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Economic Evaluation of Dissemination of High Temperature-Tolerant Rice in Japan Using a Dynamic Computable General Equilibrium Model

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Abstract

This paper uses the dynamic computable general equilibrium (DCGE) model to evaluate the economic impact of technologies developed to foster adaptation to climate change in domestic rice production, related food industries, and economic welfare in Japan, where high temperatures in 2010 led to rice quality deteriorating and other serious problems over and above a mere decline in output. Three scenarios were simulated: one without temperature change, one with temperature change but rice cultivars unchanged, and one with both an increase in temperature and the adoption of high temperature-tolerant rice varieties. Our simulations indicate that new rice cultivars with high temperature tolerance would reduce economic welfare losses from 264 to 118 billion yen during the simulation period. Paddy-rice farming production increased because product prices increased. Farming inputs also rose correspondingly, triggering an increase in agricultural land rents. Non-agricultural household and small-scale paddy rice-growing household suffered welfare loss. Conversely, medium- and large-scale paddy rice-growing and other farming households saw their welfare boosted. These differences were attributable to the impact of changes in agricultural land rents to their total income. All impacts, not only on economic welfare but also production in the case with new cultivars of high temperature-tolerant rice were smaller than in the those without such cultivars, which indicates that adopting new adaptive technologies eases the economic impact of a warmer climate.

Discipline: Agricultural economics
Additional key words: economic welfare loss, farm size, multi-types of household, rice quality

Introduction

Recently, rice production, the principal agricultural activity in Japan, has been adversely impacted by climate changes. The recent trend of high summer temperatures has led to rice quality rather than just quantity declining and in 2010 in particular, serious problems with regard to rice quality. The percentage of first-grade rice — graded as having the highest quality — was only 62% in 2010 compared with the usual 80% or so. In contrast, the volume of rice production was little affected; the 2010 yield was 8.6 million tons compared with yields of approximately 8.5–8.6 million tons in 2008, 2009, and 2012.

Scientists studying rice production have researched and developed production technologies to adapt and to moderate the effects of climate variations. One of these advancements is high temperature-tolerant rice, called "new cultivars (NCs)" in this paper. It was testified that this technology had a clear advantage in terms of retaining quality compared with existing rice cultivars without high temperature tolerance (ECs) in the historical hottest summer of 2010. In Niigata prefecture, 53% of NCs were graded as first grade compared with 21% of ECs given the same grade. In other prefectures, namely Fukuoka, Saga and Oita, the percentage of first-grade NCs was 70–90%, whereas the percentage of first-grade ECs was 15–40%. The higher percentages of NCs compared to ECs in 2010 thus exemplified the advantage of using this technology against higher temperatures in summer.

Although it has become clear that NCs fare better compared with existing rice cultivars in a warmer climate, not all rice cultivated in Japan shows high temperature tolerance. If the Ministry of Agriculture, Forestry, and

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Fisheries (MAFF) or local governments are to formulate an agricultural policy to encourage farmers to grow rice cultivars with high temperature tolerance, they will need to indicate the economic impacts of high temperature-tolerant rice on Japanese agriculture, related food industries, and economic welfare.

Previous studies evaluated Japanese agriculture using the Computable General Equilibrium (CGE) model (e.g. Kunimitsu 2009, Fukuda & Kondo 2012, Adi & Tokunaga 2006, Tanaka & Hosoe 2011.) These studies focused on the effects of public investments and increasing international grain prices on Japanese agriculture as well as the effect of free trade in agricultural products in Japan. However, we could not find any studies evaluating the impact of technological adaptation to a warmer climate on Japanese agriculture. Accordingly, we used the dynamic computable general equilibrium (DCGE) model to evaluate the economic impacts on Japanese rice production from technology developed to adapt to climate change. For this purpose, we used three scenarios to simulate the effects of using technology to adapt to the warmer climatic conditions predicted to occur between 2005 and 2030. The base scenario comprises a climate that is not warmer. Scenario 1 is the non-adoption of high temperature-tolerant rice in a warmer climate. Scenario 2 is the adoption of high temperature-tolerant rice in a warmer climate in 2017. We also evaluated the effects of growing high temperature-tolerant rice in a warmer climate by comparing scenarios 1 and 2.

This paper is structured as follows. We explain the core structure of the DCGE model in section 2 and subsequently evaluate the economic effect of adaptation of high temperature-tolerant rice on Japanese domestic agriculture, related food industries, and economic welfare using the simulation results in section 3. We finally conclude this paper and discuss the remaining issues in section 4.

Methodology

This paper's model is based on Lofgren et al. (2002) known as the International Food Policy Research Institute's (IFPRI's) standard CGE model, and comprises a combination of production activities, commodities, trade, households, government, and the rest of the world. Moreover, it involves a recursive dynamic mechanism that is the core mechanism of the MONASH model (Dixon & Rimmer 2002).

Table 1 lists the model's activities and commodities and comprises three parts: agriculture, food, and non-agri-food. The agricultural element includes five activities: (1)-(3) three types of paddy-rice farming, (4) livestock farming, (5) agriculture, fishing, and forestry (excluding paddy-rice farming.) Paddy-rice farming is divided into three activities based on the rice acreage cultivated. Small acreages span areas smaller than 3ha, medium acreages cover between 3 and 10ha, and large acreages cover areas exceeding 10ha. Even though the three sizes of farms produce rice of equivalent quality, their output is graded into two types depending on temperature, namely first- and second-grade rice respectively. The other activities each produce one commodity.

The food element includes nine activities, eight of which comprising food manufacturing and the ninth being the food service industry. Specifically, detailed food activities are set to define the rice food system and we will denote the flow of rice production and consumption later. Non-agri

Table 1. Activities and commodities in the model

	Activity	Commodity
Agriculture	Paddy rice farming: small size	Paddy rice: first grade Paddy rice: second grade
	Paddy rice farming: medium size	
	Paddy rice farming: large size	
	Livestock farming	Livestock
	Agriculture, fishery and forestry ex. paddy rice	Agricultural, fisheries, and forestry products
Food	Rice cleaning and polishing for first-grade paddy rice	Rice: first grade
	Rice cleaning and polishing for second-grade paddy rice	Rice: second grade
	Mfg. of flour and grain mill products ex. rice	Flour and grain mill products
	Mfg. of livestock, seafood, vegetables, and fruits products	Livestock, seafood, vegetables, and fruits products
	Mfg. of bakery and confectionery products	Bakery and confectionery products
	Mfg. of seasonings, sugar processing, oils, and fats	Seasonings, sugar, oils, and fats
	Mfg. of miscellaneous foods	Miscellaneous foods
	Mfg. of beverages, tobacco, and feed	Beverages, tobacco, and feed
	Eating and drinking places	Eating and drinking places
Non-food	Manufacturing ex. processed foods	Manufacturing products ex. processed foods
	Service ex. eating and drinking places	Service ex. eating and drinking places

Note: "Mfg" indicates manufacturing.

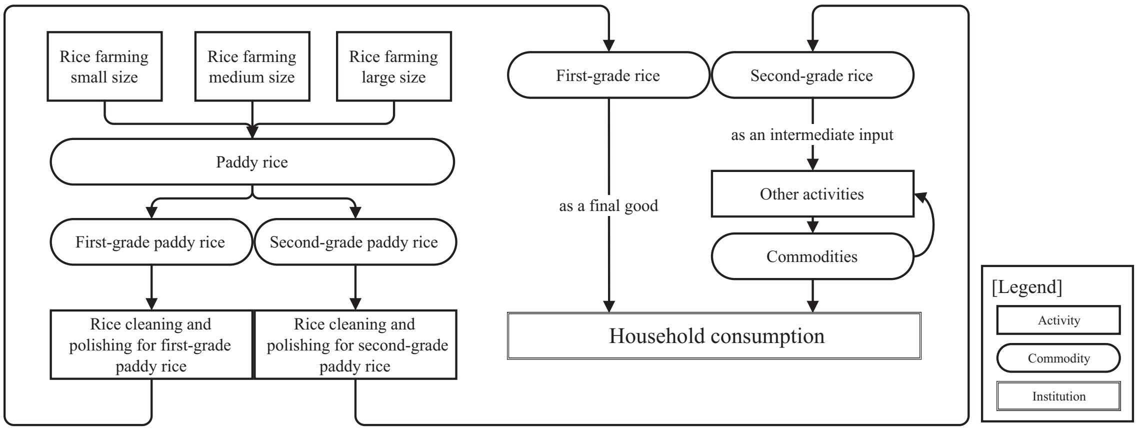


Fig. 1. Rice food system in the model

food comprises manufacturing but excludes food processing and the service industry without the food service. Each of these activities produces one commodity.

In this model, we focus particularly on activities and commodities related to rice production in the rice food system, shown in Figure 1. The three sizes of rice farming produce paddy rice of two different grades, the relative percentages of which are affected by the minimum temperature in August. We use this structure to separate commodities based on their usage as a final good or an intermediate input. With regard to rice cleaning and polishing, each grade of rice has two associated activities. Cleaning and polishing for first-grade rice produces a commodity that is a final good for household consumption, while rice cleaning and polishing for second-grade rice results in a commodity used as an intermediate input for food related to other activities. Accordingly, first-grade rice is consumed as a final good by households, whereas second-grade rice is used as an intermediate input in other activities.

In this model each producer is assumed to maximize profits subject to several production technologies, the model of which assumes perfect competition in these activities. Figure 2 shows the production structures of the two types of activities in agricultural and non-agricultural elements. The production structure of agricultural activities comprises three production stages, as opposed to two for that of non-agricultural activities. The main difference between the two structures centers on the treatment of land. In the agricultural element, land is used to produce the composite factor, which mixes value-added and land. It is assumed that non-agricultural activities do not use land in their production structures. Top-level technology is specified by a Leontief function of the quantities of aggregate intermediate inputs and value-added in non-agricultural activities and by a

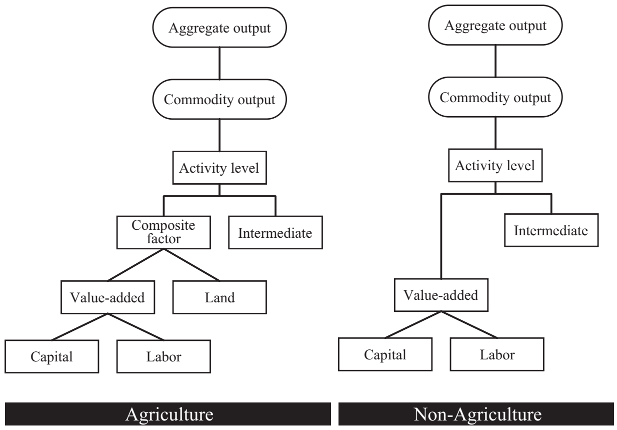


Fig. 2. Production structures of agricultural and non-agricultural activities

Leontief function of the composite factor in agricultural activities. Agricultural activities comprise capital and labor at the next lower level. At the bottom level, each activity evaluates the value added by composite factors under the constant elasticity of substitution (CES) function. Each activity produces one or two commodities.

Each paddy-rice activity level is divided into two commodities, first- and second-grade paddy rice, based on fixed yield coefficients according to the ratio of the first-grade paddy rice as influenced by temperature. Conversely, each activity is assumed to produce a single commodity. For this reason, fixed yield coefficients of the remaining commodities are unity.

The commodity-distribution process comprises a combination of activities-commodities and trade sectors, as shown in Figure 3. In the case of paddy rice, commodities of uniform quality from the three different activities comprise a single commodity under the Cobb-Douglas aggrega-

* The elasticity of substitutions under the CES function is the value in the Global Trade Analysis Project (GTAP) database (version 7). Similar to previous studies, we used double values of the CES function for the elasticity of substitutions under the CET function.

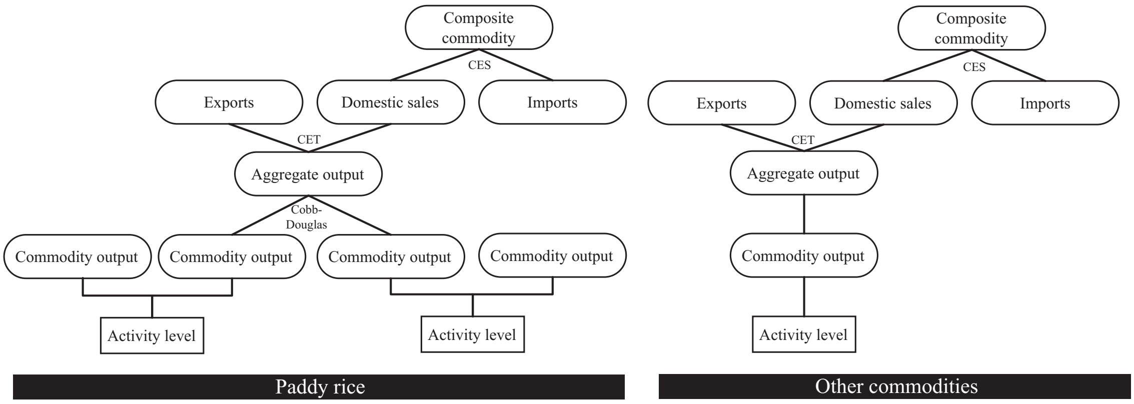


Fig. 3. Flows of commodities (Paddy rice and other commodities)

tion function. The remaining commodities skip this process because there is no need to aggregate them. In the trade sector, domestically-produced commodities are distributed for both export and domestic sales under the constant elasticity of transformation (CET) function. Meanwhile, imports comprise generated composite goods with domestic sales, as determined using the CES function under Armington's assumptions (Armington 1969) and are supplied to the domestic market.*

Domestic demand comprises household and government consumption, investment, and intermediate inputs. We assume five household types: (1) small-scale paddy rice-growing household (HRS), (2) medium-scale paddy rice-growing household (HRM), (3) large-scale paddy rice-growing household (HRL), (4) other farmers' household (HA), and (5) non-farmers' household (HH). All households gain their income from holding primary factors. HRS, HRM, HRL, and HA take labor income, rent of capital and land, and the amount of land income depends on the size of the farm. HH earns labor income and rent of capital. All household consumptions are assumed to maximize the Stone-Geary utility function. According to the linear expenditure system (LES), demand functions derived from these utility functions are subject to budget constraints, while government consumption is determined as comprising a specific consumption share for each commodity. Private and government savings are determined by multiplying each average propensity to save. Investment demand is equal to total private, government, and foreign savings.

This model includes the following market equilibrium condition: domestic markets for goods and primary factors and the external balance. Firstly, each composite good supplied equals the sum of demand from households, government, investment, and intermediate inputs. Secondly, there are three markets for primary factors: labor, capital, and land. The total land demanded by agricultural activities equals the total of farming households' land endowments. The aggregate demand of labor and capital activities equals the total supply from all households. Finally, the current account is balanced under fixed foreign savings in each year.

This model involves the use of a recursive dynamic mechanism. We use Dixon and Rimmer's (2002) core mechanism of the MONASH model. An activity's capital stock in a given year comprises capital stock discounted by depreciation and investment in the activity during the previous year. Another important mechanism is the capital-growth function and expected rate of return. In this function, if an activity's capital growth exceeds its historically normal capital-growth rate, its expected rate of return will exceed its historically normal rate of return, which implies that the activity is attracting sufficient investment.

Simulation Results

This paper simulates the effects of using technology to adapt to the warmer climatic conditions predicted to occur between 2005 and 2030 under the three DCGE model scenarios. The base scenario comprises a climate that is not warmer. Scenario 1 (SIM1) is the non-adoption of high temperature-tolerant rice in a warmer climate. Scenario 2 (SIM2) is the adoption of high temperature-tolerant rice in a warmer climate in 2017, which implies that all rice growers in Japan will eventually shift to NCs with high temperature tolerance. We evaluated the effects of growing high temperature-tolerant rice by comparing both scenarios.

The simulation scenario assumes that NCs will be introduced by 2017. According to a report by the MAFF of Japan (2001), rice quality will decline if the minimum temperature during the 20 days after the heading stage exceeds 23 to 24°C. Accordingly, Kawatsu et al. (2007) estimated the coefficient between average daily minimum temperature during the 10 to 30 days after heading and the ratio of first-grade rice. The period of 10–30 days after heading falls in August. According to aggregate data on expected future climate by Iizumi et al. (2011), the national average mini-

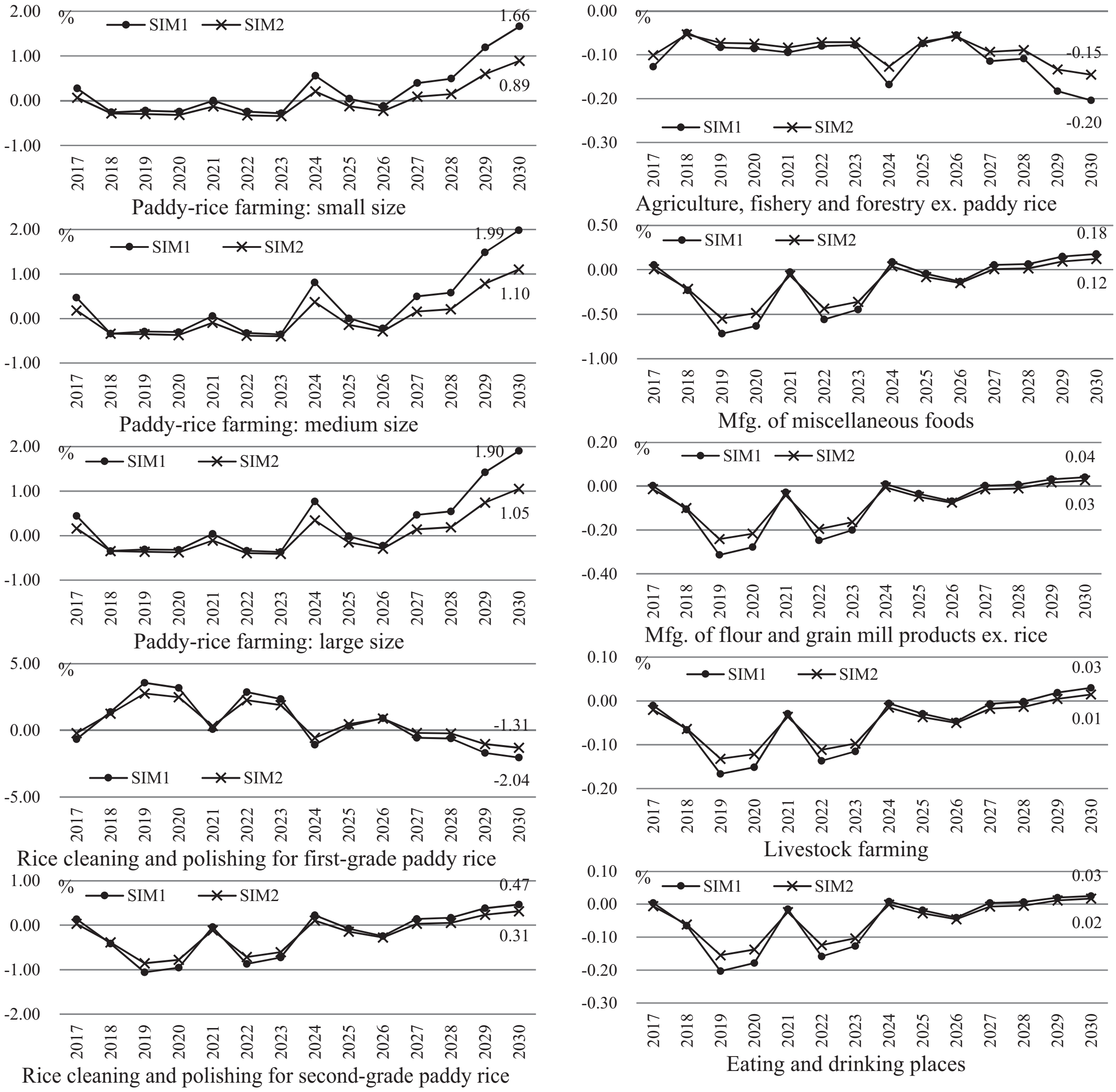
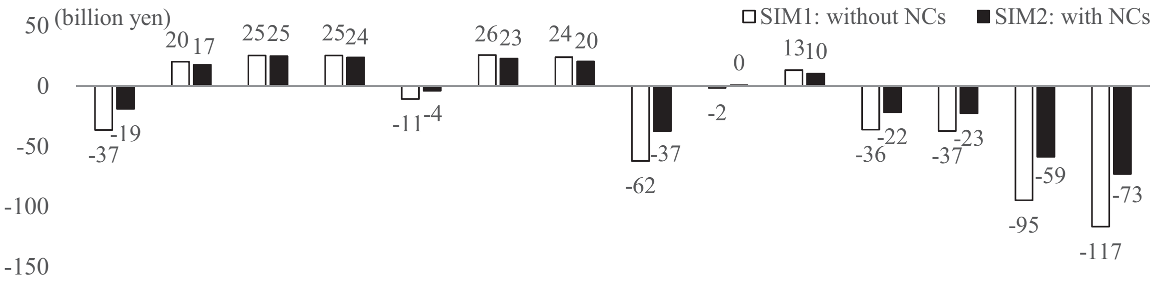


Fig. 4. Effects on activity levels with/without high temperature-tolerant rice in a warmer climate

mum temperature in August will exceed 23°C in 2017, 2024, and all years following 2024. Accordingly, we presume that the introduction of NCs in 2017 will be the first year when the minimum temperature exceeds 23°C.

In this model, temperature influences fixed yield coefficients for the activity level to commodity output in the activities-commodities sector. The fixed yield coefficient for paddy-rice farming to first-grade rice in the base year is 0.628, which is the ratio of first-grade rice to all rice. Kawatsu et al. (2007) provided −3.57 as the estimated coefficient between first-grade rice and minimum temperature during the 10 to 30 days after heading, which implies that the ratio of first-grade rice will decline by 3.57% if the minimum temperature increases by 1°C, where −3.57 is used as a sensitivity coefficient for ECs in the base scenario. Moreover, the sensitivity coefficient for the NCs in the simulation scenario is set at −2.52, as estimated using 2010 data on 13 cultivars with high temperature tolerance. In each scenario, the fixed yield coefficient for paddy-rice farming to first-grade rice varies depending on these sensitivity coefficients. At the same time, the fixed yield coefficient for paddy-rice farming to second-grade rice is also adjusted by subtracting the changed ratio of first-grade rice from 1.

Figure 4 shows activity levels with and without the NCs under a warmer climate from 2017 to 2020. The numerical values show the ratio of change against the base scenario. A warmer climate will damage rice cleaning and polishing for first-grade paddy rice as well as harm agriculture, fisheries, and forestry. Conversely, other activities such as the following will experience increased activity levels: three paddy-rice farmings, rice cleaning and polishing for second-grade paddy rice, manufacturing of miscella-



		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
SIM1	HRS	-1	1	2	2	0	2	2	-1	0	1	-1	-1	-2	-2
	HRM	1	0	1	1	0	1	0	1	0	0	1	1	2	2
	HRL	0	0	0	0	0	0	0	1	0	0	0	0	1	1
	HA	3	0	1	1	1	0	0	4	0	0	2	2	6	7
	HH	-40	19	22	22	-13	23	22	-67	-3	13	-39	-40	-102	-125
SIM2	HRS	0	1	2	2	0	2	1	-1	0	1	0	0	-1	-1
	HRM	1	0	0	0	0	0	0	1	0	0	1	0	1	1
	HRL	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	HA	2	0	0	0	1	0	0	3	0	0	1	1	4	4
	HH	-22	17	22	21	-6	21	18	-41	0	10	-24	-24	-63	-78

Note: "Mfg" indicates manufacturing.

Fig. 5. Economic welfare (EV) with/without high temperature-tolerant rice in a warmer climate

neous foods, manufacturing of flour and grain mill products, livestock farming, and eating and drinking places.

Against expectations, all paddy-rice farmings are positively impacted by a warmer climate, reflecting the fact that the rice price increases when the output of first-grade rice declines, while that of second-grade paddy rice decreases due to increased quantities. The extent of the impact of the price of an entire paddy's rice is equal to the ratio of first-grade rice, 62.8%, and the ratio of second-grade rice, 37.2%, in the base case. The impact of an increase in the price of first-grade rice exceeds that of a decrease in the price of second-grade paddy rice, which means a greater impact when all paddy rice farms increase their activity levels due to the overall increase in paddy rice price. Accordingly, they require increased inputs, which, in turn, cause agricultural land rents to increase by 4.4% in SIM1 and 2.7% in SIM2. Consequently, their unit costs increase according to their input structures — by 6.5% for small-size farms, 6.2% for medium-size farms, and 6.3% for large-size farms in SIM1, reflecting the differing impacts on paddy-rice farming activity levels by size —1.7% for small-size farms, 2.0% for medium-size farms, and 1.9% for large-size farms in SIM1. Moreover, the values in SIM2 are smaller than those in SIM1, which indicates that the NCs ameliorate the impact of a warmer climate.

These activity levels influence macroeconomic indicators. In a warmer climate, the price index increases by 0.04% in SIM1 and 0.03% in SIM2. In addition, capital stock rents rise by 0.05% in SIM1 and 0.03% in SIM2, as do rents of agricultural land. Accordingly, although households face higher prices for goods and services, their incomes increase as they comprise primary factors.

We evaluate economic welfare using equivalent variation (EV) shown as Figure 5. It can be seen that the whole EV for both SIM1 and SIM2 decline after a shift to a warmer climate in 2017, 2024, and after 2027. Meanwhile, the welfare loss during this period is 264 billion yen in SIM1 and 118 billion yen in SIM2, which indicates that the economic loss for NCs with high temperature tolerance decreases by around 145 billion yen. However, even if adaptive technology is used to produce paddy rice, economic welfare declines.

The economic impacts are not evenly distributed across all households. Non-farmer household (HH), comprising all households except farmer households, and small-size paddy rice farmer household (HRS) saw their welfare decrease. Conversely, the EVs of the remaining farmers' households (HRM, HRL, and HA) saw their welfare increase. These differences are attributable to the influence of agricultural land rents. All households suffer the negative impact of increased prices but gain from increased capital rents. Moreover, farmer households that own agricultural land earn income from increased land rent. Total gains in HRM, HRL, and HA exceed the impact of the increased price index, whereas HRS's gain is lower than the latter, the outcome of which reflects the overall negative impact for general household, given their lack of primary factor income from agricultural land. Accordingly, the impact of a warmer climate varies by household type. Using NCs with high temperature tolerance helps mitigate these economic losses and gains.

Conclusion

This paper used the DCGE model to evaluate the economic impact of technologies developed to foster adaptation to climate change upon domestic rice production, related food industries, and economic welfare in Japan. The simulation showed that using the new rice cultivars with high temperature tolerance would reduce economic welfare losses from 264 to 118 billion yen during the simulation period. Paddy-rice farming expanded due to higher prices for first-grade rice. However, this expansion increases demand for farming inputs and triggers a rise in agricultural land rents, which means non-farmer household and small-scale paddy rice-growing household suffer a loss of welfare. Conversely, the welfare of medium- and large-size farmer households increased. These differences are attributable to the influence of increased agricultural land rents. All values in the simulation with the new high temperature-tolerant rice cultivars were smaller than those in the simulation without these cultivars, which indicates that adopting adaptive technology weakens the negative economic impact of a warmer climate.

Finally, we would like to note the significance of using the dynamic model by comparing the results simulated under a warmer climate in 2030 between static and dynamic models. Values in the static model were smaller than those in the dynamic model. For example, the total EV in the static model was −100 billion yen, whereas the value in the dynamic model was −117 billion yen. The impact on large-size paddy-rice farming was 1.73% in the static model but 1.90% in the dynamic model, which indicates that the dynamic model reflects the accumulated impact over time.

Two tasks remain. The first is to elaborate the input structures and primary factors' markets, land, and family labor in greater detail than in the current model. The second is to explore the conditions underlying the relation between rice cultivar's choice behavior of farmers, and climate change in more detail.

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