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 indicia 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 public 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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Received 17 December 2019; accepted 3 June 2020.
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).

\[
\begin{align*}
\ln \left( \frac{Y_{t,c}}{Y_{t-1,c}} \right) &= a_1 \ln \left( \frac{\text{TMIN}_{t,c}}{\text{TMIN}_{t-1,c}} \right) + a_2 \ln \left( \frac{\text{TMAX}_{t,c}}{\text{TMAX}_{t-1,c}} \right) + a_3 \ln \left( \frac{\text{PRC}_{t,c}}{\text{PRC}_{t-1,c}} \right) + a_4 \ln \left( \frac{\text{AGIS}_{t,c}}{\text{AGIS}_{t-1,c}} \right) + a_5 \ln \left( \frac{\text{DMF}_{t,c}}{\text{DMF}_{t-1,c}} \right) + a_6 \ln \left( \frac{\text{LD}_{t,c}}{\text{LD}_{t-1,c}} \right) + a_7 \ln \left( \frac{\text{AME}_{t,c}}{\text{AME}_{t-1,c}} \right) \\
\ln \left( \frac{\text{LD}_{t,c}}{\text{LD}_{t-1,c}} \right) &= a_8 \ln \left( \frac{\text{IRP}_{t,c}}{\text{IRP}_{t-1,c}} \right) + a_9 \ln \left( \frac{\text{WP}_{t,c}}{\text{WP}_{t-1,c}} \right) + a_{10} \ln \left( \frac{\text{DP}_{t,c}}{\text{DP}_{t-1,c}} \right) + a_{11} \ln \left( \frac{\text{DMF}_{t,c}}{\text{DMF}_{t-1,c}} \right) + a_{12} \ln \left( \frac{\text{LD}_{t,c}}{\text{LD}_{t-1,c}} \right) + a_{13} \ln \left( \frac{\text{LD}_{t,c}}{\text{LD}_{t-1,c}} \right)
\end{align*}
\]

where \( Y \) is paddy rice yield, \( \text{TMIN} \) is minimum temperature, \( \text{TMAX} \) is maximum temperature, \( \text{PRC} \) is precipitation, \( \text{IRP} \) is the domestic price of indica rice, \( \text{WP} \) is the domestic price of wheat, and \( a_1-7 \) are the other parameters. Tables A-1 and A-2 list these estimated parameters.

\[
\begin{align*}
\ln \left( \frac{\text{APR}_{t,c}}{\text{APR}_{t-1,c}} \right) &= a_8 \ln \left( \frac{\text{JRP}_{t,c}}{\text{JRP}_{t-1,c}} \right) + a_9 \ln \left( \frac{\text{IRP}_{t,c}}{\text{IRP}_{t-1,c}} \right) + a_{10} \ln \left( \frac{\text{WP}_{t,c}}{\text{WP}_{t-1,c}} \right) + a_{11} \ln \left( \frac{\text{DMF}_{t,c}}{\text{DMF}_{t-1,c}} \right) + a_{12} \ln \left( \frac{\text{LD}_{t,c}}{\text{LD}_{t-1,c}} \right) + a_{13} \ln \left( \frac{\text{LD}_{t,c}}{\text{LD}_{t-1,c}} \right)
\end{align*}
\]

where \( \text{APR} \) is the planted area of rice, \( \text{JRP} \) is the domestic price of japonica rice, \( \text{IRP} \) is the domestic price of indica rice, \( \text{WP} \) is the domestic price of wheat, and \( a_8-13 \) are the other parameters. Tables A-3 and A-4 list these estimated parameters.3 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.4 For larger countries, the values for grids that correspond to major rice-producing areas are averaged.5 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 P5&5 online.

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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, 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). 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. 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 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.

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 (IMF 2018). International wheat prices are cited from OECD-FAO Agricultural Outlook 2019-2028 (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, and the development and maintenance of infrastructure derived from OECD’s General Service Support Estimates (GSSE) to China, Japan, South Korea, the US, EU28, Vietnam, and the Philippines (OECD 2019). GSSE covers public agricultural investment, not private investment. 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 &

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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/m² 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.

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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. 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). 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. 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. 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

| 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)

| Country    | 2015-2017 Harvested area (1,000 ha) | 2015-2017 Yield (t/ha) | 2015-2017 Production (1,000 t) | 2015-2017 Annual growth rate (2015/2017-2040) | 2040 Harvested area (1,000 ha) | 2040 Yield (t/ha) | 2040 Production (1,000 t) | 2040 Annual growth rate (2015/2017-2040) |
|------------|-----------------------------------|------------------------|---------------------------------|-----------------------------------------------|--------------------------------|-------------------|---------------------------------|-----------------------------------------------|
| World      | 147,286                           | 2.8                    | 412,129                         | -0.5%                                         | 163,882                       | 2.8               | 507,538                         | 0.9%                                          |
| Thailand   | 10,125                            | 6.9                    | 15,457                          | 0.9%                                          | 12,514                        | 6.9               | 18,311                          | 1.0%                                          |
| Vietnam    | 7,726                             | 5.2                    | 27,976                          | 0.4%                                          | 8,414                         | 5.2               | 36,471                          | 1.2%                                          |
| Indonesia  | 12,197                            | 5.2                    | 36,686                          | 0.8%                                          | 14,696                        | 5.2               | 45,080                          | 0.9%                                          |
| Malaysia   | 693                               | 4.2                    | 1,813                           | -0.1%                                         | 676                           | 4.2               | 1,781                           | -0.1%                                         |
| India      | 43,762                            | 4.2                    | 108,035                         | 0.4%                                          | 48,415                        | 4.2               | 136,995                         | 1.0%                                          |
| China      | 21,007                            | 6.9                    | 95,488                          | -0.3%                                         | 19,530                        | 6.9               | 94,409                          | 0.0%                                          |
| Japan      | 0                                 | 0                      | 0                               | -                                            | 0                             | 0                 | 0                               | -                                             |
| South Korea| 0                                 | 0                      | 0                               | -                                            | 0                             | 0                 | 0                               | -                                             |
| USA        | 899                               | 8.3                    | 5,023                           | 1.3%                                          | 1,204                         | 9.3               | 6,987                           | 1.4%                                          |
| EU28       | 99                                | 8.1                    | 514                             | -1.1%                                         | 76                             | 8.1               | 432                             | -0.8%                                         |
| Cambodia   | 3,100                             | 7.5                    | 3,695                           | 0.3%                                          | 3,313                         | 7.5               | 4,332                           | 0.9%                                          |
| Lao PDR    | 972                               | 4.9                    | 1,958                           | 0.0%                                          | 980                           | 4.9               | 2,899                           | 1.7%                                          |
| Myanmar    | 7,010                             | 3.7                    | 12,670                          | 0.7%                                          | 8,195                         | 3.7               | 19,003                          | 1.8%                                          |
| Philippines| 4,700                             | 4.4                    | 11,665                          | 0.4%                                          | 5,163                         | 4.4               | 15,074                          | 1.1%                                          |
| Bangladesh | 11,595                            | 5.3                    | 33,909                          | 1.0%                                          | 14,631                        | 5.3               | 51,239                          | 1.8%                                          |
| Brazil     | 1,984                             | 6.0                    | 7,889                           | 0.7%                                          | 2,324                         | 6.0               | 9,436                           | 0.8%                                          |
| Côte d’Ivoire | 887                           | 2.9                    | 1,370                           | 0.5%                                          | 1,001                         | 2.9               | 1,867                           | 1.4%                                          |
| Egypt      | 0                                 | 0                      | 0                               | -                                            | 0                             | 0                 | 0                               | -                                             |
| Madagascar | 1,450                             | 3.2                    | 2,269                           | 0.4%                                          | 1,591                         | 3.2               | 3,252                           | 1.6%                                          |
| Nepal      | 1,451                             | 3.7                    | 3,195                           | 0.7%                                          | 1,705                         | 3.7               | 4,256                           | 1.2%                                          |
| Nigeria    | 3,106                             | 2.3                    | 3,834                           | 0.7%                                          | 3,653                         | 2.3               | 5,335                           | 1.4%                                          |
| Pakistan   | 2,754                             | 4.9                    | 7,050                           | 0.6%                                          | 3,178                         | 4.9               | 10,316                          | 1.7%                                          |
| Sri Lanka  | 925                               | 4.7                    | 2,601                           | 1.0%                                          | 1,175                         | 4.7               | 3,718                           | 1.6%                                          |

| Country    | Consumption (1,000 t) | Exports (1,000 t) | Imports (1,000 t) |
|------------|----------------------|-----------------|------------------|
| World      | 407,240              | 506,226         | 40,544           |
| Thailand   | 10,754               | 10,998          | 264              |
| Vietnam    | 22,200               | 26,497          | 400              |
| Indonesia  | 37,883               | 47,096          | 3,218            |
| Malaysia   | 2,731                | 3,206           | 3,834            |
| India      | 95,565               | 118,087         | 11,665           |
| China      | 95,239               | 99,766          | 5,199            |
| Japan      | 263                  | 236             | 263              |
| South Korea| 52                   | 57              | 52               |
| USA        | 3,344                | 3,848           | 772              |
| EU28       | 2,222                | 1,912           | 1,684            |
| Cambodia   | 4,000                | 5,256           | 23               |
| Lao PDR    | 2,077                | 3,990           | 137              |
| Myanmar    | 10,100               | 14,240          | 4,005            |
| Philippines| 12,967               | 17,396          | 1,164            |
| Bangladesh | 35,100               | 52,601          | 1,350            |
| Brazil     | 7,975                | 12,051          | 739              |
| Côte d’Ivoire | 2,767           | 4,309           | 7                |
| Egypt      | 84                   | 120             | 84               |
| Madagascar | 2,664                | 4,033           | 395              |
| Nepal      | 3,758                | 5,948           | 540              |
| Nigeria    | 6,550                | 12,265          | 2,400            |
| Pakistan   | 3,033                | 6,902           | 7                |
| Sri Lanka  | 3,108                | 3,978           | 394              |

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### 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% |

### 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 | 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 | 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 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.

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

We wish to thank Dr. Motoki Nishimori, a staff member of the National Institute of Agro-Environmental Sciences, Japan, for providing the historical and forecast climate data. We also appreciate the valuable comments from anonymous reviewers.

References

China’s National Statistical Bureau and China National Grain and Oils Information Center (2018): Statistics. http://www.grain.gov.cn/ [In Chinese].
Climate Research Unit (CRU) at the University of East Anglia (2017): Time-series datasets of variations in climate with variations in other phenomena. http://catalogue.ceda.ac.uk/uuid/3f8944800cc48ec1cb29a5ee12d8542d.
Eurostat (2018): Comet database - International trade in goods-. https://ec.europa.eu/eurostat/web/international-trade-ingoods/data.
FAO (2018): FAOSTAT, FAO Statistics databases. http://www.fao.org/faostat/en/#home.
Furuya, J. & Koyama, O. (2015) Impacts of Climate Change on World Agricultural Product Markets: Estimation of Macro Yield Function, JARQ, 39, 121-134.
Intergovernmental Panel on Climate Change (IPCC) (2007): Radiative forcing. https://www.ipcc.ch/report/ar4/syr/
International Monetary Fund (IMF) (2018): World Economic Outlook Database. https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/index.aspx.
International Monetary Fund (IMF) (2019): International Financial Statistics. https://data.imf.org/?sk=4FB52B2-3653-409A-B471-D47B46D904B5.
Koizumi, T. & Furuhashi, G. (2020) Global Rice Market Projections Distinguishing Japonica and Indica Rice under Climate Change. JARQ, 54, 63-91.
Lobell, D. B. (2007) Changes in diurnal temperature range and national cereal yields. Agricultural and Forest Meteorology, 145, 229-338.
National Bureau of Statistics of China (2017) China’s Statistical Yearbook. National Bureau of Statistics of China.
OECD (2019) GSSE (General Service Support Estimates). https://stats.oecd.org/glossary/detail.asp?ID=1100.
OECD & FAO (2019) OECD-FAO Agricultural Outlook 2019-2028, Cereals. http://www.agri-outlook.org/commodities/cereals.html.
Peng, S. et al. (2004) Rice yields decline with higher night temperature from global warming. Agricultural Sciences, 101, 9971-9975.
United Nations, Department of Economics and Social Affairs (2017) World Population Prospects, the 2017 Revision. http://esa.un.org/unpd/wpp.
United Nations, Statistics Division (2018) UN Comtrade Database - International Trade Statistics. Import / Export Data. http://comtrade.un.org.
United States Department of Agriculture, Economic Research Service (USDA-ERS) (2018) Rice Yearbook. https://www.ers.usda.gov/data-products/rice-yearbook.
United States Department of Agriculture, Foreign Agricultural Service (USDA-FAS) (2018) Production, Supply and Distribution Online. https://apps.fas.usda.gov/psdonline/app/index.html#/app/home.
United States Department of Agriculture, National Agricultural Statistics Service (USDA-NASS) (2018) Data & Statistics, Statistics by State, California Field Office. https://www.nass.usda.gov/Statistics_by_State.
Wailes E. J. & Chavez, E. (2011) Updated Arkansas Global Rice Model. http://ageconsearch.umn.edu/bitstream/102650/2/AGRM%20MODEL%20DOCUMENTATION_revised%20April%202013%20.pdf.
Welch, J. R. et al. (2010) Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivites to minimum and maximum temperatures. Sustainability Science, 107, 14562-14567.
| Parameter Description                                    | Country     | t statistics (Year for dummy) |
|--------------------------------------------------------|-------------|---------------------------------|
| a1, Minimum temperature (t/t-1)                        | China       | -0.0136 -3.4886 -0.3059 -1.1570 |
|                                                       | USA         | -0.5888 -3.9044 -0.0560 -1.1053 |
|                                                       | Spain       | -0.2837 -1.2381 -0.6434 -0.8977 |
|                                                       | Vietnam     | 0.0170 -1.8472 -1.0900 -2.9181 |
|                                                       | Philippines | -0.3411 -0.3272 0.3252 5.0536  |
|                                                       | India       | -0.1611 -1.7180                |
|                                                       | Thailand    | -1.018 -2.4403 -0.0101 -1.018  |
|                                                       | Sample      | 2002-2016 1989-2009 1988-2009 2000-2017 2000-2016 1988-2008 1998-2008 |
| a2, Maximum temperature (t/t-1)                        | China       | -                    |
|                                                       | USA         | -                    |
|                                                       | Spain       | -                    |
|                                                       | Vietnam     | -                    |
|                                                       | Philippines | -                    |
|                                                       | India       | -                    |
|                                                       | Thailand    | -                    |
|                                                       | Sample      | -                    |
| a3, Precipitation (t/t-1)                              | Vietnam     | 0.0202 4.5773 0.0431 1.7579 |
|                                                       | Spain       | 0.0872 2.1734        |
|                                                       | Vietnam     | 0.0208 1.2994 -0.0225 1.2553 |
|                                                       | Philippines | 0.1243 1.2655 -0.0218 1.2229 |
|                                                       | India       | -                    |
|                                                       | Thailand    | -                    |
|                                                       | Sample      | -                    |
|                                                       | Note: Each dummy year is utilised to exclude political, speculative and other factors impacting the rice markets.
| Country          | a1, Minimum temperature (t/t-1) | a2, Maximum temperature (t/t-1) | a3, Precipitation (t/t-1) | a4, Agricultural knowledge and innovation system (t-1/t-2) | a5, Development and maintenance of infrastructure (t-1/t-2) | a6, Land development (t-1/t-2) | a7, Agricultural machinery & equipment (t-1/t-2) | Constant | Dummy 1 | Dummy 2 | Dummy 3 | Sample | R-squared | Adjusted R-squared | Durbin-Watson stat |
|------------------|---------------------------------|---------------------------------|---------------------------|----------------------------------------------------------|----------------------------------------------------------|-----------------------------|---------------------------------------------|-----------|---------|---------|---------|--------|-----------|--------------------|---------------------|
| China            | -0.0085                         | -0.0266                         | 0.1060                    | 0.0338                                                   | 0.0160                                                   | -                           | -                                           | 0.2709    | 0.0680  | 0.0338  | 0.0306  | 2002-2015 | 0.9793     | 0.9327            | 2.0467          |
| USA              | -1.5919                         | -1.1347                         | 1.7048                    | 1.8814                                                   | 1.5202                                                   | -                           | -                                           | 7.6937    | 3.9705  | 2.144  | 1.9145  | 1988-2016 | 0.7964     | 0.7896            | 1.6684          |
| Japan            | -0.2212                         | -2.1952                         | 4.0030                    | 1.2457                                                   | -                                                        | -                           | -                                           | 6.2351    | 2.1995  | -0.0132 | -0.0092 | 1988-2016 | 0.9017     | 0.9017            | 1.9312          |
| South Korea      | -0.1311                         | -2.1268                         | -0.0896                   | 0.0387                                                   | 0.0896                                                   | -                           | -                                           | 38.0499   | -0.2822 | -2.146  | -3.0901 | 1988-2015 | 0.8507     | 0.8507            | 0.0534          |
| Italy            | -0.1311                         | -2.1268                         | -0.0882                   | 1.2056                                                   | 0.0882                                                   | -                           | -                                           | 0.8507    | -0.0693 | 0.1108 | 0.0534 | 1988-2015 | 5.6783     | 5.6783            | 1.9427          |
| Egypt            | -0.0472                         | -1.8938                         | -3.1851                   | 1.8237                                                   | 0.0906                                                   | -                           | -                                           | -         | -0.2624 | -2.9072 | -3.0901 | 1988-2016 | 0.8420     | 0.8420            | -                |
| Dummy 1          |                                 |                                 |                           |                                                          |                                                          |                             |                              | 0.2709    | 0.0680  | 0.0338  | 0.0306  | 2002-2015 | 0.9793     | 0.9327            | 2.0467          |
| Dummy 2          |                                 |                                 |                           |                                                          |                                                          |                             |                              | 7.6937    | 3.9705  | 2.144  | 1.9145  | 1988-2016 | 0.7964     | 0.7896            | 1.6684          |
| Dummy 3          |                                 |                                 |                           |                                                          |                                                          |                             |                              | 6.2351    | 2.1995  | -0.0132 | -0.0092 | 1988-2016 | 0.9017     | 0.9017            | 1.9312          |
| Sample           |                                 |                                 |                           |                                                          |                                                          |                             |                              | 38.0499   | -0.2822 | -2.146  | -3.0901 | 1988-2015 | 0.8507     | 0.8507            | 0.0534          |
| R-squared        |                                 |                                 |                           |                                                          |                                                          |                             |                              | 0.9793    | 0.0680  | 0.0338  | 0.0306  | 2002-2015 | 0.9793     | 0.9327            | 2.0467          |
| Adjusted R-squared|                                 |                                 |                           |                                                          |                                                          |                             |                              | 0.7964    | 0.7964  | 0.7964  | 0.7964  | 1988-2016 | 0.7964     | 0.7964            | 0.7964          |
| Durbin-Watson stat |                                 |                                 |                           |                                                          |                                                          |                             |                              | 0.9017    | 0.9017  | 0.9017  | 0.9017  | 1988-2015 | 0.9017     | 0.9017            | 0.9017          |

Note: Each dummy year is utilised to exclude political, speculative and other factors impacting the rice markets.
|                        | 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) | Sample 2003-2016 | R-squared | Adjusted R-squared | Durbin-Watson stat |
|------------------------|--------------------------------------|-------------------------------------|---------------------------------------|-----------------------|---------------------------|----------------------------------------|------------------------|-----------------|-----------|---------------------|-------------------|
| a8, Domestic japonica  | -                                    | -                                   | -                                     | -                     |                           | -                                      | -                      | 2003-2016       | 0.9874   | 0.9672              | 1.7733            |
| rice price (t-1/t-2)   |                                      |                                     |                                       |                       |                           |                                        |                        | 1991-2016       | 0.8534   | 0.9761              | 1.7521            |
| a9, Domestic indica    | 0.0534                               | 6.7350                              | 0.2006                                | 0.3179                | 4.6338                    | 0.0103                                 | 1.2630                 | 2000-2016       | 0.9491   | 0.8374              | 1.9941            |
| rice price (t-1/t-2)   |                                      |                                     |                                       |                       |                           |                                        |                        | 1993-2016       | 0.9761   | 0.8766              | 1.8071            |
| a10, Domestic wheat    | -                                    | -                                   | -                                     | -                     |                           | -                                      | -                      | 2000-2016       | 0.9327   | 0.8144              | 1.9629            |
| price (t-1/t-2)        |                                      |                                     |                                       |                       |                           |                                        |                        | 1974-2004       | 0.8886   | 0.8411              | 1.7080            |
| a11, Precipitation (t-1/t-2) | 0.0113                               | 5.9696                              | 0.3180                                | 0.1681                | 2.3952                    | -0.1158                                | -2.6917                | 2000-2016       | 0.0322   | 0.6852              | -0.1671           |
| a12, Development and   | 0.0203                               | 2.3380                              | 0.0586                                | 0.0916                | 1.8861                    | 0.0231                                 | 1.9537                 | 1991-2016       | 0.0780   | 0.6852              | -0.1671           |
| maintenance of         |                                      |                                     |                                       |                       |                           |                                        |                        | 1993-2016       | 0.0234   | 0.6852              | -0.1671           |
| infrastructure (t-1/t-2) |                                      |                                     |                                       |                       |                           |                                        |                        | 2000-2016       | 0.0103   | 0.6852              | -0.1671           |
| a13, Land development  | -                                    | -                                   | -                                     | -                     |                           | -                                      | 0.7178                 | 2000-2016       | 0.0452   | 2.0016              | -                  |
| (t-1/t-2)              |                                      |                                     |                                       |                       |                           |                                        |                        | 1991-2016       | 0.0320   | 1.4605              | -                  |
| a14, Agricultural      | -                                    | -                                   | -                                     | -                     |                           | -                                      | 0.0157                 | 2000-2016       | 0.0247   | -0.0452             | -                  |
| knowledge and          |                                      |                                     |                                       |                       |                           |                                        |                        | 1991-2016       | 0.0210   | -0.0452             | -                  |
| innovation system (t-1/t-2) |                                      |                                     |                                       |                       |                           |                                        |                        | 1993-2016       | 0.0127   | -0.0452             | -                  |
| Constant               | 6.2608                               | 9.6184                              | 3.5982                                | 2.0112                | 1.2137                    | 5.2479                                 | 8.8668                 | 841.7210        | 7.1418   | 12.9773             | 9.9797            |
| Dummy 1                | -0.0846                              | -0.1319                             | -0.1343                               | -2.7169               | -0.8025                   | -13.7030                               | 993                    | -                | -0.0697  | -3.1316             | -                  |
| Dummy 2                | -0.0210                              | -0.0161                             | 0.1690                                | 3.6979                | -0.2525                   | -4.3355                               | 1995                   | -                | 0.0320   | 1.4605              | -                  |
| Dummy 3                | -0.0127                              | -0.0247                             | -0.1684                               | -2.4798               | 0.0941                    | 1.6073                                | 2007                   | -                | 0.0452   | 2.0016              | -                  |
| Dummy 4                | -                                    | -                                   | -                                     | -                     | 0.1747                    | 3.1062                                | 2011                   | -                | -        | -                   | -                  |
| R-squared              | 0.9874                               | 0.8534                              | 0.9761                                | 0.9491                | 0.9327                    | 0.8886                                | 0.8411                 | -                | -        | -                   | -                  |
| 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     | USA        | Japan      | South Korea | Italy    | Egypt    | t statistics (Year for dummy) |
|----------------|-----------|------------|------------|-------------|----------|----------|-------------------------------|
| a8, Domestic japonica rice price (t-1/t-2) | 0.0507    | 3.2955     | 0.2261     | 0.09495     | 3.9495   | 0.0887   | 2.2160 (2000)                |
| a9, Domestic indica rice price (t-1/t-2)   | -         | -          | -          | -           | -        | -        | -                            |
| a10, Domestic wheat price (t-1/t-2)        | -         | -          | -          | -           | -        | -        | -                            |
| a11, Precipitation (t-1/t-2)               | 0.0216    | 2.0808     | 0.1014     | 0.0486      | 1.6532   | 0.0252   | 1.1919 (2000)                |
| a12, Development and maintenance of infrastructure (t-1/t-2) | -         | -          | 0.0194     | 1.5405      | 0.0252   | 1.1919   | 1.3644 (2000)                |
| a13, Land development (t-1/t-2)            | -         | -          | -          | -           | -        | -        | -                            |
| a14, Agricultural knowledge and innovation system (t-1/t-2) | -         | -          | -          | -           | -        | -        | -                            |
| Constant                                    | 8.7181    | -1.003     | 4.2090     | 7.765       | 8.8826   | 8.9447   | 178.8160 (2000)             |
| Dummy 1                                     | -0.1554   | -4.0702 (2003) | -0.0962   | -2.4936 (1998) | 0.0492   | 2.4501 (2006) | -0.0361 (2000) |
| Dummy 2                                     | -0.0162   | -2.7619 (2005) | -0.1635   | -2.7136 (2008) | 0.0539   | 2.4858 (2016) | -0.0316 (2003) |
| Dummy 3                                     | 0.0104    | 1.8506 (2011) | -0.2960   | -6.5629 (2015) | -       | 0.0384   | 5.3772 (2009)          |
| Dummy 4                                     | -0.0262   | -3.8759 (2014) | -       | -          | -       | -0.0102 | -1.5525 (2011)          |

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