absolute levels of externalities in the model. Further incorporation of alternative environmental externalities may indicate different results for optimal land allocation. Consequently, it is important to emphasize the *relative effect* of each agri-environmental policy on private and social welfare.

There are two phases of the analysis (Figure 3). The first analysis compares the private optimum (producers maximize their profit while disregarding both positive and negative externalities) and social optima (government planners maximize the producers' as well as society's profit whilst incorporating both positive and negative externalities). Direct payments (national average) have been included as a prerequisite in this model.

The second analysis compares different policy options for reducing nitrogen runoff and GHG emissions. The policy scenarios assume the maximization of personal profit by producers.

- Policy 1: Imposing a 50% reduction in the application of chemical fertilizers plus an environmental area payment in order to compensate the amount of profit lost as compared to the private optimum.
- Policy 2-1: Imposing a tax on the prices of chemical fertilizers (tax rate is 50%).
- Policy 2-2: Imposing a tax on the prices of chemical fertilizers (tax rate is 300%).
- Policy 3: Imposing a minimum organic matter application (1t/10a for rice paddy and 1.5t/10a for wheat) plus an environmental area payment (8,000 JPY/10a for rice paddy as well as for wheat), which compensates the additional cost of using organic matter.
- Policy 4: Environmental payment on the basis of the amount of organic matter applied (8,000 JPY/1t for rice paddy and 8,000 JPY/1.5t for wheat), which compensates the additional cost of using organic matter.

The rice production adjustment policy allocated a rice production quota to each region on the basis of the sales records of the previous two years. Although a farm level analysis could not reflect the impact of this quota (which prevents a decrease in the price of rice by controlling production in order to meet only the decreased demand), the "without production adjustment" case was also calculated as a part of this analysis by assuming that the price decrease resulting from the relaxation of the quota is 4.66%, which has been estimated by OECD (2009).

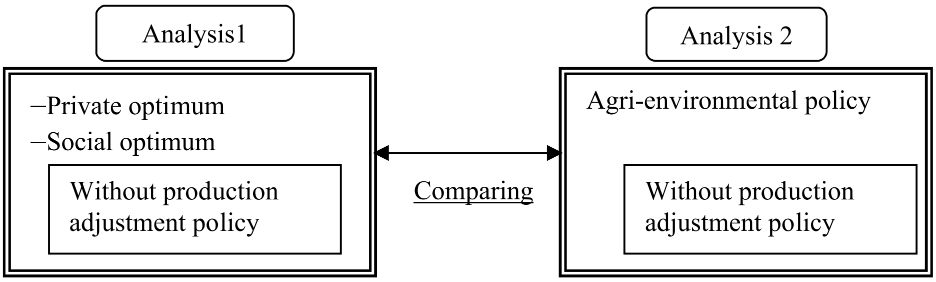

Figure 3. Analysis framework

4.1. Analysis 1: Private and Social optima

4.1.1. Under the production adjustment policy

First, the benchmark private and social optima are estimated. The private optimum reflects the price of rice under the production adjustment policy (quota) as well as the subsidy. This indicates the current level of the farmer's profit the maximization. Consequently, the area that is allocated for rice paddy cultivation under the private optimum is assumed to be the production quota available for rice paddy. The results are compared to the private and social optimum without any corrective policies. The comparison between private and social optima, i.e., the impact of market failure on the utilization of land, has been analyzed in this model.

Estimated land allocation and fertilize application per 10a (Table 1), total production and total fertilizer use (Table 2), N runoff and GHG emission (Table 3), and profit and social welfare (Table 4) are recorded in each table.

Private Optimum

- Farmer's profit: The farmer maximizes yield by using relatively large amounts of chemical fertilizer under the profit maximization behaviour. Very limited quantities of organic fertilizers, which are considered to be expensive owing to high input price, transportation, and spreading costs, are used (0.23−0.39t/10a in rice paddy and 0.67−0.77 t/10a in wheat). From among all the scenarios, the farmer's profit is the highest under the private optimum.
- Land use: 41 parcels are allocated to rice paddy and 19 parcels are allocated to wheat. There is no abandonment of land. Rice paddy was not cultivated on all of the parcels owing to the relatively high cost of rice production as well as its characteristic limited nitrogen response even in a high land quality field. Since this analytical framework assumed a relatively large farm in the flat area, deficit (land abandonment) did not occur. In this regard, the primary reason for the abandonment of cultivation is structural, for example, lack of succession. In fact, the current land use of rice paddy and upland crop is approximately 1.6 million ha (production quota) and 0.79 million ha, respectively. Therefore, the simulation results may essentially indicate the actual current utilization of land.
- Environmental externalities: Chemical fertilizer application leads to nitrogen runoff. The impact of CH_4 emission and carbon sequestration through organic fertilizer application on GHG is fairly limited.

Social optimum

- Farmer's profit: Social planners maximize social welfare. Consequently, a farmer's profit in this case is lower than the profit of a farmer under private optimum.
- Land use: Maximum social welfare was obtained within the rice production adjustment policy (The maximum allocation for rice paddy cultivation is restricted to 41 parcels only).
- Environmental externalities: Organic fertilizers have partially been substituted for chemical fertilizers. The volume of nitrogen runoff has decreased by approximately 50%. The use of organic matter (0.75−0.84t/10 in rice paddy and 1.03−1.09t/10a) promotes carbon sequestration, which significantly decreases the net GHG emissions as compared to the emissions under the private optimum.

4.1.2. Without production adjustment policy

In the subsequent simulation, private and social optima are estimated *without* considering the rice production adjustment policy (quota). It is assumed that the rice price decreases by 4.66% and the diversion payment for wheat production is maintained at the same level. A direct payment for covering the decrease in income owing to the reduction in the price of rice is set at 6,000 JPY/10a (decoupling payment) in order to achieve the same social welfare outcome as achieved under the production adjustment scenario. The gross amount of the decoupled payment is not included in the social welfare calculation because it is assumed that payments are allocated from the existing agricultural budget.

Private optimum

- Results similar to those obtained under the production adjustment scenario are obtained as a corollary for determining the decoupled payment amount.

Social optimum

- Farmer's profit: Social planners maximize social welfare. Consequently, a farmer's profit in this case is lower than the profit of a farmer under private optimum.
- Land use: Social welfare was maximized by expanding the area for the cultivation of rice paddy, which has a larger positive externality. Rice paddy was allocated to all parcels.
- Environmental externalities: Organic fertilizers have partially been substituted for chemical fertilizers. Although CH_4 emissions increased due to the expansion of the area for cultivating of rice paddy, nitrogen purification has been completely achieved. It must be noted that the increase in the carbon sequestration volume exceeds the increase in the volume of CH_4 emissions.

4.2 Analysis 2: The impact of agri-environmental policy

4.2.1. Under the production adjustment policy

In Analysis 2, several agri-environmental policy simulations have been conducted on the basis of the results obtained in Analysis 1. The policy scenarios assume private profit maximization by producers and different policy options for reducing nitrogen runoff and GHG emissions have been compared. Amongst the policy scenarios, it can be assumed that the objectives of policies 1 and 2 are to control nutrient runoff and policies 3 and 4 are to enhance soil carbon sequestration. It must be noted that policies aiming to decrease nitrogen runoff by controlling the use of chemical fertilizers simultaneously impact the net GHG emission owing to the substitution from chemical to organic fertilizer as a result of farmer's profit maximization behavior. In addition, it must be noted that the policy mix with policy 1 (or policy 2) and policy 3 (or policy 4) has not been undertaken in this study.

Results

- Social welfare in policies 1–4 resembles the social optimum. Since social welfare is optimized under the rice production quota, there are no noticeable differences when it is compared with the social optimum.
- As previously analysed (e.g., Opschoor *et al*, 1994), a low rate of environmental tax (policy 2-1) do not significantly impact the profits of the farmer and do fail to motivate the farmers to amend their behaviour. High tax rates (policy 2-2) are required in order to achieve the environmental effects that are as constructive as those achieved with the help of other environmental policies; however, such a policy dramatically decreases the farmer's profits. Consequently, reducing the use of chemical fertilizers by promoting the use of organic fertilizers is an effective method for controlling nitrogen runoff. Agri-environmental payments that are subject to chemical nitrogen application standards are more effective than the unit tax or unit payment.
- In general, the increase in the volume of soil carbon sequestration exceeds the increase in the CH_4 emissions. Therefore, on comparison with the GHG emissions under the private optimum, the net GHG emissions decrease significantly.
- Agri-environmental payments based on the amount of organic application (policy 4) result in large amounts of carbon sequestration, while its excess application increases the risk of eutrophication and also increases the fiscal budget burden.

4.2.2. Without production adjustment policy

In the subsequent step, the agri-environmental policy impact was considered *without* the production adjustment policy. In this case, it is assumed that the rice price drops by 4.66% and the diversion payment is maintained at the same level. As undertaken in Analysis 1, a direct payment for compensating the decrease in income owing to the reduction in the price of rice price is set at 6,000 JPY (decoupling payment). The gross amount of the decoupled payment is not included in the social welfare calculation because it is assumed that payments are allocated from the existing agricultural budget.

Results

- The degree of social welfare obtained under the policy scenarios is higher than that under the production adjustment simulation.
- High levels of efficiency were achieved though agri-environmental payments (policies 1 and 3); however, these results must be interpreted prudently since transfer efficiency and transaction costs have not been considered.

Table 1. Land allocation and amount of fertilizer used

Policy	Land use		Fertilizer use per 10a			
			Rice		wheat	
	Rice	Wheat	Chemical (kg)	Organic (t)	Chemical (kg)	Organic (t)
Private optimum:under the production adj.	41	19	9.42-9.92	0.23-0.39	15.31-15.61	0.67-0.77
Social optimum:under the production adj.	41	19	6.69-6.76	0.77-0.86	13.24-13.29	0.92-0.99
Private optimum:without the production adj.	41	19	9.62-10.15	0.17-0.34	15.31-15.62	0.67-0.77
Social optimum: without the production adj.	60	0	6.89-6.98	0.69-0.83	-	-
Policy1: Chemical N -50% + Payment: under the production adj.	40	20	4.71-4.96	0.91-1.11	7.65-7.80	1.42-1.54
Policy1: Chemical N -50% + Payment: without the production adj.	52	8	4.74-5.07	0.86-1.13	7.71-7.65	1.42-1.53
Policy2-1: Chemical N tax (50%): under the production adj.	41	19	9.03-9.44	0.30-0.45	14.92-15.12	0.73-0.81
Policy2-1: Chemical N tax (50%): without the production adj.	43	17	9.22-9.64	0.24-0.40	15.13-15.72	0.38-0.72
Policy2-2: Chemical N tax (300%): under the production adj.	41	19	7.07-7.22	0.62-0.73	12.87-12.98	0.93-1.00
Policy2-2: Chemical N tax (300%): without the production adj.	52	8	7.16-7.31	0.58-0.72	12.95-12.98	0.97-1.00
Policy3: Minimum Organic + Payment: under the production adj.	41	19	6.71-6.86	1.00	12.15-12.25	1.50
Policy3: Minimum Organic + Payment: without the production adj.	46	14	6.69-6.86	1.00	12.18-12.25	1.50
Policy4: Organic payment (quantity payment): under the production adj.	41	19	4.27-4.47	1.57-1.58	13.08-13.09	1.27-1.30
Policy4: Organic payment (quantity payment): without the production adj.	49	11	4.22-4.48	1.57-1.59	13.09	1.29-1.30

Table 2. Total production and total fertilizer use

Policy	Total production (kg)		Fertilizer use (total)					
			Rice		Wheat		Total	Total
	Rice	Wheat	Chemical	Organic	Chemical	Organic	Chemical	Organic
Private optimum: under the production adj.	22242	12555	396	13	294	14	690	27
Social optimum: under the producion adj.	22719	12671	276	34	252	18	528	52
Private optimum: without the production adj.	22164	12555	405	11	294	14	699	24
Social optimum: without the producion adj.	34248	0	412	48	0	0	418	46
Policy1: Chemical N -50% + Payment: under the production adj.	22055	13463	193	41	155	29	348	70
Policy1: Chemical N -50% + Payment: without production adj.	29250	5384	255	52	61	12	317	65
Policy2-1: Chemical N tax (50%): under the production adj.	23488	11340	397	16	255	13	653	29
Policy2-1: Chemical N tax (50%): without production adj.	23415	11340	406	14	255	13	661	27
Policy2-2: Chemical N tax (300%): under the production adj.	22570	12652	294	28	246	18	540	46
Policy2-2: Chemical N tax (300%): without production adj.	29135	5537	379	34	104	8	482	42
Policy3: Minimum Organic + Payment: under the production adj.	22889	12901	279	41	232	29	511	70
Policy3: Minimum Organic + Payment: without production adj.	25901	9669	312	46	171	21	483	67
Policy4: Organic payment (quantity payment): under the production adj.	23003	12877	180	65	249	24	429	89
Policy4: Organic payment (quantity payment): without production adj.	27868	7661	214	77	144	14	358	92

Table 3. Nitrogen (N) runoff and GHG emission

Policy	N runoff * (kg)	GHG emission and sequestration * (CO_2 t)			
		CH_4	N_2O	CO_2	Total
Private optimum: under the production adj.	101.0	11.4	3.3	-3.4	11.3
Social optimum: under the production adj.	56.4	11.9	2.8	-8.5	6.2
Private optimum: without the production adj.	103.4	11.4	3.0	-3.0	11.4
Social optimum: without the production adj.	-58.9	17.3	1.3	-8.0	10.7
Policy1: Chemical N -50% + Payment: under the production adj.	11.3	11.8	2.3	-9.0	5.1
Policy1: Chemical N -50% + Payment: without production adj.	-34.4	15.3	1.7	-9.7	7.3
Policy2-1: Chemical N tax (50%): under the production adj.	76.9	12.1	2.8	-4.0	10.9
Policy2-1: Chemical N tax (50%): without production adj.	78.8	12.0	2.8	-3.6	11.2
Policy2-2: Chemical N tax (300%): under the production adj.	54.1	11.8	2.7	-6.3	8.2
Policy2-2: Chemical N tax (300%): without production adj.	-10.1	14.9	1.9	-6.6	10.2
Policy3: Minimum Organic + Payment: under the production adj.	45.5	12.1	2.9	-9.0	6.0
Policy3: Minimum Organic + Payment: without production adj.	17.9	13.5	2.5	-9.3	6.8
Policy4: Organic payment(quantity Payment): under the production adj.	50.7	12.5	3.0	-11.8	3.7
Policy4: Organic payment(quantity Payment): without production adj.	1.7	15.0	2.4	-13.0	4.4

* The minus represent the purification for Nitrogen and the sequestration for Cabon

Table 4. Profit and social welfare

Policy	Profit	Profit +payment (tax)	Budget outlays	Runoff damage (Purification benefit)	GHG emission damage (Sequestration benefit)	Social welfare (1000JPY)	SW/SO
Private optimum:under the production adj.	1854	1854	-	73	-79	1847	0.94
Social optimum: under production adj.	1802	1802	-	203	-43	1962	1.00
Private optimum:without the production adj.	1873	1873	(246)	57	-80	1850	0.89
Social optimum: without production adj.	1765	1765	(360)	387	-75	2077	1.00
Policy1: Chemical N -50% + Payment: under the production adj.	1703	1871	168	247	-36	1914	0.98
Policy1: Chemical N -50% + Payment: without production adj.	1663	1827	164	354	-51	1966	0.95
Policy2-1: Chemical N tax (50%): under the production adj.	1853	1792	-61	121	-76	1898	0.97
Policy2-1: Chemical N tax (50%): without production adj.	1871	1811	-61	109	-79	1902	0.92
Policy2-2: Chemical N tax (300%): under the production adj.	1813	1515	-298	197	-58	1951	0.99
Policy2-2: Chemical N tax (300%): without production adj.	1814	1548	-266	300	-72	2041	0.98
Policy3: Minimum Organic + Payment: under the production adj.	1738	2218	480	209	-42	1906	0.97
Policy3: Minimum Organic + Payment: without production adj.	1755	2235	480	257	-48	1965	0.95
Policy4: Organic payment (quantity payment): under the production adj.	1619	2266	647	230	-26	1822	0.93
Policy4: Organic payment (quantity payment): without production adj.	1592	2287	695	314	-31	1876	0.90

Note: SW/SO represents the social welfare ratio of the scenario relative to the social optimum, and the denominators (SO) which are used in the each case (under or wothout production adj.) are those of social optimum, relatively.

5. Summary and Discussion

The results indicate that different agri-environmental policies demonstrate rather different outcomes in terms of land use, production, and environmental externalities. A special feature of this study is the integration of rice paddy production with an upland field crop in the same analytical framework. In general, this study indicates that farm management practices determine whether paddy fields influence the environment positively or negatively. Consequently, providing incentives to farmers that encourage environmentally friendly production practices significantly influence the environmental effects of rice paddy production.

In this study, the sensitivity of the results to the valuation of environmental externalities was tested by changing the monetary value of N runoff (purification) and GHG emission by 10% in order to align with other uncertainties (output price and fertilizer price). In addition, a 30% change was also imposed on the stated preference values in order to consider a higher degree of uncertainty. A key result of this study is that in the case of without production adjustment (quota) policy, the results indicated a positive impact for nitrogen runoff reduction, carbon sequestration, and social welfare, which continued to hold within the range of this sensitivity analysis. The sensitivity analysis is a small illustration of the range of possible alternatives that can be explored. Nevertheless, they cover the most important variables, and an uncertainty range of 10% and 30%.

Finally, some caveats must also be noted. Although it is true that the results in terms of farmer's profit, nitrogen surplus, etc., are all crucially dependant on the assumptions employed in the model, the analysis presented in this report does not critically depend on the absolute level of the results obtained. It is not necessary that these results will be relevant for every rural area since national average data as well as available scientific data have been employed in this modelling exercise. For example, in case intermediate and mountainous areas are being analysed, then data for the profit function and externalities must be adapted accordingly. This analysis assumes that farmers change their land use patterns within the multi-purpose paddy field in order to deal with the continuous land use of rice paddy and upland crops. Moreover, the following variables have not been considered: CO_2 emissions from agricultural land, transaction costs, and transfer efficiency.

The following points summarize the primary findings of this study:

- In the every scenario, a greater number of parcels were allocated to rice paddy than to wheat. The quantity of rice paddy production outweighed that of wheat production in raising the farmer's profit as well as in improving environmental performance (externalities).
- In terms of social optimization, social welfare is maximized when all the parcels are allocated to cultivation of rice paddy. In this case, a farmer's profit is lower than the profit of a farmer under private optimum.
- Agri-environmental policy could compensate for the reduction of social welfare of the private optimum by reducing negative and increasing positive externalities. However, even in this case, every parcel is not allocated to rice paddy production owing to the limited nitrogen response of rice paddy and its high production cost.
- Reducing the usage of chemical fertilizers by promoting the usage of organic fertilizers in order to control nitrogen runoffs results in environmental improvements. Agri-environmental payments, which are subject to a chemical nitrogen application constraint, are more effective than nitrogen tax.
- With regard to carbon sequestration, the social welfare derived from agri-environmental payments on the basis of the application of minimum organic matter, which can prevent the excess application of organic matter, is higher than that derived from unit payments on the basis of the level of organic application.
- Without a production adjustment (quota) policy scenario, the results indicate a positive impact for nitrogen runoff reduction, carbon sequestration, and social welfare.

This integrated model approach is subject to limitations with respect to the data, model parameters, as well as economic and biophysical relationships. However, this approach operates as a valuable tool for enabling policy makers in designing and implementing effective and efficient policies.

References

Akiyama, H., Yan, X., Yagi, K. (2006), Estimations of emission factors for fertilizer-induced direct N_2O emissions from agricultural soils in Japan: Summary of available data, *Soil Science and Plant Nutrition*, 52-6, 774-787.

IPCC (2006), 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use.

Japan Soil Association (2009), A mail survey on the project for the GHG mitigation from rice paddy (in Japanese), http://www.japan-soil.net/WORKS/pdf_report/H20_inawara.pdf (in Japanese)

Kunimatsu, T and Muraoka, H. eds. (1989), Modelling analysis on river pollution. Nagoya university publishing. (in Japanese)

Lankoski, J. and M. Ollikainen (2003), Agri-Environmental Externalities: A framework for designing targeted policies. *European Review of Agricultural Economics* 30, 51-75.

Lankoski, J, Lichtenberg, E. and Ollikainen, M. (2004), Performance of alternative policies in addressing environmental dimension of multifunctionality. Discussion Papers 4. University of Helsinki, Department of Economics and Management.

Lankoski, J., Ollikainen M. and P. Uusitalo (2006). No-till technology: benefits to farmers and the environment? Theoretical analysis and application to Finnish agriculture. *European Review of Agricultural Economics* 33: 193-221.

Lichtenberg, E. (1989), Land quality, irrigation development, and cropping patterns in the

Lichtenberg, E. (2002), Agriculture and the environment. In B. Gardner and G. Rausser (eds.), *Handbook of Agricultural Economics*. Vol 2A: Agriculture and its linkages. Amsterdam: North Holland.

MOE (2008), National Greenhouse Gas Inventory Report of Japan, Ministry of the Environment Greenhouse Gas Inventory Office of Japan (GIO), CGER and NIES.

National Institute for Agro-environmental Sciences (1998), Agri-environmental Monitoring Manual for Water Conservation. (in Japanese)

National Institute for Agro-environmental Sciences (2007), The ascertain of soil carbon fluctuation with 20 000 points agricultural land data -agricultural land has possibility to mitigate global warming by appropriate management-, Press released on 14/11/2007.

Nishio, M. (2001), Analysis of the actual state of nitrogen application in arable farming in *Japanese Journal of Soil Science and Plant Nutrition* 72 (4): 513-521. (in Japanese with English summary)

Nishio, M. (2007), The basic knowledge for organic fertilizer, Nosan-gyoson-bunka kyoukai.(in Japanese)

Nishimura, S., T. Sawamoto, H. Akiya, S. Sudo, K. Yagi(2004), Methane and nitrous oxide emissions from a paddy field with Japanese conventional water management and fertilizer application, *Global Biogeochemical Cycles*, 18.

Nishimura, S., Yonemura, S., Sawamoto, T., Shirato, Y., Akiyama, H., Sudo, S. and Yagi, K. (2008), Effect of land use change from paddy rice cultivation to upland crop cultivation on soil carbon budget of a cropland in Japan, *Agriculture, Ecosystems and Environment* 125, 9-20.

OECD (2008), Environmental performance of agriculture in OECD countries since 1990, OECD, Paris.

OECD (2009), The evaluation of agricultural policy reforms in Japan, OECD, Paris.

Ollikainen, M. (2006), "Manure policies and dairy production: a farm model". Consultant paper prepared for the OECD.

Ollikainen, M. and Lankoski, L. (2005), Multifunctional agriculture: the effect of non-public goods on socially optimal policies, MTT, Discussion Papers 1.

Shiratani, E., Yoshinaga, I., Feng, Y. and Hitomi, T. (2004), Economic valuation of nitrogen removal/load of cultivated land by a new replacement cost method, *Journal of Water and Environment Technology* 27(7): 491- 494. (in Japanese with English summary)

Shiratani, E., Kiri, H. Tanji, H., (2008), Economic valuation of the agricultural impact on nitrogen in the water environmental by a newly proposed replacement cost, *The Japan Agricultural Research Quarterly*, 42 (4): 285-289.

Shibahara, F., K. Takehiko, S. Komatsu and T. Habe (1999) "Effect of Long term Application of Organic Matter and Soil Improvement fertilizer on Paddy rice 1. Changes of Growth and Yield of Rice, Nutrients Uptake by Rice, and Chemical Properties of Soils", *Bulletin of Shiga Prefecture's Agricultural Research Centre* 40, 54-77.(in Japanese with English summary)

Tabuchi, T. and Takamura, Y. (1985), Nitrogen and phosphorus outflow from catchment area. Tokyo University Press, Japan. (in Japanese)

Tabuchi, T. (1998a), Nitrogen outflow model with nitrogen removal function by paddy fields –studies on nitrogen outflow analysis in agricultural watersheds (1)-, *Journal of the Japanese Society of Soil Physics* 78: 11-18. (in Japanese with English summary)

Tabuchi, T. (1998b), Application of nitrogen outflow model for agricultural watershed –studies on nitrogen outflow analysis in agricultural watersheds-, *Journal of the Japanese Society of Soil Physics* 78: 19-24. (in Japanese with English summary)

Takeda, I (1997), Nonpoint pollution in agricultural land, Journal *of Water and Environment*, 20 (12), 816□820. (in Japanese)

Toriyama, K. (2002), Estimation of fertilizer nitrogen requirement for average rice yields in Japanese fields. *Soil Science & Plant Nutrition* 48(3): 293-300.

Acknowledgments

The author acknowledges the data provision from policymakers MAFF and researchers in the national institutes.