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Impact of Public Agricultural Investments on Global Indica and Japonica Rice Markets under Climate Change

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Abstract

Indica and japonica rice are subject to different market structures, and the international prices of both varieties display different trends. We project and simulate the future global indica and japonica rice markets under climate change in the mid- and long-term, developing a partial equilibrium model, the Rice Economy Climate Change (RECC) model that covers the indica and japonica rice markets in 24 countries and regions. The simulation results suggest that public agricultural knowledge and innovation system in Vietnam and China play a crucial role in stabilizing the international prices of indica and japonica in the mid- to long-term in target countries, as both rice production markets become increasingly affected by climate change.

Discipline: Social Science

Additional key words: agricultural knowledge and innovation system, China, development and maintenance of infrastructure, price stability, Vietnam

Introduction

Rice in the global market is not, strictly speaking, a homogeneous commodity. Two major types of rice, commonly classified as indica and japonica rice, are traded in the global market. Japonica rice is mainly produced in temperate zones with partly cooler climates, whereas indica rice is produced in tropical, subtropical, and partly temperate zones. In this study, temperate japonica rice is considered as japonica rice, while indica and other rice varieties are categorized as indica rice (Koizumi & Furuhashi 2020). In 2017, Japonica rice accounted for an estimated 14.6% of global rice production, 14.4% of global rice consumption, and 4.8% of global rice trade. India is the largest indica rice producer and China is the largest japonica rice producer. Indica and japonica rice are subject to different market structures, and the international prices of both varieties display different trends.

Many studies have been made on how future climate change could impact global agricultural and rice production. Peng et al. (2004) examined how higher night temperature affected rice yield. Welch et al. (2010) examined how minimum and maximum temperatures impacted the rice yields in tropical/subtropical Asia. Lobell (2007) examined the changes in diurnal temperature range and national cereal yield. Moreover, Furuya & Koyama (2005) examined the relationship between climate change and world food markets. Furthermore, Wailes & Chavez (2011) developed the Arkansas Global Rice Model, distinguishing only the markets for long-grain and short- and medium-grain rice in the United States (US), without specifying the markets for other types of rice. Koizumi & Furuhashi (2020) projected and simulated the future global indica and japonica rice markets under climate change by developing a partial equilibrium model. It simulated Representation Concentration Pathway (RCP) scenarios and projected the global indica and japonica rice markets without considering the impact of any agricultural investments under climate change. General Service Support Estimates (GSSE) released country-based time-series data on public agricultural investment, such as agricultural knowledge and innovation system, development and maintenance of infrastructure, and other data. FAOSTAT also released country-based time-series data on agricultural investment, such as land development, agricultural machinery & equipment, and other data. The growth rate of public agricultural investment in developed countries is lower than that in developing countries. The purpose of this study is to examine how public agricultural investments will contribute to stabilizing global indica

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and japonica rice prices in the mid- and long-term by developing the partial equilibrium model.

Methods and data

The Rice Economy Climate Change (RECC) model covers rice markets in 24 countries and regions (Thailand, Vietnam, Indonesia, Malaysia, Philippines, Cambodia, Lao PDR, Myanmar, China, Japan, South Korea, India, the US, EU28,[1] Bangladesh, Sri Lanka, Nepal, Pakistan, Brazil, Côte d'Ivoire, Egypt, Madagascar, Nigeria, and the rest of the world) to represent the entire global rice market. The RECC model includes equations for projecting rice yield and planted area affected by climate change and public agricultural investments. We applied an Error Correction Model (ECM) to evaluate the long-term equilibrium relationships among economic variables. In this study, the base year is 2015/2017 (three-year average for 2015-2017). Each country or region's market consists of production, consumption, exports, imports, and ending stock for indica and japonica rice up to the year 2040. For the detailed model structures, refer to Koizumi & Furuhashi (2020). We modified the estimated parameters for indica and japonica rice yield and the planted area for the target countries.[2]

The japonica and indica rice yield equations depend on the annual averages of minimum temperature, maximum temperature, precipitation, and lagged public agricultural investments (Eq. 1). The planted area equations for japonica and indica rice depend on the lagged domestic prices of japonica and indica rice, lagged price of wheat, lagged precipitation, and lagged public agricultural investments (Eq. 2).

$$\ln (Y_{v,t,c} / Y_{v,t-1,c}) = a1 \ln (TMIN_{v,t,c} / TMIN_{v,t-1,c}) + a2 \ln (TMAX_{v,t,c} / TMAX_{v,t-1,c}) + a3 \ln (PRC_{v,t,c} / PRC_{v,t-1,c}) + a4 \ln (AGIS_{t-1,c} / AGIS_{t-2,c}) + a5 \ln (DMF_{t-1,c} / DMF_{t-2,c}) + a6 \ln (LD_{t-1,c} / LD_{t-2,c}) + a7 \ln (AME_{t-1,c} / AME_{t-2,c}) \quad (1)$$

where Y is paddy rice yield, $TMIN$ is minimum temperature, $TMAX$ is maximum temperature, PRC is precipitation, $AGIS$ is the amount of investment in agricultural knowledge and innovation system, DMF is that in development and maintenance of infrastructure, LD denotes investments in land development, AME denotes investments in agricultural machinery & equipment,[3] v is rice varieties (japonica or indica), t is the time period in years, c denotes countries/region, and $a1$-$a7$ are the other parameters. Tables A-1 and A-2 list these estimated parameters.

$$\ln (APR_{v,t,c} / APR_{v,t-1,c}) = a8 \ln (JRP_{t-1,c} / JRP_{t-2,c}) + a9 \ln (IRP_{t-1,c} / IRP_{t-2,c}) + a10 \ln (WP_{t-1,c} / WP_{t-2,c}) + a11 \ln (PRC_{v,t,c} / PRC_{v,t-1,c}) + a12 \ln (DMF_{t-1,c} / DMF_{t-2,c}) + a13 \ln (LD_{t-1,c} / LD_{t-2,c}) \quad (2)$$

where APR is the planted area of rice, JRP is the domestic price of japonica rice, IRP is the domestic price of indica rice,[4] WP is the domestic price of wheat, and $a8$-13 are the other parameters. Tables A-3 and A-4 list these estimated parameters.[5] These equations and parameters are applied to the projection. Historical annual data on minimum/maximum temperatures and precipitation are derived from *CRU TS. 3.2* at the University of East Anglia.[6] For larger countries, the values for grids that correspond to major rice-producing areas are averaged.[7] For other countries, the values for all grids that cover the entire territory are spatially averaged. Historical data for the planted area, yield, production, per capita consumption, imports, exports, and ending stocks for indica and japonica rice are estimated from *PS&D* online

[1] EU28 refers to an entire region in this study.

[2] We changed public agricultural investment variables (agricultural knowledge and innovation system, development and maintenance of infrastructure, land development, and agricultural machinery & equipment) from nominal bases to real bases. We applied Ordinary Least Squares (OLS) regression for estimating parameters. For the estimated parameters, refer to Appendix Tables A-1, A-2, A-3 and A-4.

[3] Minimum temperature, maximum temperature, and precipitation are based on the japonica and indica rice growing location. Therefore, the data are distinguished by japonica and indica rice varieties. Agricultural knowledge and innovation system, development and maintenance of infrastructure, investments in land development, and investments in agricultural machinery & equipment are not distinguished by japonica and indica varieties due to limited data.

[4] These domestic prices are derived from China's Statistical Yearbook (2017), EU Rice Economic Fact Sheet (European Commission 2015), Rice Yearbook (USDA-ERS 2018), and FAOSTAT (FAO).

[5] Refer to Koizumi & Furuhashi (2020). Each dummy is utilized for excluding political factors (e.g., sudden change in rice program, rice export restrictions, and others), financial speculative factors, and other external factors that impact rice markets. The harvested areas of indica and japonica rice are derived from the difference between the planted area and abandoned area. The abandoned area is an exogenous variable to be utilized for simulation in future studies. We assume that the abandoned area is set to 0 in all countries during the projection period.

[6] All monthly average minimum temperature, maximum temperature, and precipitation data are applied to all countries.

[7] For the detailed value for grids, refer to Koizumi & Furuhashi (2020).

(USDA-FAS 2018).[8] The baseline scenario (hereinafter called the baseline) adopts a set of assumptions for the general economy, agricultural policies, and technological changes without any shocks due to policy changes during the projection period. The climate variables (minimum/maximum temperatures and precipitation) in each country and region are exogenous to the model, and all climate variables in this study are derived from future climate change projections by the *Model for Interdisciplinary Research on Climate (MIROC),* a global climate model under the RCP 4.5 scenario.[9] The RCP 4.5 scenario denotes an intermediate emission scenario among all RCP scenarios. Therefore, this study applies the RCP4.5 scenario's climate conditions to the climate change assumption for the baseline. Spatially averaged[10] climate variables for each country are computed in the same manner as the historical climate data used for regression estimation. The standard deviations of minimum/maximum temperatures and precipitation are projected to increase during the decades of 1980-2009 and 2015-2040 in most of the target areas and countries, based on the above climate conditions.[11]

Population data for all countries were taken from the 2017 revision (medium variant) of *World Population Prospects*, United Nations (2017). Per capita real GDP was also treated as an exogenous variable, and GDP growth rate assumptions were set based on *World Economic Outlook 2018*[12] (IMF 2018). International wheat prices are cited from *OECD-FAO Agricultural Outlook 2019-2028*[13] (OECD & FAO 2019). The current agricultural and trade policies are assumed to continue for the projection period in this study, and the abandoned area of cultivation is set to zero in all countries throughout the study period. This study applies public agricultural investment data as agricultural knowledge and innovation system,[14] and the development and maintenance of infrastructure[15] derived from *OECD's General Service Support Estimates* (GSSE) to China, Japan, South Korea, the US, EU28, Vietnam, and the Philippines (OECD 2019).[16] GSSE covers public agricultural investment, not private investment.[17] Therefore, the flow of public agricultural investment (agricultural knowledge and innovation system, and the development and maintenance of infrastructure) leads to public agricultural innovation and related policy.

Land development and agricultural machinery &

[8] The rice balance of japonica rice in selected countries mainly producing and exporting japonica rice is principally estimated from the trade shares of japonica and indica rice (Koizumi & Furuhashi 2020), and custom statistics of the countries covered, based on the UN Comtrade Database, United Nations Statistics Division (2018), and the rice balance sheets of the USDA PS&D (USDA-FAS 2018). Some specific countries' balances with their trade, supply and demand are estimated using the statistics from China's Statistical Yearbook (National Bureau of Statistics of China 2017), China's National Statistical Bureau and the China National Grain and Oils Information Center (2018), USDA-NASS (2018), Rice Yearbook (USDA-ERS 2018), and Eurostat (2018), including custom data of their countries. And because Italy and Spain account for a large part of the EU rice market, both countries can principally represent the EU rice market, with historical rice data on both countries being derived from FAOSTAT (FAO 2018) and Eurostat (2018) with their custom data. Therefore, their food balance sheets of indica rice are derived from the food balance sheets of non-japonica rice as assumed in this study. The results of unit root tests (ADF test) confirmed that the time-series data of dependent variables and explanatory variables used in this study are stationary series with logarithmic differences.

[9] RCPs are time- and space-dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCP 4.5 is defined as stabilization without an overshoot pathway to 4.5 W/m^2 at stabilization after 2100. Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism (IPCC 2007).

[10] The values for all grids are the same as the historical minimum/maximum temperatures and precipitation.

[11] Refer to Koizumi & Furuhashi (2020).

[12] These GDP growth rates are available until the year 2023. This study assumes that the average per capita GDP growth rates from 2017 to 2023 in each country will continue during 2024-2040. See Appendix Table A-5.

[13] International wheat prices are expected to increase from 212.5 USD/t in 2015/2017 to 237.5 USD/t in 2028.

[14] The agricultural knowledge and innovation system cover the generation of agricultural knowledge and transfer of knowledge.

[15] Development and maintenance of infrastructure cover hydrological infrastructure, storage, marketing, other physical and institutional infrastructure, and farm restructuring.

[16] GSSE data cover rice and other crops. Therefore, the GSSE data were divided by the rice production value ratio of total agricultural production value in each country/region and each year. Agricultural production value data are derived from FAOSTAT (FAO 2018). As for EU28, the rice ratio in Italy is applied for japonica rice production, and the rice ratio in Spain is applied for indica rice production. However, these ratios in EU28 do not represent the amount of investment value for indica and japonica rice in a strict sense. The data indicate the total amount of investment value for indica and japonica rice in all countries/region. GSSE covers China, Japan, South Korea, the US, EU28, Vietnam, and the Philippines. However, it does not cover other countries. Therefore, FAOSTAT data are applied for the other countries.

[17] GSSE does not cover private investment in technology and productivity, including private seed companies, private machinery makers, and private firms that provide managerial services and labor.

equipment estimates are applied to the other developing countries.[18] We assume that the current growth rates of agricultural knowledge and innovation system, and development and maintenance of infrastructure from 2010 to 2017 will continue for the projection period (2015/2017-2040) (Table 1).[19] We also assume that the current growth rates of agricultural machinery & equipment and land development from 2000 to 2007 in the other developing counties will continue for the projection period.[20] These are all in real terms and deflated from each country and region's CPI. For analyzing time-series data on a real price basis, we apply the annual CPIs of China, Japan, South Korea, the US, EU28, Vietnam, the Philippines, and other countries. The CPI data are taken from the IMF's International Financial Statistics (IMF 2019).

The following alternative scenarios are applied to the baseline as a sensitivity analysis. We evaluate the current impact of public agricultural investment on world indica and japonica rice markets, by comparing the investment growth condition with the no growth condition from the beginning of the projection year. Consequently, the growth rates for future public agricultural investments would be set to zero for some major rice producing countries as an assumption in simulation scenarios.[21] Scenarios 1 through 4 concern the growth rates of agricultural knowledge and innovation system in Vietnam, the rates of development and maintenance of infrastructure in Vietnam, the rates of agricultural knowledge and innovation system in the Philippines, and the rates of development and maintenance of infrastructure in the Philippines, respectively, all of which are hypothesized to be zero from 2015/2017 to 2040. Moreover, scenarios 5 and 6 concern the growth rates of agricultural knowledge and innovation system in China, and the rates of development and maintenance of infrastructure in China, respectively, both of which are hypothesized to be zero throughout the projection period.

Results

1. Baseline

In the baseline, world indica rice production and consumption are expected to increase at a rate of 0.9%, exports at 1.4%, imports at 1.6%, and ending stocks at 1.4% per annum during the same period (Table 2). The

Table 1. Growth rate of agricultural investments (real basis)

Countries/Region	Type of GSSE	Annual growth rate
USA	Agricultural knowledge and innovation system	0.4%
	Development and maintenance of infrastructure	1.7%
China	Agricultural knowledge and innovation system	4.3%
	Development and maintenance of infrastructure	6.4%
Japan	Agricultural knowledge and innovation system	−2.4%
	Development and maintenance of infrastructure	1.1%
South Korea	Agricultural knowledge and innovation system	0.1%
	Development and maintenance of infrastructure	−1.1%
Vietnam	Agricultural knowledge and innovation system	6.4%
	Development and maintenance of infrastructure	6.7%
Philippines	Agricultural knowledge and innovation system	5.1%
	Development and maintenance of infrastructure	4.0%
EU28	Agricultural knowledge and innovation system	0.6%
	Development and maintenance of infrastructure	−6.7%

Source: OECD (2019)

[18] Land development is the result of actions leading to major improvements in land quantity, quality, or productivity, or which prevent land deterioration. The data are derived from FAOSTAT (FAO 2018).

[19] The average growth rates of investments in agricultural knowledge and innovation system, and the development and maintenance of infrastructure in the Philippines from 2010 to 2017 were 12.9% and 17.0%, respectively, which appear to be too high. Thus, we applied the growth rates from 2014 to 2017 for the Philippines to the baseline outlook period.

[20] These FAOSTAT time-series data are available up to 2007.

[21] This study focuses on the impact of OECD-based public agricultural investments on world indica and japonica rice price stability, meaning that it does not target scenario simulations for FAO-based land development and agricultural machinery & equipment in other countries. Most public agricultural investments do not target rice in the EU, and most recent public agricultural investments do not target rice in Japan and South Korea. Therefore, this study does not set alternative scenarios for the EU, Japan, and South Korea.

real international price of indica rice is projected to increase from 396.9 USD/t in 2015/2017 to 461.1 USD/t in 2040. Global japonica rice production is expected to increase at a rate of 0.2%, consumption at 0.4%, exports and imports at 1.6%, and ending stocks at 0.2% per annum during the outlook period (Table 3), whereas the real international price of japonica rice is projected to increase from 670.2 USD/t in 2015/2017 to 707.5 USD/t in 2040. Future climate change is projected to have different impacts on both indica and japonica rice production. The Coefficient of Variation (CV) for the international price of indica rice is 0.1083, and the CV for the international price of japonica rice is 0.1776 from 2015/2017 to 2040. Thus, the international price of japonica rice is more volatile than the international price of indica rice in the baseline projection.

2. Main results in the scenarios

In scenario 1, indica rice production in Vietnam is expected to decrease by 9.0% and exports by 34.0% compared to the baseline average, from 2018 to 2040 (Table 4). Therefore, the international price of indica rice is expected to increase by 7.0%. In scenario 2, indica rice production in Vietnam is expected to decrease by 3.2% and exports by 12.1% from 2018 to 2040 (Table 4). Accordingly, the international price of indica rice is expected to increase by 2.4%. In scenario 3, indica rice production in the Philippines is expected to decrease by 0.9%, and imports are expected to increase by 6.0% from 2018 to 2040. As a result, the international price of indica rice is expected to increase by 0.3%. In scenario 4, indica rice production in the Philippines is expected to decrease by 3.9%, and imports are expected to increase by 27.2%, from 2018 to 2040. Accordingly, the international price of indica rice is expected to increase by 1.2%. The japonica rice market is impacted in scenarios 1, 2, 3, and 4. However, the international price of japonica rice is expected to increase by 0.02%-0.4%. Consequently, the impacts on japonica rice markets are quite limited in these scenarios.

In scenario 5, japonica rice production in China is expected to decrease by 1.0% and exports by 24.9% compared to the baseline average, from 2018 to 2040 (Table 5). Therefore, the international price of japonica rice is expected to increase by 9.9%. Indica rice production in China is expected to decrease by 1.2%, and its imports are expected to increase by 19.0% from 2018 to 2040 (Table 5). Accordingly, the international price of indica rice is expected to increase by 2.9%. In scenario 6, japonica rice production in China is expected to decrease by 0.7% and exports by 17.5%, from 2018 to 2040 (Table 5). As a result, the international price of japonica rice is expected to increase by 6.8%. Indica rice production in China is expected to decrease by 1.3%, and its imports are expected to increase by 19.7% from 2018 to 2040 (Table 5). Accordingly, the international price of indica rice is expected to increase by 2.9%.

Vietnam is the major indica rice exporter and is expected to account for 17.4% of global indica exports in 2040 in the baseline projection, thus accounting for a higher share of indica rice exports than the other scenario target countries. The changing rate of agricultural knowledge and innovation system, and development and maintenance of infrastructure in Vietnam are higher than other public agricultural investments among indica rice producing countries during the baseline projection. Moreover, the magnitude of the agricultural knowledge and innovation system parameter in Vietnam is much higher than that of the development and maintenance of infrastructure parameter in Vietnam and other public agricultural investment parameters in the indica rice yield equation (Appendix Table A-1). This explains the more significant impact of agricultural knowledge and innovation system in Vietnam (scenario 1) on the global indica rice market than in all other scenarios. The results of market impact from these scenarios affect the volatility of the international price of indica rice. Therefore, the standard deviation of scenario 1 is 63.3054 and higher than in other scenarios: 52.6988 (scenario 2), 48.3614 (scenario 3), 50.1778 (scenario 4), 53.3731 (scenario 5), and 53.4634 (scenario 6). As a result, CVs are calculated as 0.1083 during the projection period (the baseline), 0.1339 (scenario 1), 0.1164 (scenario 2), 0.1091 (scenario 3), 0.1121 (scenario 4), 0.1174 (scenario 5), and 0.1175 (scenario 6), as shown in Table 6. As a result, the CV for the international price of indica rice from scenario 1 is higher than in other scenarios. Consequently, the impact of agricultural knowledge and innovation system in Vietnam in scenario 1 is the most significant factor stabilizing the international price of indica rice in all scenarios.

China is the largest japonica rice producer and exporter; it is expected to account for 68.3% of total japonica production and 24.6% of total japonica exports in 2040 in the baseline projection. In China, the changing rate of development and maintenance of infrastructure is higher than that of agricultural knowledge and innovation system in the baseline projection. However, the magnitude of the agricultural knowledge and innovation system parameter is higher than that of the development and maintenance of infrastructure parameter in the Chinese japonica rice equation (Appendix Table A-2). This explains why agricultural knowledge and innovation system in China had the largest impact on the global

Table 2. Global Indica Rice Markets (Baseline projection)

	Harvested area (1,000 ha)			Yield (t/ha)			Production (1,000 t)		
	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)
World	147,286	163,882	0.5%	-	-	-	412,129	507,538	0.9%
Thailand	10,125	12,457	0.9%	2.8	2.8	0.1%	18,457	23,111	1.0%
Vietnam	7,726	8,414	0.4%	5.7	6.9	0.8%	27,976	36,471	1.2%
Indonesia	12,197	14,696	0.8%	5.1	5.2	0.1%	36,686	45,080	0.9%
Malaysia	693	676	−0.1%	4.2	4.2	0.0%	1,813	1,781	−0.1%
India	43,762	48,415	0.4%	3.7	4.2	0.6%	108,035	136,995	1.0%
China	21,007	19,530	−0.3%	6.5	6.9	0.3%	95,488	94,409	0.0%
Japan	0	0	-	0	0	-	0	0	-
South Korea	0	0	-	0	0	-	0	0	-
USA	899	1,204	1.3%	8.0	8.3	0.2%	5,023	6,987	1.4%
EU28	99	76	−1.1%	7.5	8.1	0.3%	514	432	−0.8%
Cambodia	3,100	3,313	0.3%	2.7	3.4	1.0%	5,195	6,950	1.3%
Lao PDR	972	980	0.0%	3.4	4.9	1.7%	1,958	2,899	1.7%
Myanmar	7,010	8,195	0.7%	2.9	3.7	1.1%	12,670	19,003	1.8%
Philippines	4,700	5,163	0.4%	3.8	4.4	0.7%	11,665	15,074	1.1%
Bangladesh	11,595	14,631	1.0%	4.4	5.3	0.8%	33,909	51,239	1.8%
Brazil	1,984	2,324	0.7%	5.8	6.0	0.1%	7,889	9,436	0.8%
Côte d'Ivoire	887	1,001	0.5%	2.4	2.9	0.8%	1,370	1,867	1.4%
Egypt	0	0	-	0.0	0.0	-	0	0	-
Madagascar	1,450	1,591	0.4%	2.4	3.2	1.2%	2,269	3,252	1.6%
Nepal	1,451	1,705	0.7%	3.3	3.7	0.5%	3,218	4,256	1.2%
Nigeria	3,106	3,653	0.7%	2.0	2.3	0.7%	3,834	5,335	1.4%
Pakistan	2,754	3,178	0.6%	3.8	4.9	1.0%	7,050	10,316	1.7%
Sri Lanka	925	1,175	1.0%	4.1	4.7	0.5%	2,601	3,718	1.6%

	Consumption (1,000 t)			Exports (1,000 t)			Imports (1,000 t)		
	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)
World	407,240	506,226	0.9%	43,211	59,834	1.4%	40,544	59,834	1.6%
Thailand	10,754	10,998	0.1%	10,661	12,123	0.6%	264	28	−9.2%
Vietnam	22,200	26,497	0.8%	6,192	10,421	2.3%	400	469	0.7%
Indonesia	37,883	47,096	1.0%	2	2	0.0%	1,133	2,038	2.6%
Malaysia	2,731	3,206	0.7%	32	0	-	872	1,430	2.2%
India	95,565	118,087	0.9%	11,604	18,957	2.2%	0	0	-
China	95,239	99,766	0.2%	356	352	0.0%	5,199	7,175	1.4%
Japan	263	236	−0.5%	0	200	-	263	236	−0.5%
South Korea	52	57	0.4%	0	0	-	52	57	0.4%
USA	3,344	3,848	0.6%	2,555	3,925	1.9%	772	778	0.0%
EU28	2,222	1,912	−0.7%	37	44	0.8%	1,684	1,521	−0.4%
Cambodia	4,000	5,256	1.2%	1,150	1,727	1.8%	23	25	0.4%
Lao PDR	2,077	3,990	2.9%	67	0	-	137	1,094	9.5%
Myanmar	10,100	14,240	1.5%	2,650	4,770	2.6%	18	18	-
Philippines	12,967	17,396	1.3%	0	0	-	1,300	2,340	2.6%
Bangladesh	35,100	52,601	1.8%	4	10	4.1%	1,164	1,388	0.8%
Brazil	7,975	12,051	1.8%	742	751	0.1%	739	3,372	6.8%
Côte d'Ivoire	2,767	4,309	1.9%	27	0	-	1,350	2,435	2.6%
Egypt	84	120	1.6%	0	0	-	84	120	1.6%
Madagascar	2,664	4,033	1.8%	0	0	-	395	781	3.0%
Nepal	3,758	5,948	2.0%	0	0	-	540	1,692	5.1%
Nigeria	6,550	12,265	2.8%	0	0	-	2,400	6,937	4.7%
Pakistan	3,033	6,902	3.6%	4,005	3,441	−0.7%	7	27	6.0%
Sri Lanka	3,108	3,978	1.1%	3	0	-	394	254	−1.9%

Table 3. Global Japonica Rice Markets (Baseline Projection)

	Harvested area (1,000 ha)			Yield (t/ha)			Production (1,000 t)		
	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)
World	13,160	13,337	0.1%	-	-	-	70,721	73,641	0.2%
China	9,181	9,233	0.0%	7.8	7.8	0.0%	50,083	50,287	0.0%
Japan	1,571	1,430	−0.4%	6.7	7.4	0.4%	7,679	7,715	0.0%
South Korea	778	756	−0.1%	7.1	7.4	0.2%	4,165	4,229	0.1%
USA	188	214	0.6%	9.7	10.4	0.3%	1,280	1,565	0.9%
EU28	337	277	−0.8%	6.6	6.7	0.1%	1,541	1,296	−0.7%
Egypt	754	989	1.2%	8.4	8.8	0.2%	4,367	6,011	1.4%

	Consumption (1,000 t)			Exports (1,000 t)			Imports (1,000 t)		
	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)	2015-2017	2040	Annual growth rate (2015/2017-2040)
World	67,650	73,572	0.4%	2,067	2,977	1.6%	2,064	2,975	1.6%
China	46,410	49,518	0.3%	436	734	2.3%	1	1	0.0%
Japan	8,254	8,412	0.1%	50	21	−3.8%	439	694	2.0%
South Korea	4,527	4,532	0.0%	23	27	0.7%	325	353	0.4%
USA	624	615	−0.1%	744	952	1.1%	18	20	0.5%
EU28	1,378	1,325	−0.2%	260	161	−2.1%	164	204	1.0%
Egypt	4,116	5,370	1.2%	117	641	7.7%	0	0	-

Table 4. Scenario Impacts on World Rice Markets (Scenarios/Baseline: 2015/2017-2040) (1)

	Impact between scenario 1 and baseline from 2015/2017 to 2040	Impact between scenario 2 and baseline from 2015/2017 to 2040	Impact between scenario 3 and baseline from 2015/2017 to 2040	Impact between scenario 4 and baseline from 2015/2017 to 2040
Indica rice market				
Country	Vietnam	Vietnam	Philippines	Philippines
Yield	−9.1%	−1.5%	0.0%	−1.4%
Area Harvested	0.1%	−1.7%	−0.9%	−2.5%
Production	−9.0%	−3.2%	−0.9%	−3.9%
Consumption	−0.1%	−0.03%	−0.03%	−0.1%
Exports	−34.0%	−12.1%	-	-
Imports	−3.4%	−1.2%	6.0%	27.2%
World				
Production	−0.3%	−0.1%	−0.01%	−0.1%
Consumption	−0.3%	−0.1%	−0.01%	−0.1%
Exports	−3.8%	−1.4%	0.1%	0.3%
Imports	−3.8%	−1.4%	0.1%	0.3%
International indica price	7.0%	2.4%	0.3%	1.2%
Japonica rice market				
World				
Production	0.02%	0.01%	0.001%	0.004%
Consumption	0.02%	0.01%	0.001%	0.004%
Exports	−0.1%	−0.04%	−0.004%	−0.02%
Imports	−0.1%	−0.04%	−0.004%	−0.02%
International japonica price	0.4%	0.1%	0.02%	0.07%

japonica rice market (scenario 5) compared to all other scenarios. The results of market impact from the scenarios affect the volatility of the international price of japonica rice. Therefore, the standard deviation of scenario 5 is 8.1855 and higher than that of scenario 6 (7.4631) and other scenarios (Table 6). Accordingly, CVs for the international price of japonica rice from 2015-2017 to 2040 in all scenarios are higher than those in the baseline. CVs are calculated as 0.1776 during the projection period (the baseline), 0.1794 (scenario 1), 0.1783 (scenario 2), 0.1777 (scenario 3), 0.1780 (scenario 4), 0.2215 (scenario 5), and 0.2079 (scenario 6), as shown in Table 6. Consequently, agricultural knowledge and innovation system in China in scenario 5 is the most crucial factor stabilizing the international price of japonica rice in all scenarios.

In the case of the Philippines, the impact on the international price of indica rice in scenario 4 is higher than that in scenario 3 because the indica yield and planted area are highly responsive to development and maintenance, and not agricultural knowledge and innovation system. Consequently, the SD and CV in scenario 4 are higher than those in scenario 3.

Conclusions

We projected and simulated the future global indica and japonica rice markets under climate change in the mid- to long-term by developing a partial equilibrium model. Future climate change is projected to have different impacts on both indica and japonica rice production. The results of the baseline and alternative

Table 5. Scenario Impacts on Chinese and World Rice Markets (Scenarios/ Baseline: 2015/2017-2040) (1)

	Impact between scenario 5 and baseline from 2015/2017 to 2040	Impact between scenario 6 and baseline from 2015/2017 to 2040
Japonica rice market		
Country	China	China
Yield	−1.5%	−1.1%
Area Harvested	0.5%	0.4%
Production	−1.0%	−0.7%
Consumption	−0.7%	−0.5%
Exports	−24.9%	−17.5%
Imports	-	-
World		
Production	−0.5%	−0.4%
Consumption	−0.5%	−0.4%
Exports	−2.7%	−1.9%
Imports	−2.7%	−1.9%
International japonica price	9.9%	6.8%
Indica rice market		
Country	China	China
Yield	−1.3%	0.0%
Area Harvested	0.1%	−1.3%
Production	−1.2%	−1.3%
Consumption	−0.02%	−0.03%
Exports	1.2%	1.7%
Imports	19.0%	19.7%
World		
Production	−0.1%	−0.1%
Consumption	−0.1%	−0.1%
Exports	0.7%	0.8%
Imports	0.7%	0.8%
International indica price	2.9%	2.9%

simulations indicate that the international price of japonica rice is more volatile than the international price of indica rice under possible future climate change scenario. We examined how future public agricultural investments would impact the world indica and japonica markets, including the stability of international prices for indica and japonica rice, by considering future climate change in the mid- to long-term. The simulation results suggested that public agricultural investments in major indica and japonica rice-producing countries would contribute to price stability in the mid- to long-term, allowing for climate change. Of the scenarios, the CV and changing rate of the international price of indica rice in scenario 1 (agricultural knowledge and innovation system in Vietnam) are higher than those in other scenarios, and the CV and changing rate of the international price of japonica rice in scenario 5 (agricultural knowledge and innovation system in China) are higher than those in other scenarios. Under the baseline and scenario assumptions, agricultural knowledge and innovation system in Vietnam and China will play a significant role in stabilizing the international prices of indica and japonica rice in the mid- to long-term in the targeted countries.

This study set public agricultural investment data as exogenous variables and assumes that current growth rates will continue for the projection period. This assumption could be a crucial limitation for the baseline and scenario projections. These public agricultural investment variables could be impacted by agricultural commodity prices, macros, and other variables. Therefore, we should apply these public agricultural investment variables as endogenous variables to the next study. This study assumes that the average per capita GDP growth rates from 2017 to 2023 in each country will continue during 2024-2040, as these GDP growth rates are available until the year 2023. We recognize the GDP projection data could be high in some countries. We must explore how to project the long-term GDP projection data at a reasonable level. Furthermore, this study assumes no effect of indica and japonica prices on their respective yields. We recognize the challenge and importance of the incorporating the price effect into both rice yield parameters as the future direction of this study. This study utilized a limited amount of time-series data for regression estimations in the model and covered limited agricultural investment data for setting its scenarios, because it is very challenging to obtain reliable time-series data for a more extended period of time in each country. We continuously strive to obtain more time-series data for the analysis of both types of rice and agricultural investment, including incorporation of the private sector into the model. This may constitute future directions of this study.

Table 6. Scenario Impacts on International Indica and Japonica Rice Prices (2015/2017-2040)

			Indica rice price			Japonica rice price		
	Target countries	Agricultural investments	Coefficient of variation (CV)	Standard deviation	Average (USD/t)	Coefficient of variation (CV)	Standard deviation	Average (USD/t)
Baseline			0.1083	47.8742	442.2263	0.1776	5.9538	33.5173
Scenario 1	Vietnam	Agricultural knowledge and innovation system	0.1339	63.3054	472.7640	0.1794	6.0375	33.6542
Scenario 2	Vietnam	Development and maintenance of infrastructure	0.1164	52.6988	452.8127	0.1783	5.9839	33.5661
Scenario 3	Philippines	Agricultural knowledge and innovation system	0.1091	48.3614	443.3616	0.1777	5.9571	33.5226
Scenario 4	Philippines	Development and maintenance of infrastructure	0.1121	50.1778	447.4401	0.1780	5.9688	33.5415
Scenario 5	China	Agricultural knowledge and innovation system	0.1174	53.3731	454.7018	0.2215	8.1855	36.9630
Scenario 6	China	Development and maintenance of infrastructure	0.1175	53.4634	454.9910	0.2079	7.4631	35.8951

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Table A-1. Estimation of parameters (Indica rice yield)

	China	t statistics (Year for dummy)	USA	t statistics (Year for dummy)	Spain	t statistics (Year for dummy)	Vietnam	t statistics	Philippines	t statistics	India	t statistics	Thailand	t statistics
a1, Minimum temparეture (t/t-1)	−0.0136	−3.4886	−0.3059	−1.1570	−0.5888	−3.9044	−0.0560	−1.1053	−0.2837	−1.2381	−0.6434	−0.8977	−0.1611	−1.7180
a2, Maximum tempareture (t/t-1)	-	-	-	-	-	-	0.0236	1.0282	-	-	-	-	0.0693	0.9710
a3, Precipitation (t/t-1)	0.0202	4.5773	0.0431	1.7579	0.0872	2.1734	0.0208	1.2994	−0.0225	1.2553	0.1243	1.2655	−0.0218	−1.2229
a4, Agricultural knowledge and innovation system (t-1/t-2)	0.0284	1.4355	-	-	0.0300	1.6100	0.1415	3.0089	-	-	-	-	-	-
a5, Development and maintenance of infrastructure (t-1/t-2)	-	-	0.0197	1.3966	-	-	0.0217	1.7390	0.0341	1.4861	-	-	-	-
a6, Land development (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.6718	1.6689	0.4594	1.4489
a7, Agricultural machinery & equipment (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.2873	1.0359	0.0146	8.9606
Constant	1.7058	138.6705	7.9385	94.0602	4.9422	2.9462	−1.8472	−11.0900	−2.9181	−3.3411	0.3272	1.1488	0.3252	5.0536
Dummy 1	0.0472	3.6399 (2002)	−0.1018	−2.4403 (1993)	0.0687	2.0886 (1996)	-	-	-	-	-	-	-	-
Dummy 2	0.0226	2.1924 (2009)	0.0834	1.9492 (2007)	0.1133	3.3821 (1999)	-	-	-	-	-	-	-	-
Dummy 3	−0.0223	−2.1447 (2013)	-	-	0.0792	2.6518 (2001)	-	-	-	-	-	-	-	-
Sample	2002-2016		1989-2009		1988-2009		2000-2017		2000-2016		1988-2008		1998-2008	
R-squared	0.9586		0.9075		0.9216		0.9737		0.8940		0.8303		0.9168	
Adjusted R-squared	0.9172		0.8679		0.8627		0.9595		0.8223		0.7576		0.8812	
Durbin-Watson stat	1.7055		1.8108		2.1765		1.8320		1.9289		1.9774		2.0577	

Note: Each dummy year is utilised to exclude political, speculative and other factors impacting the rice markets.

Table A-2 Estimation of parameters (Japonica rice yield)

	China	t statistics (Year for dummy)	USA	t statistics (Year for dummy)	Japan	t statistics (Year for dummy)	South Korea	t statistics (Year for dummy)	Italy	t statistics (Year for dummy)	Egypt	t statistics (Year for dummy)
a1, Minimum tempareture (t/t-1)	−0.0085	−1.5919	−0.0266	−1.1347	−0.2212	−2.1952	−0.1311	−2.1268	−0.0472	−1.8938	−1.1702	−1.7861
a2, Maximum tempareture (t/t-1)	-	-	-	-	0.4919	3.2873	0.4632	2.8814	0.1881	1.4256	-	-
a3, Precipitation (t/t-1)	0.1060	1.7048	0.1248	4.0030	−0.0896	−2.7704	−0.0882	−3.1851	0.0906	1.1280	0.1192	1.8489
a4, Agricultural knowledge and innovation system (t-1/t-2)	0.0338	1.8814	0.0173	1.2457	0.0387	1.2056	0.0262	1.8237	0.0420	1.5363	-	-
a5, Development and maintenance of infrastructure (t-1/t-2)	0.0160	1.5202	-	-	-	-	-	-	-	-	-	-
a6, Land development (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.1247	0.4864
a7, Agricultural machinery & equipment (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	-	-
Constant	0.2709	1.5835	7.6937	6.2351	1.6983	38.0499	0.8507	2.8064	5.6783	2.4615	1.7579	42.6056
Dummy 1	0.0680	3.9705 (2004)	0.0946	2.1995 (1991)	−0.2822	−9.3115 (1993)	−0.0693	−1.8079 (1993)	0.0938	2.0177 (1989)	0.0118	0.3213 (1991)
Dummy 2	0.0338	2.2144 (2006)	−0.0132	−2.1146 (1996)	-	-	0.1108	2.9072 (1996)	0.1253	2.8682 (2000)	-	-
Dummy 3	0.0306	1.9145 (2011)	−0.0092	−3.0901 (2005)	-	-	0.0534	1.4927 (2015)	-	-	-	-
Sample	2002-2015		1988-2016		1988-2016		1986-2016		1988-2016		1990-2016	
R-squared	0.9793		0.7896		0.9017		0.7811		0.7538		0.9563	
Adjusted R-squared	0.9327		0.6535		0.8689		0.6543		0.6024		0.9324	
Durbin-Watson stat	2.0467		1.6684		1.9312		2.0773		2.0047		1.4704	

Note: Each dummy year is utilised to exclude political, speculative and other factors impacting the rice markets.

Table A-3 Estimation of parameters for Indica rice planted area in major producing countries

	China	t statistics (Year for dummy)	USA	t statistics (Year for dummy)	Spain	t statistics (Year for dummy)	Vietnam	t statistics	Philippines	t statistics	India	t statistics (Year for dummy)	Thailand	t statistics
a8, Domestic japonica rice price (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a9, Domestic indica rice price (t-1/t-2)	0.0534	6.7350	0.2006	2.5083	0.3179	4.6338	0.0103	1.2630	0.0422	−1.2381	0.0780	2.9657	0.0119	1.5599
a10, Domestic wheat price (t-1/t-2)	-	-	-	-	−0.2567	−2.7875	-	-	-	-	−0.0230	−0.9719	-	-
a11, Precipitation (t-1/t-2)	0.0113	5.9696	0.3180	4.4243	0.1681	2.3952	−0.1158	−2.6917	−0.0249	−1.9697	0.0322	0.6852	−0.1671	−2.8625
a12, Development and maintenance of infrastructure (t-1/t-2)	0.0203	2.3380	0.0586	4.7911	0.0916	1.8861	0.0231	1.9537	0.0584	1.3989	-	-	-	-
a13, Land development (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.7178	1.8989	0.8361	1.0718
a14, Agricultural knowledge and innovation system (t-1/t-2)	-	-	-	-	-	-	-	-	0.0157	1.5568	-	-	-	-
Constant	6.2608	9.6184	3.5982	2.0112	1.2137	5.2479	8.8668	841.7210	7.1418	12.9773	9.9797	50.7900	9.0150	82.1580
Dummy 1	−0.0846	−0.1319 (2003)	−0.1343	−2.7169 (1996)	−0.8025	−13.7030 (1993)	-	-	-	-	−0.0697	−3.1316 (1982)	-	-
Dummy 2	−0.0210	−0.0161 (2005)	0.1690	3.6979 (1999)	−0.2525	−4.3355 (1995)	-	-	-	-	0.0320	1.4605 (1991)	-	-
Dummy 3	−0.0127	−0.0247 (2014)	−0.1684	−2.4798 (2008)	0.0941	1.6073 (2007)	-	-	-	-	0.0452	2.0016 (2002)	-	-
Dummy 4	-	-	-	-	0.1747	3.1062 (2011)	-	-	-	-	-	-	-	-
Sample	2003-2016		1991-2016		1993-2016		2000-2016		2000-2016		1974-2004		1989-2011	
R-squared	0.9874		0.8534		0.9761		0.9491		0.9327		0.8886		0.8772	
Adjusted R-squared	0.9672		0.7361		0.9541		0.8374		0.8766		0.8144		0.8411	
Durbin-Watson stat	1.7733		1.7521		1.9941		1.8071		1.9629		1.7080		2.3143	

Note: Each dummy year is utilised to exclude political, speculative and other factors impacting the rice markets.

Table A-4 Estimation of parameters for Japonica rice planted area in major producing countries

	China	t statistics (Year for dummy)	USA	t statistics (Year for dummy)	Japan	t statistics (Year for dummy)	South Korea	t statistics (Year for dummy)	Italy	t statistics (Year for dummy)	Egypt	t statistics (Year for dummy)
a8, Domestic japonica rice price (t-1/t-2)	0.0507	3.2955	0.2261	4.6244	0.0999	2.2610	0.0439	3.9954	0.0887	3.2216	0.2819	2.0266
a9, Domestic indica rice price (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	-	-
a10, Domestic wheat price (t-1/t-2)	-	-	-	-	-	-	-	-	−0.2549	−4.7606	−0.0907	−0.8014
a11, Precipitation (t-1/t-2)	0.0216	2.0808	0.1014	3.3569	0.0486	1.6532	−0.0478	−1.8494	0.0523	1.3779	0.0388	1.8207
a12, Development and maintenance of infrastructure (t-1/t-2)	-	-	0.0194	1.5405	0.0486	1.6532	0.0252	1.1919	0.1819	3.1644	-	-
a13, Land development (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.6774	1.2648
a14, Agricultural knowledge and innovation system (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	-	-
Constant	8.7181	−1.003	4.2090	7.765	8.8826	81.4821	8.9447	178.8160	0.0458	1.5743	6.0186	83.1899
Dummy 1	−0.1554	−4.0702 (2003)	−0.0962	−2.4936 (1998)	0.0492	2.4501 (2006)	−0.0361	−4.0058 (2000)	−0.1175	−3.6864 (2000)	−0.1187	−1.7197 (1998)
Dummy 2	−0.0162	−2.7619 (2005)	−0.1635	−2.7136 (2008)	0.0539	2.4858 (2016)	−0.0316	−3.3177 (2003)	0.1420	1.9470 (2012)	0.1317	1.8797 (2000)
Dummy 3	0.0104	1.8506 (2011)	−0.2960	−6.5629 (2015)	-	-	0.0384	5.3772 (2009)	−0.1041	−2.9990 (2014)	-	-
Dummy 4	−0.0262	−3.8759 (2014)	-	-	-	-	−0.0102	−1.5525 (2011)	-	-	-	-
Sample	2004-2016		1992-2016		2003-2016		2000-2016		1992-2016		1990-2008	
R-squared	0.9860		0.9334		0.9826		0.9982		0.8603		0.8821	
Adjusted R-squared	0.9760		0.8859		0.9677		0.9965		0.7605		0.8071	
Durbin-Watson stat	2.0360		1.9164		2.3874		1.8367		1.9913		1.5835	

Note: Each dummy year is utilised to exclude political, speculative and other factors impacting the rice markets.

Table A-5. Exogenous variables for growth rate of per capita GDP and popoulation

	Per capita GDP annual growth rate (2018-2040) (%)	Population annual growth rate (2018-2040) (%)
Thailand	5.7	−0.1
Vietnam	7.6	0.6
Indonesia	5.7	0.7
Malaysia	6.7	1.0
Cambodia	7.2	1.2
Lao PDR	7.3	1.1
Myanmar	7.3	1.0
Philippines	6.7	0.6
India	7.2	0.0
China	8.2	−0.4
Japan	5.4	0.1
South Korea	4.6	0.8
USA	3.4	0.6
EU28	4.2	−0.0001
Italy	2.6	−0.2
Spain	3.9	−0.01
Bangladesh	8.1	0.8
Sri Lanka	3.3	0.1
Nepal	8.3	0.8
Pakistan	3.7	1.5
Brazil	2.1	0.4
Madagascar	3.9	2.4
Egypt	5.4	1.5
Cote d’Ivoire	6.2	2.4
Nigeria	7.5	2.4
Iran (Rest of the World)	3.4	0.5