Effects of mid-summer drainage in paddy fields on a reduction in methane gas emissions: Application of dynamic spatial computable general equilibrium model

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Abstract

Rice production is affected by global warming, while, at the same time, global warming is accelerated by emissions of methane gas (CH4) from paddy fields. Rice sector needs to take suitable mitigation measures, such as prolonging mid-summer drainage (MSD) before heading time of rice. In order to propose mitigation policy, this study aims to show the environmental and economic effects of MSD in Japanese paddy fields by using a dynamic spatial computable general equilibrium (CGE) model. Environment subsidy with carbon tax scheme is considered to promote MSD measure. Results demonstrate that global warming will cause a decrease in rice price and nominal income of rice farmers, because of bumper harvests until the 2050's. MSD in paddy fields is effective to reduce CH4 emissions as well as to prevent a decrease in farmers' nominal income. However, some farmers can potentially increase their own yield by avoiding MSD under a high rice price that is maintained by the participation of other farmers. Thus, there is a strong motivation for some farmers to get a free-ride. To motivate every farmer to adopt MSD, a environment subsidy with carbon tax is useful. Farmers' income can reach a higher level than the present situation as well as free-ride, and macroeconomic indexes, such as equivalent variation and GDP, will increase and GHG emissions can be reduced more in Japan.

Key words: environment subsidy with carbon tax, crop model, total factor productivity (TFP), representative concentration pathway (RCP) scenario, free-ride

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1. Introduction

Rice production highly depends on climate conditions, including temperature, solar radiation, and precipitation. Future global warming will affect rice production, while at the same time greenhouse gas (GHG) emissions from rice production will accelerate global warming. Among several GHGs, methane (CH4) is the second largest GHG emissions and CH4 emissions from paddy fields account for more than 10 % of the entire CH4 emissions in the world. These numbers are not ignorable, so the rice sector needs to take suitable mitigation measures on methane reduction for tackling future global warming. To make a better policy, quantifying merits and demerits of policy measures is crucial from environment and economic points of view.

Mid-summer drainage (MSD) before the heading time of rice generates cracks in paddy fields and introduces air into root zone. Due to such aeration of root zone, rice yield can increase and total CH4 production from paddy fields can be reduced, but too long MSD period causes a reduction in rice production in spite of more reduction of CH4 emissions (Ito et al., 2015). It is a trade-off effects of prolonging MSD. Of course, farmers are not obliged to participate in MSD, because rice production had begun thousands of years ago, before starting of global warming. In addition, most paddy fields would turn into swamp and still continue to emit CH4 even when rice production stopped, so stopping rice production does not solve the problem. Taking such trade-off effects and backgrounds into considerations, merits for farmers need to be introduced for encouraging all farmers to cooperate.

Ito et al. (2015) measured trade-off effects of MSD from field surveys in several regions in Japan. They compared prolonging MSD period for one more week against setting the conventional period (Fig.1). Their data showed that an additional MSD period decreased CH4 emissions by 30% on average (11-55%) but also decreased rice yield by 5% (from 14% decrease to 10% increase). If all farmers take MSD measure, 1.67 million tons of CH4 can be reduced all over Japan.

This study aims to quantify the effects of prolonging MSD period and environment subsidy with carbon tax as mitigation measures by using a dynamic spatial computable general equilibrium (CGE) model. When future situations are simulated, (i) projection results of Global Climate Model and crop-yield model are used, (ii) trade-off effects of MSD and compensation effects of environment subsidy with carbon tax are concretely quantified, and (iii) regional differences are taken into accounts in the simulation analysis.

2. Method

(1). Structure of the recursive-dynamic spatial CGE model

The model used here is the recursive-dynamic CGE model with multiple regions. The structure of our model is based on the work of Bann (2007) and Kunimitsu (2015a). The major modification points from the original model are as follows.

Climate factors are assumed to influence rice production via rice total factor productivity, TFP. The TFP function was estimated from statistical data in a previous study by Kunimitsu *et al*. (2015b);

$$\ln(TFP_{r,t}) = \beta_0 + \beta_1 \ln(MA_{r,t}) + \beta_2 \ln(KK_t) + \beta_3 \ln(CHI_{r,t}) + \beta_4 \ln(CQI_{r,t}) + \beta_5 \ln(CFI_{r,t}) + \rho\varepsilon_{r,t} + \varepsilon_{r,t-1} \quad (1)$$

Here, $TFP_{r,t}$ is total factor productivity in year t and region r, MA is the management area per farmer, representing economies of scale, KK is knowledge capital stocks accumulated through research and development (R&D) investments, CHI is the rice-yield-index, CQI is the rice quality index, CFI is the flood index caused by heavy rain, and ε is the error terms. CHI, CQI and CFI are estimated by only climate conditions such as temperature, solar radiation and precipitation with the crop-yield model, crop-quality model and extraction method of maximum precipitation from August to October, respectively (Appendix). Estimation results by panel data with 38 prefectures and 31 years show that β_0 =-0.440269, β_1 =0.323960, β_2 =0.140851, β_3 =0.294481, β_4 =0.087842, β_5 =-0.023215, β_7 =-0.0055, ρ =0.544163.

MA and KK are assumed to be constant during the simulation periods in order to make simulation simple. By dividing both sides of Eq. (1) with referenced year which is the start year, $t0$=2015, of our simulation, the following conjunction equation for TFP is derived;

$$TFP_{r,t} / TFP_{r,t0} = \left(CHI_{r,t} / CHI_{r,t0}\right)^{\beta_3} \cdot \left(CQI_{r,t} / CQI_{r,t0}\right)^{\beta_4} \cdot \left(CFI_{r,t} / CFI_{r,t0}\right)^{\beta_5} \quad (2).$$

(2) Data for the calibration of CGE model

To calibrate the parameters of the model, the social accounting matrix (SAM) was estimated from Japan's 2014 inter-regional input-output table[1]. To analyze rice production more precisely, the rice sector was separated from the sector in the original table by using information of the regional tables (404 × 350 sectors) (Ministry of Economy, Trade and Industry). Then, the sectors were reassembled into 18 sectors: (1) paddy rice, (2) other cultivation plants, (3) livestock, (4) agricultural service, (5) forestry, fishery and mining, (6) rice milling, (7) noodle, bread, other milling, (8) dairy and meet products, (9) other food and drinks, (10) chemical products, (11) machinery, (12) electric equipment, (13) other manufacturing, (14) construction, (15) electricity, gas and water, (16) whole sale and retail sale, (17) financial service, and (18) other service sector.

The number of regions was nine: Hokkaido, Tohoku, Kanto including Niigata Prefecture, Chubu, Kinki, Chugoku, Shikoku, Kyushu, and Okinawa.

The input value of farmland, not shown in the Japanese I/O-table, was estimated by farmland cultivation areas (Statistical Yearbook of Ministry of Agriculture, Forestry and Fisheries (MAFF), for every year) by multiplying the areas with farmland rent. Then, the value of farmland was subtracted from the operation surplus in the I/O table and the remaining operation surplus was added to the value for capital input (depreciation of capital stocks).

(3) Simulation method

To measure influences of climate change and effects of mitigation measures, the following cases are considered.

CASE 0 (Reference case): This case represents a reference situation, and is used as the base line. In this case, TFP of rice production is set to 1, showing no progress in technology and no change in climate conditions.

CASE 1 (Only global warming): This case represents future climate change that affects only rice production, but do not consider mitigation measures. The levels of future rice TFP are calculated by

[1] The inter-regional I/O data in 2014 were estimated from the inter-regional I/O data in 2005 published by Ministry of Economy, Trade and Industry. The RAS method and the controlled total production measured from statistics of social national accounts in 2005 and 2014 (Cabinet Office of Japan) were used to update the data.

using Eq. (2). Changes in annual climate factors are projected by the crop-growth model, crop-quality model, and maximum precipitation. For inputs of these models and method, the projection results of climate conditions, such as solar radiation, temperature and precipitation, are obtained from the global climate model (GCM), MIROC version 5 (K-1 Model Developers, 2004). The GHG emission scenario is representative concentration pathways 8.5 (RCP 8.5) that shows the highest rise in future temperature among RCP scenarios. The RCP 8.5 scenario assums high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, and world average temperature in this scenario rises by 2.6-4.8 degree Celsius in 2100.

CASE 2 (MSD under global warming): This case considers prolonging MSD period under the future RCP 8.5 scenario. All rice farmers are supposed to additionally prolong MSD for one week, and accept a 5% decrease in rice yield in order to decrease CH_4 emissions from paddy fields by 30 %. These numbers are based on Fig. 1.

CASE 3 (Environment subsidy with carbon tax): This case considers environment subsidy with carbon tax under the future RCP8.5 scenario. The environment subsidy is provided to farmers who reduces CH_4 emissions from paddy fields by prolonging MSD, but influences of the TFP change by MSD are not considered in order to see the pure effect of the subsidy and tax. The unit price for environment subsidy is 9.45 $ / ton (1040 yen / ton), which is the actual carbon price realized in the European carbon trade market. The same amount of money as total subsidies for a reduction of CH_4 emissions is collected from all industrial production including rice production in accordance with CO_2 emission amounts in each industry as a carbon tax.

CASE 4 (Policy mix): This case considers prolonging MSD and environment subsidy with carbon tax under global warming to promote farmer motivation. The settings for MSD are the same as CASE 2 and the settings for the environment subsidy with carbon tax are the same as CASE 3.

Exogenous variables are set as follows in all cases. The growth rate of population used for labor supply in each region is based on projections of the National Institute of Population and Social Security Research. Government savings, foreign savings and regional money transfer are fixed at the present levels shown in the SAM data. The technological growth rate of the Japanese economy is assumed to be 0 % per year to make simulation simple and to analyze influence paths in the outputs of CGE model.

3. Results

(1) Effects of MSD and environment subsidy with carbon tax (CASE 2 to 4 vs. CASE 1)

Figure 7 shows the effects of prolonging MSD (CASE 2) under global warming as compared to CASE 1 (only global warming). The values in this figure were calculated by subtracting or dividing CASE 1 from CASE 2 to show the net effects of policy measures.

Fig. 8 shows the net effect of only environment subsidy with carbon tax. Plotted values were calculated by the difference or ratio between CASE 3 and CASE 1.

Environment subsidy with carbon tax caused opposite effects in rice sector as compared to prolonging MSD shown in CASE 2. That is, there was an increase in production and a decrease in rice price. However, influences in price were a bit weaker than quantity change, so nominal income increased in spite of a decline in price.

Fig. 9 shows the net effects of the policy-mix, i.e. prolonging MSD and environment subsidy with carbon tax, simulated by CASE 3. In this figure, as in the previous figures, the difference or ratio between CASE 3 and CASE 1 were calculated in order to exclude other influences.

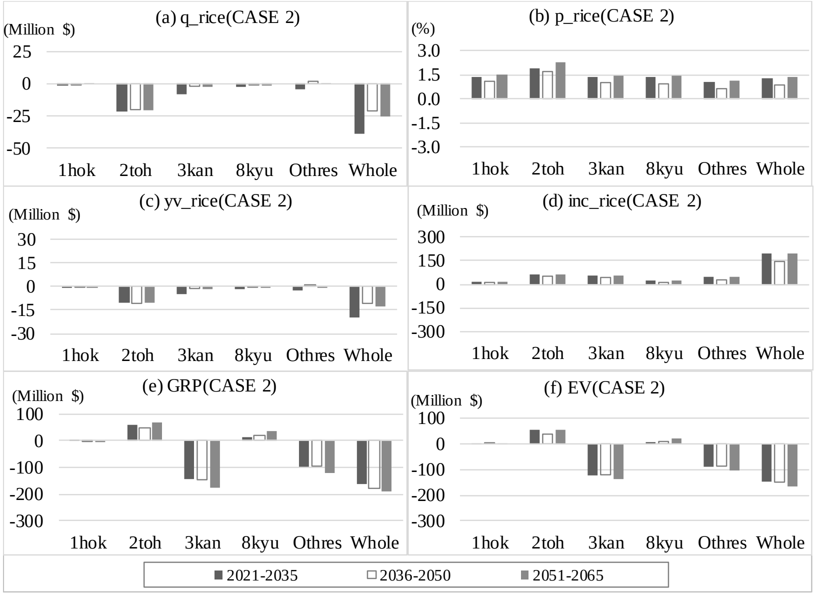

Fig. 7. Effects of prolonging MSD (CASE 2)

(Note) q_rice, p_rice, yv_rice, inc_rice, GRP and EV were respectively total rice production, price of rice, added value of rice production, nominal income of rice farmers, gross regional production and equivalent variation. These values were calculated by subtracting or dividing CASE 1 from CASE 2 values to show pure effects of the policy measures. The signs at horizontal axis are the same as Fig. 6.

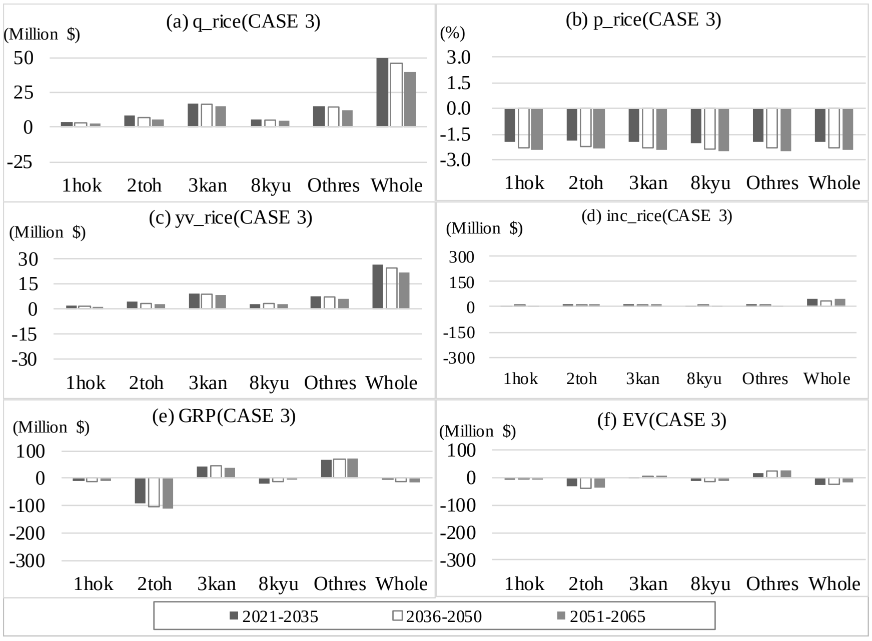

Fig. 8. Effects of environment subsidy with carbon tax (CASE 3)

(Note) Variables and signs of region are the same as Fig. 7 and these values were calculated by subtracting or dividing CASE 1 from CASE 3 to show pure effects of the policy measures.

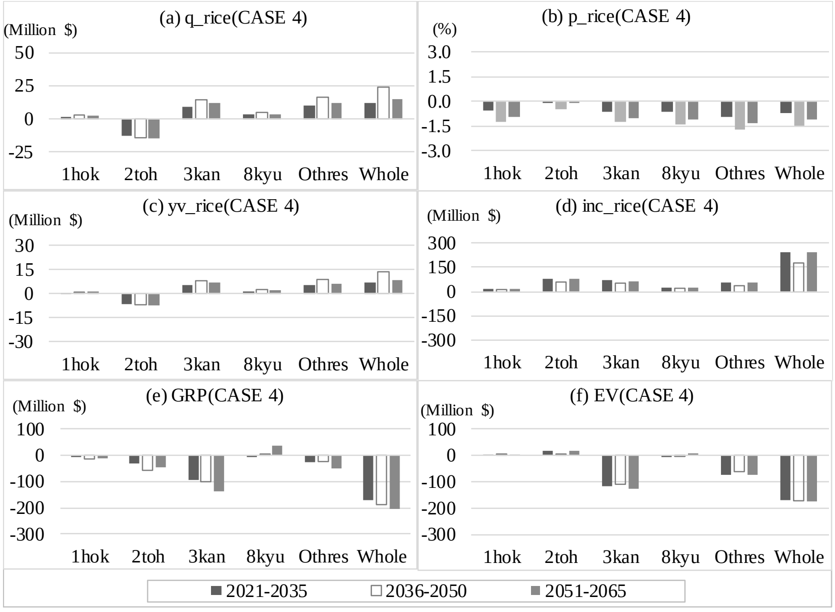

Fig. 9. Effects of MSD and environment subsidy with carbon tax (CASE 4)

(Note) Variables and signs of region are the same as Fig. 7 and these values were calculated by subtracting or dividing CASE 1 from CASE 4 to show pure effects of the policy measures.

(2) Possibility of free-ride and environmental effects of policy measures

Table 1 shows the disposable income per area of farmers. Disposable income was calculated by excluding tax payment from nominal income of rice farmers. The nominal income of the free ride case was assumed to be 1.015 times ($1 / 0.95^{0.294}$, which was the inverse value of TFP change caused by the yield change) of nominal income in CASE 2, assuming that there was no decrease in production caused by prolonging MSD.

From this table, the level of disposable income per area was in the order of CASE 1 < CASE 2 < Free Ride < CASE 4. In other words, as predicted by Fig. 7, prolonging MSD prevented a decrease in nominal income of rice farmers by maintaining rice price at the higher level, if all farmers participated in this measure. Since the case of free ride became better than CASE 1 and 2, farmers' agreement on prolonging MSD was always at risk of the emergence of free riders by betrayal. However, it was most beneficial for farmers to be paid subsidies by participating in prolonging MSD among the possible policy measures. An incentive for free ride could be reduced by paying the environment subsidy, although it depended on the amount of subsidy,

Table 2 shows total amounts of reduction in CO2 and CH4 emissions by policy measures. Emissions of CH4 were converted to CO2 equivalent amounts by using efficiency coefficient on GHG emissions.

Even by only CO2 emissions, environmental effects were the greatest in CASE 4. With consideration of CH4 emissions, the merits of prolonging MSD and environment subsidy with carbon tax (shown by CASE 4) were superior to other cases.

Table 1. Changes in farmer's income per area by the policy measures

				($ / ha)
	CASE1	CASE2	CASE4	FR
Average income (2021-65)	4,216	4,319	4,563	4,393
(Rank order)	(4)	(3)	(1)	(2)

(note) Values of free ride were calculated by multiplying $1/0.95^{0.294}$ to CASE 2. All values in this table included environment subsidy minus carbon tax in each case and then those values were divided by the total areas of paddy fields in Japan.

Table 2. Environmental effects (GHG emission change) of policy measures in whole country

		(1000 eq. CO_2 ton)	
	CASE 2	CASE 3	CASE 4
CO2	-61	-104	-165
CH4	-35,070	0	-35,070

4. Summary, policy implication and conclusion

The results demonstrate that a rise in temperature causes a decrease in rice price and nominal income of rice farmers because of bumper harvests until around 2050. Prolonging MSD in paddy fields is effective to reduce methane gas emissions as well as to prevent a decrease in farmers' income. However, some farmers can potentially increase own income by avoiding MSD and getting higher yield under high rice price that is maintained by the participation of other farmers in MSD. In this sense, there is a strong motivation for some farmers to take a free-ride on this measure.

To motivate every farmer to adopt MSD, environment subsidy with carbon tax is useful, and can increase farmers' income without worthening public balance sheet, although such policy cannot have double dividend effects. By adopting both MSD and environment subsidy with carbon tax, farmer income reaches a higher level than the present situation, and macroeconomic indexes, such as equivalent variation and GDP, increase and GHG emissions, such as CO_2 and CH_4, can be reduced in the whole country.

Based on these findings, a policy-mix of environmental measures, such as MSD and environment subsidy with carbon tax as shown in this study, can be a key to obtain environmental benefits with a suitable economic benefit. There are several trade-offs in the environmental policy measures, but a mixture of policy measures can ease such contradictions. In order to design the best policy mix, simulations with the CGE model play an important role in planning.

Having said so, how to monitor the performance of MSD is another issue to consider. Easy technology sometimes causes a problem in control and accountability. Further research and development on this matter should be carried out by conducting experimental studies. Especially, dealing with global warming is a worldwide issue that needs to be solved, so the role of governments and worldwide consensus cannot be ignored.