Global Rice Market Projections Distinguishing Japonica and Indica Rice under Climate Change

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Abstract
Rice is not strictly a homogeneous commodity, with the international rice market largely divided into the japonica and indica rice markets. Both follow different market structures and the international prices of japonica and indica show different trends. We projected and simulated the future global japonica and indica rice markets under climate change in the long term, using a partial equilibrium model. The Rice Economy Climate Change (RECC) model thus developed covers the japonica and indica rice markets in 24 countries and regions as the entire world rice market. The simulation results suggest that the international price of japonica rice will be more volatile than that of indica rice, and that both price indicators will exhibit different trends due to the impact of long-term climate change.

Discipline: Social Science
Additional key words: rice varieties, price volatility, MIROC, RCPs, partial equilibrium model

Introduction
Rice production and consumption have gradually increased over the years, reaching a trade volume of almost 46 million tons in 2016 (USDA-FAS 2018b). However, rice in the global market is not, strictly speaking, a homogeneous commodity. There are two major species of domesticated and cultivated rice: *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice). However, the rice varieties grown across the world belong overwhelmingly to *Oryza sativa*. Many *Oryza sativa* varieties cultivated commercially in the world belong to two major subspecies: Indica, mainly long grain rice characterized by a wide adaptability to different environments, and Japonica, round grain rice commonly distinguished by its strong responsiveness to fertilizer applications (Calpe 2006). These two major types of rice as a common classification under *Oryza sativa* are traded in the global market. Historically, indica rice has enjoyed relatively lower tariffs, while the trade in japonica rice has been restricted by high protection rates (Calpe 2006) owing to political factors. A recent report argued that the movement in prices for japonica and indica rice may be somewhat independent (OECD 2018, John 2014). On models for rice projections, Wailes and Chavez (2010) developed the Arkansan Global Rice Model, distinguishing only the markets for long-grain and short-/medium-grain rice in the United States (US), without completely specifying the markets for other types of rice. Koizumi and Kanamaru (2016) conducted a simulation using a partial equilibrium model to alleviate climate risks to rice production systems and rice markets. However, none of these studies projected the global japonica and indica rice markets after factoring in the impact of future climate change and agricultural investments. The purpose of this study is to conduct a projection and simulation for the global japonica and indica rice markets under climate change in the long term by using a partial equilibrium model.

Global japonica and indica rice markets
There are different varieties of cultivated rice, such as japonica, indica, glutinous, and aromatic. Japonica

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rice is mainly produced in temperate zones with partly cooler climates, while indica rice is produced in tropical, subtropical, and partly temperate zones. The japonica variety is further differentiated in terms of temperate and tropical japonica varieties. In this study, only temperate japonica rice is considered as japonica rice, with tropical japonica, indica, and other rice varieties categorized as indica rice. Japonica rice is mostly produced in more temperate zones with partly cooler climates, whereas indica rice is produced in tropical, subtropical, and partly temperate zones. Global japonica rice production was estimated at 71,255,000 tons in 2017 and increased by an average of 2.6% per annum during 2010-2017 (Table 1). Global indica rice production was estimated at 417,349,000 tons in 2017, six times that of japonica, and increased by 0.9% per annum between 2010 and 2017 (Table 2). In contrast, the world’s japonica rice consumption was estimated at 69,286,000 tons in 2017, with global japonica rice exports and imports being estimated at 2,329,000 tons. Japonica rice trade increased by 2.7% per annum during 2010-2017. Consequently, 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 in 2017. The international price of rice is normally Thailand’s export price as the 5 percent broken milled white rice, which acts as an indicator for the price of long-grain indica rice. Additionally, the export price of California, milled rice, average, f.o.b. serves as an indicator for the price of international japonica rice (OECD-FAO 2018) in this study. In the global market, the prices for both japonica and indica varieties might generally move together in the long term (Chen and Shaghoian 2016). However, the price premium of japonica rice over indica rice has weakened since 2008 because the price of indica rice has gradually grown over the last decade. The prices for both frequently diverged in their movements, due to limited substitutability among the different rice types and their quality (Fig. 1). Most japonica rice markets are dominated by domestic production and have limited imports, resulting in higher domestic prices than the international rice price. Therefore, potential uncertainties in the commodity markets might trigger short-term volatility in consumption, production, and prices in the smaller global japonica rice market as compared to the market for indica and other major grains (OECD-FAO 2018). Moreover, the international rice market would be largely divided into japonica and indica rice markets. The japonica and indica rice markets also have different market structures, and their international prices reflect different trends due to consumption in regions and countries where preferences differ substantially. Therefore, we separate the global rice sector into the japonica and indica rice markets in our world rice model.

Methods and data

1. Method

The Rice Economy Climate Change (RECC) model covers rice markets in 24 countries and regions as the entire world rice market. The RECC model includes equations for projecting rice yield and harvested areas affected by climate change and agricultural investments

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1 Temperate japonica rice varieties are mainly produced in China’s Heilongjiang, Jilin and Liaoning provinces, in parts of Jiangsu, Anhui and Hubei provinces, in California in the US, in Japan and South Korea, and in Italy, Egypt, and Russia. Tropical japonica varieties are mainly produced in Arkansas and Louisiana in the US, certain parts of Iran, Uruguay, and in some South American countries whose tropical japonica rice is typically involved in their domestic indica rice markets due to common appearances and tastes that resemble the indica type. Therefore, we define the temperate japonica rice variety as being categorized as the japonica rice market, and the tropical japonica, indica and others as being categorized as the indica rice market in this study. And regarding China’s japonica data, China’s japonica rice production and area shares of total rice are estimated, through discussion with researchers at the Chinese Academy of Agricultural Sciences (CAAS), based on China’s statistical yearbooks, some statements in Chinese government documents announced occasionally, including the China national grain and oils information center and reports in the private sector, including Zhengzhou Commodity Exchange documents (because China’s government does not regularly release rice-related information and some official statements on websites may suddenly disappear). Trade on japonica rice in China is estimated based on China’s rice custom data of the “UN Comtrade” with countries producing and consuming mainly japonica rice, such as Australia, Japan, and South Korea. According to this japonica rice estimation, China’s japonica rice data applied to China’s rice balance sheet of “USDA PS&D” statistics are estimated. Moreover, japonica rice stocks in China are simply calculated by its estimated production shares multiplied by China’s rice stock data of the USDA PS&D because China’s government has not released it for many years.

4 China accounted for 72% of global japonica rice production in 2017. Japan, Egypt, South Korea, and the US are the other main producers.

5 India and China collectively account for 49% of global indica production.

6 Thailand, Vietnam, Indonesia, Malaysia, the Philippines, Cambodia, Lao PDR, Myanmar, China, Japan, South Korea, India, US, EU27, Bangladesh, Sri Lanka, Nepal, Pakistan, Brazil, Côte d’Ivoire, Egypt, Madagascar, Nigeria, and the rest of the world. As for detailed models, please refer to Koizumi and Kanamaru (2016) and Koizumi (2018). The food loss rate of the rice equation is not utilized in this study.
Table 1. Global japonica rice markets

|                      | 2003       | 2010       | 2011       | 2012       | 2013       | 2014       | 2015       | 2016       | 2017       | Growth rate (2003-2017) |
|----------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------------------|
| **Japonica Rice Production** |            |            |            |            |            |            |            |            |            |                        |
| World                | 47,329     | 59,501     | 65,017     | 66,407     | 69,201     | 69,479     | 69,258     | 71,651     | 71,255     | 3.0%                   |
| China                | 29,690     | 41,237     | 44,039     | 45,045     | 47,890     | 48,717     | 49,124     | 50,009     | 51,116     | 4.0%                   |
| Japan                | 7,091      | 7,781      | 7,922      | 7,907      | 7,931      | 7,849      | 7,670      | 7,780      | 7,586      | 0.5%                   |
| South Korea          | 4,451      | 4,295      | 4,224      | 4,006      | 4,230      | 4,241      | 4,327      | 4,197      | 3,972      | -0.8%                  |
| USA                  | 1,239      | 1,375      | 1,523      | 1,432      | 1,523      | 1,204      | 1,188      | 1,484      | 1,167      | -0.4%                  |
| EU28                 | 0          | 0          | 1,339      | 1,339      | 1,179      | 1,300      | 1,529      | 1,598      | 1,497      | -                      |
| Egypt                | 3,900      | 3,100      | 4,250      | 4,675      | 4,750      | 4,530      | 4,000      | 4,800      | 4,300      | 0.7%                   |
| Thailand             | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | -                      |
| Malaysia             | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | -                      |
| **Japonica Rice Consumption** |            |            |            |            |            |            |            |            |            |                        |
| World                | 53,661     | 63,108     | 63,873     | 65,608     | 65,488     | 65,795     | 67,875     | 69,286     | 69,286     | 1.8%                   |
| China                | 34,626     | 41,528     | 42,663     | 44,429     | 45,228     | 45,501     | 46,461     | 47,267     | 47,267     | 2.2%                   |
| Japan                | 8,148      | 8,001      | 8,124      | 8,151      | 8,089      | 8,275      | 8,304      | 8,197      | 8,197      | 0.1%                   |
| South Korea          | 4,512      | 4,295      | 4,224      | 4,006      | 4,230      | 4,241      | 4,327      | 4,197      | 4,197      | 0.4%                   |
| Egypt                | 3,225      | 3,278      | 3,294      | 4,035      | 3,967      | 3,966      | 3,800      | 4,199      | 4,351      | 2.5%                   |
| EU28                 | 0          | 0          | 1,377      | 1,206      | 1,258      | 1,288      | 1,280      | 1,380      | 1,473      | -                      |
| USA                  | 749        | 457        | 744        | 635        | 842        | 507        | 588        | 642        | 643        | -1.1%                  |
| Thailand             | 0          | 0          | 2          | 5          | 1          | 2          | 5          | 0          | 0          | -                      |
| Malaysia             | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | -                      |
| **Japonica Rice Exports** |            |            |            |            |            |            |            |            |            |                        |
| World                | 2,067      | 2,615      | 2,407      | 2,042      | 1,749      | 2,123      | 2,329      | 2,329      | 2,329      | 0.9%                   |
| USA                  | 506        | 815        | 185        | 193        | 168        | 385        | 765        | 674        | 674        | 2.1%                   |
| China                | 72         | 228        | 185        | 193        | 226        | 365        | 385        | 376        | 376        | 18.3%                  |
| EU28                 | 0          | 0          | 182        | 209        | 242        | 236        | 280        | 263        | 263        | -                      |
| Japan                | 211        | 3          | 2          | 2          | 2          | 2          | 2          | 4          | 4          | -8.3%                  |
| South Korea          | 230        | 123        | 57         | 70         | 50         | 50         | 50         | 50         | 50         | -10.3%                 |
| Egypt                | 826        | 700        | 600        | 250        | 200        | 100        | 50         | 50         | 50         | -18.2%                 |
| Thailand             | 0          | 0          | 2          | 2          | 3          | 1          | 0          | 0          | 0          | -                      |
| Malaysia             | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | -                      |
| **Japonica Rice Imports** |            |            |            |            |            |            |            |            |            |                        |
| World                | 2,067      | 2,615      | 2,407      | 2,042      | 1,749      | 2,123      | 2,329      | 2,329      | 2,329      | 0.9%                   |
| USA                  | 547        | 387        | 489        | 365        | 310        | 415        | 406        | 494        | 494        | -0.7%                  |
| China                | 193        | 323        | 283        | 261        | 309        | 275        | 411        | 290        | 290        | 2.9%                   |
| EU28                 | 0          | 0          | 114        | 133        | 169        | 166        | 156        | 156        | 156        | -                      |
| USA                  | 5          | 12         | 46         | 42         | 17         | 17         | 17         | 17         | 17         | 10.1%                  |
| Malaysia             | 0          | 2          | 2          | 3          | 1          | 0          | 0          | 6          | 6          | -                      |
| China                | 1          | 5          | 0          | 1          | 1          | 0          | 1          | 1          | 1          | 1.9%                   |
| Egypt                | 0          | 2          | 9          | 0          | 0          | 0          | 0          | 1          | 1          | -                      |
| Thailand             | 0          | 0          | 2          | 5          | 1          | 2          | 5          | 0          | 0          | -                      |
| Malaysia             | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | -                      |

Notes:
1. The rice balance of japonica rice in selected countries mainly producing and exporting japonica rice is principally estimated from trade shares of japonica and indica rice, custom statistics of the coverage countries, based on the UN Comtrade Database, United Nations Statistics Division (2018) and the rice balance sheets of the USDA PS&D (USDA-FAS 2018b).
2. 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), Global Agricultural Trade System, Standard Query (USDA-FAS 2018a), USDA-NASS (2018), Rice Yearbook (USDA-ERS 2018), EU Rice Economic Fact Sheet (European Commission 2015), and Eurostat (2018), including custom data of specific countries.
Indica Rice Production

| Year | Thailand | Vietnam | Indonesia | Malaysia | India | China | Japan | South Korea | Pakistan | Cambodia | China | India | Sri Lanka | Bangladesh | Egypt | Nigeria | Bangladesh | Cote d'Ivoire | Egypt | Madagascar | Malaysia | Philippines | Bangladesh | Thailand | Vietnam | Indonesia | Malaysia | Bangladesh |
|------|----------|---------|-----------|----------|-------|-------|-------|-------------|----------|-----------|-------|-------|----------|------------|-------|---------|------------|-------------|-------|-------------|---------|-----------|------------|---------|--------|----------|---------|-----------|----------|---------|--------|----------|
| 2010 | 390,870  | 410,287 | 403,978   | 415,062  | 417,349| 1.4%  | 31,131| 39,485      | 36,587   | 39,199    | 39,486| 5,1%  | 1.6%     | 0.9%        | 0.2%  | 2.9%    | 1.2%       | 0.3%         | 0.2%  | 0.0%       | 2.0%    | 0.2%      | 0.3%      | 1.2%    | 2.9%    | 0.2%     | 0.0%      | 0.2%    | 0.0%     | 0.2%    | 0.0%      | 0.2%    | 0.0%     | 0.2%    |
| 2014 | 390,870  | 410,287 | 403,978   | 415,062  | 417,349| 1.4%  | 31,131| 39,485      | 36,587   | 39,199    | 39,486| 5,1%  | 1.6%     | 0.9%        | 0.2%  | 2.9%    | 1.2%       | 0.3%         | 0.2%  | 0.0%       | 2.9%    | 0.2%      | 0.3%      | 1.2%    | 2.9%    | 0.2%     | 0.0%      | 0.2%    | 0.0%     | 0.2%    | 0.0%      | 0.2%    | 0.0%     | 0.2%    |
| 2015 | 390,870  | 410,287 | 403,978   | 415,062  | 417,349| 1.4%  | 31,131| 39,485      | 36,587   | 39,199    | 39,486| 5,1%  | 1.6%     | 0.9%        | 0.2%  | 2.9%    | 1.2%       | 0.3%         | 0.2%  | 0.0%       | 2.9%    | 0.2%      | 0.3%      | 1.2%    | 2.9%    | 0.2%     | 0.0%      | 0.2%    | 0.0%     | 0.2%    | 0.0%      | 0.2%    | 0.0%     | 0.2%    |
| 2016 | 390,870  | 410,287 | 403,978   | 415,062  | 417,349| 1.4%  | 31,131| 39,485      | 36,587   | 39,199    | 39,486| 5,1%  | 1.6%     | 0.9%        | 0.2%  | 2.9%    | 1.2%       | 0.3%         | 0.2%  | 0.0%       | 2.9%    | 0.2%      | 0.3%      | 1.2%    | 2.9%    | 0.2%     | 0.0%      | 0.2%    | 0.0%     | 0.2%    | 0.0%      | 0.2%    | 0.0%     | 0.2%    |
| 2017 | 390,870  | 410,287 | 403,978   | 415,062  | 417,349| 1.4%  | 31,131| 39,485      | 36,587   | 39,199    | 39,486| 5,1%  | 1.6%     | 0.9%        | 0.2%  | 2.9%    | 1.2%       | 0.3%         | 0.2%  | 0.0%       | 2.9%    | 0.2%      | 0.3%      | 1.2%    | 2.9%    | 0.2%     | 0.0%      | 0.2%    | 0.0%     | 0.2%    | 0.0%      | 0.2%    | 0.0%     | 0.2%    |

Indica Rice Imports

| Year | World | Thailand | Vietnam | Indonesia | Malaysia | India | China | Japan | South Korea | Pakistan | Cambodia | China | India | Sri Lanka | Bangladesh | Egypt | Nigeria | Bangladesh | Cote d'Ivoire | Egypt | Madagascar | Madagascar | Philippines | Bangladesh | Thailand | Vietnam | Indonesia | Malaysia | Bangladesh |
|------|-------|----------|---------|-----------|----------|-------|-------|-------|-------------|----------|-----------|-------|-------|----------|------------|-------|---------|------------|-------------|-------|-------------|-----------|-----------|------------|---------|--------|----------|
| 2010 | 31,131| 29,485   | 36,587  | 39,199    | 39,199   | 5,1%  | 1.6%  | 0.9%  | 0.2%        | 0.2%    | 2.9%      | 0.0%  | 0.2%  | 0.3%     | 0.2%       | 0.0%  | 0.2%    | 0.3%       | 0.2%         | 0.2%  | 0.0%       | 0.2%      | 0.2%      | 0.0%      | 0.2%    | 0.2%    | 0.0%      | 0.2%    | 0.0%    | 0.2%    |
| 2014 | 31,131| 29,485   | 36,587  | 39,199    | 39,199   | 5,1%  | 1.6%  | 0.9%  | 0.2%        | 0.2%    | 2.9%      | 0.0%  | 0.2%  | 0.3%     | 0.2%       | 0.0%  | 0.2%    | 0.3%       | 0.2%         | 0.2%  | 0.0%       | 0.2%      | 0.2%      | 0.0%      | 0.2%    | 0.2%    | 0.0%      | 0.2%    | 0.0%    | 0.2%    |
| 2015 | 31,131| 29,485   | 36,587  | 39,199    | 39,199   | 5,1%  | 1.6%  | 0.9%  | 0.2%        | 0.2%    | 2.9%      | 0.0%  | 0.2%  | 0.3%     | 0.2%       | 0.0%  | 0.2%    | 0.3%       | 0.2%         | 0.2%  | 0.0%       | 0.2%      | 0.2%      | 0.0%      | 0.2%    | 0.2%    | 0.0%      | 0.2%    | 0.0%    | 0.2%    |
| 2016 | 31,131| 29,485   | 36,587  | 39,199    | 39,199   | 5,1%  | 1.6%  | 0.9%  | 0.2%        | 0.2%    | 2.9%      | 0.0%  | 0.2%  | 0.3%     | 0.2%       | 0.0%  | 0.2%    | 0.3%       | 0.2%         | 0.2%  | 0.0%       | 0.2%      | 0.2%      | 0.0%      | 0.2%    | 0.2%    | 0.0%      | 0.2%    | 0.0%    | 0.2%    |
| 2017 | 31,131| 29,485   | 36,587  | 39,199    | 39,199   | 5,1%  | 1.6%  | 0.9%  | 0.2%        | 0.2%    | 2.9%      | 0.0%  | 0.2%  | 0.3%     | 0.2%       | 0.0%  | 0.2%    | 0.3%       | 0.2%         | 0.2%  | 0.0%       | 0.2%      | 0.2%      | 0.0%      | 0.2%    | 0.2%    | 0.0%      | 0.2%    | 0.0%    | 0.2%    |

Note: The values represent the growth rate from 2010 to 2017.
Global Rice Market Projections Distinguishing Japonica and Indica Rice

(Fig. 2). In this study, the base year is 2015/2017 (three-year average for 2015 to 2017). Each country’s and region’s market consists of production, consumption, exports, imports, and ending stock for japonica and indica rice up to the year 2040. We decompose the RECC model into the world japonica and indica rice markets for this study. The japonica and indica rice yield equations depend on the annual averages of minimum temperature, maximum temperature, precipitation, and lagged agricultural investments (Eq. 1). The planted area equations for japonica and indica rice depend on the lagged domestic prices of japonica and indica rice, the lagged price of wheat, lagged precipitation, and lagged agricultural investments (Eq. 2). The harvested areas of japonica and indica rice are derived from the difference between the planted area and abandoned area (Eq. 3). Japonica and indica rice production are calculated by multiplying the harvested area by the respective yields of japonica and indica rice (Eq. 4).

\[
\ln \left( \frac{Y_{v,t,c}}{Y_{v,t-1,c}} \right) = a_1 \ln \left( \frac{TMIN_{v,t,c}}{TMIN_{v,t-1,c}} \right) + a_2 \ln \left( \frac{TMAX_{v,t,c}}{TMAX_{v,t-1,c}} \right) + a_3 \ln \left( \frac{PRC_{v,t,c}}{PRC_{v,t-1,c}} \right) + a_4 \ln \left( \frac{AGIS_{v,t,c}}{AGIS_{v,t-1,c}} \right) + a_5 \ln \left( \frac{DMF_{v,t,c}}{DMF_{v,t-1,c}} \right) + a_6 \ln \left( \frac{LD_{v,t,c}}{LD_{v,t-1,c}} \right) + a_7 \ln \left( \frac{AME_{v,t,c}}{AME_{v,t-1,c}} \right) \]
\]

where \( Y \) is the paddy rice yield, \( TMIN \) is the minimum temperature, \( TMAX \) is the maximum temperature, \( PRC \) is precipitation, \( AGIS \) is the amount of investment for the agricultural knowledge and innovation system, \( DMF \) is that for the development and maintenance of infrastructure, \( LD \) denotes investments in land development, \( AME \) denotes investments in agricultural machinery/equipment, \( v \) is rice variety (japonica or indica), \( t \) is time, \( c \) denotes the country/region, and \( a_1-a_7 \) are parameters. Tables A1-1 and A1-2 list these estimated parameters.

\[
\ln \left( \frac{APR_{v,t,c}}{APR_{v,t-1,c}} \right) = a_8 \ln \left( \frac{JRP_{v,t,c}}{JRP_{v,t-1,c}} \right) + a_9 \ln \left( \frac{IRP_{v,t,c}}{IRP_{v,t-1,c}} \right) + a_{10} \ln \left( \frac{WP_{v,t,c}}{WP_{v,t-1,c}} \right) + a_{11} \ln \left( \frac{PRC_{v,t,c}}{PRC_{v,t-1,c}} \right) + a_{12} \ln \left( \frac{DMF_{v,t,c}}{DMF_{v,t-1,c}} \right) + a_{13} \ln \left( \frac{LD_{v,t,c}}{LD_{v,t-1,c}} \right) \]
\]

where \( APR \) is the planted area of rice, \( JRP \) is the domestic price for japonica rice, \( IRP \) is the domestic price for indica rice, \( WP \) is the wheat price, \( PRC \) is the price of japonica rice, \( DMF \) is the development and maintenance of infrastructure, and \( LD \) denotes investments in land development.

Minimum temperature, maximum temperature, and precipitation are based on the japonica and indica rice growing locations, and thus are distinguished by japonica and indica rice varieties. The 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.
WP is the domestic price for wheat, and $a_{8-13}$ are other parameters. Tables A2-1 and A2-2 list these estimated parameters.

$$AHR_{v,t,c} = APR_{v,t,c} - ABD_{v,t,c}$$  \hspace*{1cm} \text{(3)}$$

where $AHR$ is the harvested area and $ABD$ is the abandoned area.

$$QPR_{v,t,c} = AHR_{v,t,c} \times Y_{v,t,c}$$  \hspace*{1cm} \text{(4)}$$

where $QPR$ denotes rice production.

The consumption of both rice varieties is calculated by multiplying the per capita rice consumption by the country’s population (Eq. 5). The per capita rice consumption of japonica and indica depends on the income, domestic prices for japonica and indica rice, and wheat prices (Eq. 6). For net rice-exporting countries, the volume of japonica and indica rice imports depends on the domestic market balance deficit remaining after the domestic market has been satisfied (Eq. 7). Japonica and indica rice imports are calculated by the exportable domestic market balance deficit remaining after the domestic market has been satisfied (Eq. 8). For net japonica and indica rice-importing countries, the volume of japonica and indica rice exports depends on the international prices for both rice varieties (Eq. 9). Japonica and indica rice exports are calculated by the exportable domestic market balance deficit remaining after the domestic market has been satisfied (Eq. 8). Japonica and indica rice exports are calculated by the exportable domestic market balance deficit remaining after the domestic market has been satisfied (Eq. 8).

$$QCR_{v,t,c} = QPR_{v,t,c} \times POP_{v,t,c}$$  \hspace*{1cm} \text{(5)}$$

where $QCR$ represents rice consumption and $POP$ represents population.

$$\ln \left( \frac{QCR_{v,t,c}}{QCR_{v,t-1,c}} \right) = a_{14} \ln \left( \frac{PCGDP_{v,t,c}}{PCGDP_{v,t-1,c}} \right) + a_{15} \ln \left( \frac{JRP_{v,t,c}}{JRP_{v,t-1,c}} \right) + a_{16} \ln \left( \frac{IRP_{v,t,c}}{IRP_{v,t-1,c}} \right) + a_{17} \ln \left( \frac{WP_{v,t,c}}{WP_{v,t-1,c}} \right)$$  \hspace*{1cm} \text{(6)}$$

where $QCR$ is the per capita consumption of japonica and indica rice, $PCGDP$ is the per capita GDP, $WP$ is the domestic price of wheat.
domestic wheat price, and \(a_{14}-a_{17}\) are parameters. Tables A3-1 and A3-2 list these estimated parameters.

\[
\ln(\text{IMR}_{v,t,c}) = a_{18} \ln(\text{JRP}_{v,t,c}) + a_{19} \ln(\text{IRP}_{v,t-1,c})
\]

where IMR represents rice imports and \(a_{18}-a_{19}\) represent parameters. Table A4 lists the estimated parameters.

\[
\text{QCR}_{v,t,c} = \text{QPR}_{v,t,c} - \text{EXR}_{v,t,c} + \text{IMR}_{v,t,c} - (\text{ESR}_{v,t,c} - \text{ESR}_{v,t-1,c})
\]

where EXR is rice exports and ESR is the ending stocks of rice.

\[
\ln(\text{EXR}_{v,t,c} / \text{EXR}_{v,t-1,c}) = a_{20} \ln(\text{IRP}_{I_{v,t,c}} / \text{IRP}_{I_{v,t-1,c}})
\]

where IRPJ is the international japonica rice price, IRPI is the international indica rice price, while \(a_{20}-a_{21}\) represent parameters. Tables A5-1 and A5-2 list the estimated parameters.

\[
\ln(\text{ESR}_{v,t,c} / \text{ESR}_{v,t-1,c}) = a_{22} \ln(\text{JRP}_{I_{v,t,c}} / \text{JRP}_{I_{v,t-1,c}})
\]

where \(a_{22}-a_{23}\) are parameters. Tables A6-1 and A6-2 list the estimated parameters.

\[
\ln(\text{JRP}_{v,t,c} / \text{JRP}_{v,t-1,c}) = a_{24} \ln(\text{IRP}_{I_{v,t,c}} / \text{IRP}_{I_{v,t-1,c}})
\]

where \(a_{24}\) is a parameter. Table A7-1 lists the estimated parameter.

\[
\ln(\text{IRP}_{v,t,c} / \text{IRP}_{v,t-1,c}) = a_{25} \ln(\text{IRP}_{I_{v,t,c}} / \text{IRP}_{I_{v,t-1,c}})
\]

where \(a_{25}\) is a parameter. Table A7-2 lists the estimated parameter.

The model determines the production, consumption, exports, imports, and ending stocks of both japonica and indica rice for each simulation year. The japonica and indica rice market clearing prices are obtained from the following equilibrium conditions by using the Gauss-Seidel algorithm; California, milled rice, average, f.o.b. price as the japonica rice price refers to the international japonica price, and 5% broken milled white rice (Thailand’s nominal price quota) as the indica rice price refers to the international indica rice market clearing price. Both market clearing prices determine the japonica and indica rice markets.

\[
\sum \text{IMR}_{v,t,c} = \sum \text{EXR}_{v,t,c}
\]

2. Data, baseline assumptions, and scenarios

Historical annual minimum/maximum temperatures and precipitation data are derived from CRU TS. 3.2 (University of East Anglia). For larger countries, the values for grids that correspond to major rice-producing areas are averaged.9 For other countries, the values for all grids that cover the entire territory are spatially averaged. Historical data for planted area, yield, production, per capita consumption, imports, exports, and ending stocks for japonica and indica rice are derived or estimated from PS&D (USDA-FAS 2018b).10 We define the rice producer price of japonica and indica rice as their domestic prices in this study. We also define the wheat producer price as the domestic wheat price, and the data are used for regression in time-series analysis.

The baseline scenario (hereinafter called “the baseline”) adopts a set of assumptions for the general economy, agricultural policies, and technological changes without any policy shocks during the projection period. The climate variables (minimum/maximum temperatures and precipitation) in each country and region are exogenous to the model. All climate variables for both the baseline projection and RCP scenarios11 are derived from climate change projections by the Model for Interdisciplinary Research on Climate (MIROC), a global climate model under scenario RCP 4.5,12 which denotes an intermediate emission scenario among all RCP scenarios. Therefore, this study applies scenario RCP 4.5 to the baseline assumption. Spatially averaged13 climate variables for each country are computed in the same manner as the historical climate data used for regression. The standard deviations of minimum/maximum temperatures and precipitation were projected to increase during the decades from 1980 to 2009 and from 2015 to 2040 in most targeted areas and countries (Tables 3, 4, and 5). Population data for all countries were taken from the 2017 Revision (medium variant) of the World Population Prospects, United Nations (2017). Per capita real GDP was also treated as an exogenous variable, and GDP growth rate assumptions were based on the World

9 California for US japonica rice; Louisiana and Arkansas for US indica rice; Heilongjiang, Jilin, and Liaoning for Chinese japonica rice; Hunan, Hubei, and Jiangxi for Chinese indica rice; West Java, Central Java, East Java, and Banten for Indonesia; West Bengal, Andhra Pradesh, Orissa, Chhattisgarh, and Tamil Nadu for India; Nueva Ecija for the Philippines.
10 Historical rice data for Italy and Spain are derived from FAOSTAT (FAO 2018). 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.
11 RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use.
12 RCP 4.5 is defined as stabilization without overshoot pathway to 4.5 W/m at stabilization after 2100.
13 The values for all grids are the same as the historical minimum/maximum temperatures and precipitation.
| Country                  | 1980-2009 | 2015-2040 (RCP 4.5 Scenario) | 2015-2040 (RCP 8.5 Scenario) |
|-------------------------|-----------|-----------------------------|-----------------------------|
| China, Heilongjian      | 2.2554    | 0.5946                      | 2.2634                      |
| China, Hunan and Hubei  | 0.3980    | 0.5679                      | 1.6956                      |
| Japan                   | 0.5386    | 0.5140                      | 1.5808                      |
| South Korea             | 0.6608    | 0.6408                      | 2.0266                      |
| Cambodia                | 0.3128    | 0.6919                      | 1.8552                      |
| Indonesia               | 0.2098    | 0.3740                      | 1.8658                      |
| Lao PDR                 | 0.3073    | 0.6657                      | 2.0050                      |
| Malaysia                | 0.2960    | 0.4123                      | 1.6447                      |
| Philippines             | 0.2757    | 0.5422                      | 1.6946                      |
| Thailand                | 0.3053    | 0.7197                      | 2.1041                      |
| Vietnam                 | 0.3099    | 0.6706                      | 1.6248                      |
| Myanmar                 | 0.2954    | 0.4563                      | 2.1248                      |
| Bangladesh              | 0.3324    | 0.5305                      | 1.8362                      |
| India                   | 0.2869    | 0.5240                      | 2.2792                      |
| Nepal                   | 0.3113    | 0.4846                      | 2.2029                      |
| Pakistan                | 0.3096    | 0.5750                      | 2.4776                      |
| Sri Lanka               | 0.2101    | 0.5353                      | 1.5144                      |
| USA, Mississippi        | 0.5528    | 0.4811                      | 2.3138                      |
| USA, California         | 2.7436    | 0.4880                      | 3.1039                      |
| Brazil, Southeast       | 0.2746    | 0.7614                      | 2.3426                      |
| Italy                   | 0.4824    | 0.5030                      | 1.7088                      |
| Spain                   | 2.0761    | 0.4541                      | 2.2206                      |
| Egypt                   | 0.3027    | 0.4714                      | 2.9203                      |
| Cote d'Ivoire           | 0.2268    | 0.5136                      | 2.0184                      |
| Nigeria                 | 0.3176    | 0.5490                      | 2.3034                      |
| Madagascar              | 0.2425    | 0.4370                      | 1.9363                      |
| Iran                    | 0.4483    | 0.4380                      | 2.8040                      |

Source: CRU and MIROC projections (RCP 4.5 and RCP 8.5)
### Table 4. Standard deviation of annual maximum temperature (Degree Celsius)

| Country                  | 1980-2009 | 2015-2040 (RCP 4.5 Scenario) | 2015-2040 (RCP 8.5 Scenario) |
|--------------------------|-----------|------------------------------|------------------------------|
| China, Heilongjian       | 0.6413    | 0.6114                       | 1.3077                       |
| China, Hunan and Hubei   | 0.4301    | 0.6140                       | 1.1968                       |
| Japan                    | 0.5574    | 0.5289                       | 0.9664                       |
| South Korea              | 0.5725    | 0.6326                       | 1.1781                       |
| Cambodia                 | 0.3861    | 0.9326                       | 1.1422                       |
| Indonesia                | 0.3044    | 0.4557                       | 1.0577                       |
| Lao PDR                  | 0.3749    | 0.7757                       | 1.1228                       |
| Malaysia                 | 0.2384    | 0.6107                       | 0.9705                       |
| Philippines              | 0.2793    | 0.7720                       | 1.0189                       |
| Thailand                 | 0.3569    | 0.9131                       | 1.2227                       |
| Vietnam                  | 0.3595    | 0.8338                       | 1.0043                       |
| Myanmar                  | 0.2699    | 0.5331                       | 1.0553                       |
| Bangladesh               | 0.3548    | 0.7829                       | 1.1294                       |
| India                    | 0.3325    | 0.6180                       | 1.3586                       |
| Nepal                    | 0.3836    | 0.6220                       | 1.4447                       |
| Pakistan                 | 0.3600    | 0.7809                       | 1.6566                       |
| Sri Lanka                | 0.1935    | 0.5739                       | 0.8998                       |
| USA, Mississippi         | 0.5987    | 0.7933                       | 1.7194                       |
| USA, California          | 0.5837    | 0.8895                       | 1.6601                       |
| Brazil, Southeast        | 0.2764    | 0.9791                       | 1.4339                       |
| Italy                    | 0.4528    | 0.5327                       | 0.9282                       |
| Spain                    | 0.7421    | 0.3802                       | 1.1830                       |
| Egypt                    | 0.4459    | 0.5754                       | 1.5207                       |
| Cote d'Ivoire            | 0.2231    | 0.5566                       | 1.1949                       |
| Nigeria                  | 0.3603    | 0.6126                       | 1.3171                       |
| Madagascar               | 0.2380    | 0.5318                       | 1.0138                       |
| Iran                     | 0.5129    | 0.7354                       | 1.7225                       |

Source: CRU and MIROC projections (RCP 4.5 and RCP 8.5)

### Table 5. Standard deviation of annual precipitation (mm)

| Country                  | 1980-2009 | 2015-2040 (RCP 4.5 Scenario) | 2015-2040 (RCP 8.5 Scenario) |
|--------------------------|-----------|------------------------------|------------------------------|
| China, Heilongjian       | 5.7880    | 8.0947                       | 12.3578                      |
| China, Hunan and Hubei   | 6.1261    | 12.3060                      | 20.4584                      |
| Japan                    | 15.1931   | 14.2294                      | 31.2075                      |
| South Korea              | 20.6269   | 32.0750                      | 31.5356                      |
| Cambodia                 | 12.2256   | 14.2456                      | 33.5982                      |
| Indonesia                | 31.2975   | 29.3955                      | 47.9251                      |
| Lao PDR                  | 14.0544   | 17.3048                      | 29.9723                      |
| Malaysia                 | 27.2936   | 29.8492                      | 55.5331                      |
| Philippines              | 28.2965   | 48.9725                      | 47.4730                      |
| Thailand                 | 10.9600   | 17.3373                      | 28.9455                      |
| Vietnam                  | 11.6650   | 18.0070                      | 31.8280                      |
| Myanmar                  | 12.5092   | 18.6999                      | 40.9557                      |
| Bangladesh               | 21.9334   | 43.0608                      | 48.7836                      |
| India                    | 7.1784    | 10.4171                      | 15.4945                      |
| Nepal                    | 11.9817   | 14.3430                      | 23.5757                      |
| Pakistan                 | 5.0722    | 8.9436                       | 14.1474                      |
| Sri Lanka                | 14.0924   | 39.8138                      | 36.1274                      |
| USA, Mississippi         | 14.8160   | 14.1813                      | 25.6895                      |
| USA, California          | 16.7100   | 15.9814                      | 15.9491                      |
| Brazil, Southeast        | 6.4637    | 10.1160                      | 23.7923                      |
| Italy                    | 6.0584    | 7.0271                       | 11.8376                      |
| Spain                    | 9.6179    | 4.2905                       | 8.8339                       |
| Egypt                    | 1.1573    | 1.1726                       | 2.8143                       |
| Cote d'Ivoire            | 7.3877    | 7.4881                       | 18.2277                      |
| Nigeria                  | 3.2771    | 6.6696                       | 17.8435                      |
| Madagascar               | 5.2873    | 13.1861                      | 23.5661                      |
| Iran                     | 3.7398    | 4.0460                       | 4.6011                       |

Source: CRU and MIROC projections (RCP 4.5 and RCP 8.5)
Economic Outlook 2017\textsuperscript{14} (IMF 2017). International wheat price is derived from the OECD-FAO Agricultural Outlook 2018-2027\textsuperscript{15} (OECD-FAO 2018). Table A8 lists the exogenous variables for per capita GDP growth rate and population.

We also assumed that the current agricultural and trade policies will continue, and that abandoned areas will decline to zero in all countries throughout the projection period. This study applies the agricultural knowledge and innovation system,\textsuperscript{16} and the development and maintenance of infrastructure\textsuperscript{17} derived from OECD’s General Service Support Estimates (GSSE) for the US, EU, China, Japan, and South Korea. Agricultural investments, land development, and agricultural machinery/equipment are applied for the other countries (FAO 2018). We assume that the current growth rate of the agricultural knowledge and innovation system, and the development and maintenance of infrastructure from 2010 to 2016 will continue during the projection period (2015/2017 to 2040) (Table A9).\textsuperscript{18} We also assume that the current growth rate of agricultural machinery/equipment and land development from 2000 to 2007\textsuperscript{19} will continue during the projection period. We applied RCP 4.5 as the baseline projection and RCP 8.5\textsuperscript{20} as the alternative scenario.

\textsuperscript{14} These GDP growth rates are available up till the year 2022. This study assumes the average per capita GDP growth rate from 2017 to 2022 in each country will continue to be the same from 2023 to 2040.

\textsuperscript{15} International wheat price will increase from 163.8 USD/t in 2015/2017 to 173.0 USD/t in 2027.

\textsuperscript{16} The agricultural knowledge and innovation system covers agricultural knowledge generation and knowledge transfer.

\textsuperscript{17} The development and maintenance of infrastructure covers hydrological infrastructure, storage, marketing, other physical and institutional infrastructure, and farm restructuring.

\textsuperscript{18} GSSE data can be used for rice and other crops. Therefore, these GSSE data were divided by the rice production value ratio of the total agricultural production value in each country/ region per 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. Land development is the result of actions leading to major improvements in land quantity, quality, or productivity, or which prevent its deterioration. The data are derived from FAOSTAT (FAO 2018).

\textsuperscript{19} These FAOSTAT data were available until 2007. As for detailed data, please refer to Koizumi and Kanamaru (2016) and Koizumi (2018).

\textsuperscript{20} Four RCPs were selected and defined by their total radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter) pathway and level by 2100. RCP 2.6 is defined as a mid-century peak in radiative forcing below 3 W/m\textsuperscript{2} and an eventual decline by 2100; RCP 6.0 is defined as stabilization without an overshoot pathway to 6 W/m\textsuperscript{2} at stabilization after 2100; and RCP 8.5 is defined as a rising radiative forcing pathway leading to 8.5 W/ m\textsuperscript{2} in 2100 (IPCC 2018). RCP 8.5 represents high emissions, RCP 6.0 represents intermediate emissions, RCP4.5 represents intermediate emissions, and RCP 2.6 denotes low emissions. Precipitation projection results for RCP 2.6 and 6.0 for China (Heilongjiang) are not exportable from the differences of radiative forcing. Thus, we did not apply RCP 2.6 and 6.0 as alternative scenarios.

\textsuperscript{21} The coefficient of variation (CV) is a measure of relative variability. It is the ratio of standard deviation to the mean.

\textsuperscript{22} Please refer to Appendix Table A1-1.
### Table 6. Global japonica rice market (the baseline projection)

|                | Harvested area (1,000ha) | Yield (t/ha) | Production (1,000t) | Consumption (1,000t) | Exports (1,000t) | Imports (1,000t) |
|----------------|--------------------------|--------------|---------------------|----------------------|------------------|-----------------|
|                | 2015-17  | 2040 | Growth Rate (2015/17-2040) | 2015-17  | 2040 | Growth Rate (2015/17-2040) | 2015-17  | 2040 | Growth Rate (2015/17-2040) | 2015-17  | 2040 | Growth Rate (2015/17-2040) |
| World          | 13,160  | 13,657 | 0.2%                | -       | -      | -                       | 70,721  | 76,967 | 0.4%                     | 2,064  | 4,123 | 3.0%                     |
| China          | 9,181   | 9,489  | 0.1%                | 5.5     | 5.6    | 0.1%                    | 50,083  | 52,827 | 0.2%                     | 1       | 1     | 0.0%                     |
| Japan          | 1,571   | 1,726  | 0.4%                | 4.9     | 5.1    | 0.2%                    | 7,679   | 8,759  | 0.6%                     | 4,165  | 4,263 | 0.1%                     |
| South Korea    | 778     | 772    | 0.0%                | 5.4     | 5.5    | 0.1%                    | 4,165   | 4,263  | 0.1%                     | 1,541  | 1,935 | 1.0%                     |
| USA            | 188     | 213    | 0.5%                | 6.8     | 8.4    | 0.9%                    | 1,280   | 1,786  | 1.5%                     | 1,541  | 1,935 | 1.0%                     |
| EU28           | 337     | 350    | 0.2%                | 4.6     | 5.5    | 0.8%                    | 1,541   | 1,935  | 1.0%                     | 1,541  | 1,935 | 1.0%                     |
| Egypt          | 754     | 746    | 0.0%                | 5.8     | 7.7    | 1.3%                    | 4,367   | 5,747  | 1.2%                     | 1,541  | 1,935 | 1.0%                     |
|                |          |        |                     |          |        |                         |          |        |                          |        |        |                          |
Table 7. Global indica rice market (the baseline projection)

|                | Harvested area (1,000ha) | Yield (t/ha) | Production (1,000t) |
|----------------|--------------------------|--------------|---------------------|
|                | 2015-17                  | 2040         | 2015/17             | 2040                  |
|                | Growth Rate              | Growth Rate  |                     | Growth Rate           |
|                | (2015/17-2040)           | (2015/17-2040)|                   | (2015/17-2040)        |
| World          | 147,286                  | 164,634      | 0.5%                | -                     | -                     | 412,129              |
| Thailand       | 10,125                   | 15,324       | 1.8%                | 1.8                   | 2.0                   | 0.4%                 | 18,457               |
| Vietnam        | 7,726                    | 8,153        | 0.2%                | 3.6                   | 6.0                   | 2.2%                 | 27,976               |
| Indonesia      | 12,197                   | 14,691       | 0.8%                | 3.0                   | 4.0                   | 1.0%                 | 36,866               |
| Malaysia       | 693                      | 675          | -0.1%               | 2.6                   | 2.6                   | 0.0%                 | 1,813                |
| India          | 43,762                   | 48,666       | 0.5%                | 2.5                   | 3.2                   | 1.1%                 | 108,035              |
| China          | 21,007                   | 19,186       | -0.4%               | 4.5                   | 4.8                   | 0.2%                 | 95,488               |
| Japan          | 0                        | 0            | -                   | 0                     | 0                     | -                    | 0                   |
| South Korea    | 0                        | 0            | -                   | 0                     | 0                     | -                    | 0                   |
| USA            | 899                      | 873          | -0.1%               | 5.6                   | 9.9                   | 2.5%                 | 5,023                |
| EU28           | 99                       | 73           | -1.3%               | 5.2                   | 5.6                   | 0.3%                 | 514                 |
| Cambodia       | 3,100                    | 3,308        | 0.3%                | 1.7                   | 2.1                   | 1.0%                 | 5,195                |
| Lao PDR        | 972                      | 980          | 0.0%                | 2.0                   | 3.0                   | 1.7%                 | 1,958                |
| Myanmar        | 7,010                    | 7,495        | 0.3%                | 1.8                   | 2.4                   | 1.3%                 | 12,670               |
| Philippines    | 4,700                    | 5,048        | 0.3%                | 2.5                   | 3.3                   | 1.3%                 | 11,665               |
| Bangladesh     | 11,595                   | 14,493       | 1.0%                | 2.9                   | 4.0                   | 1.4%                 | 33,909               |
| Brazil         | 1,984                    | 2,322        | 0.7%                | 4.0                   | 4.1                   | 0.1%                 | 7,889                |
| Cote d'Ivoire  | 887                      | 994          | 0.5%                | 1.5                   | 1.9                   | 0.8%                 | 1,370                |
| Egypt          | 0                        | 0            | -                   | 0.0                   | 0.0                   | -                    | 0                   |
| Madagascar     | 1,450                    | 1,590        | 0.4%                | 1.6                   | 2.0                   | 1.2%                 | 2,269                |
| Nepal          | 1,451                    | 1,703        | 0.7%                | 2.2                   | 3.2                   | 1.6%                 | 3,218                |
| Nigeria        | 3,106                    | 3,259        | 0.2%                | 1.2                   | 1.5                   | 0.7%                 | 3,834                |
| Pakistan       | 2,754                    | 3,172        | 0.6%                | 2.6                   | 3.2                   | 1.0%                 | 7,050                |
| SriLanka       | 925                      | 1,174        | 1.0%                | 2.8                   | 3.2                   | 0.5%                 | 2,601                |

|                | Consumption (1,000t)      | Exports (1,000t) | Imports (1,000t) |
|----------------|--------------------------|-----------------|-----------------|
|                | 2015-17                  | 2040            | 2015/17         | 2040                  | 2015-17             | 2040             |
|                | Growth Rate              | Growth Rate     | Growth Rate     |                      | Growth Rate         |                  |
|                | (2015/17-2040)           | (2015/17-2040)  | (2015/17-2040)  |                      | (2015/17-2040)       |                  |
| World          | 407,240                  | 549,770        | 1.3%            | 43,211               | 74,724              | 2.4%             | 40,544             |
| Thailand       | 10,754                   | 10,958         | 0.1%            | 10,661               | 19,405              | 2.6%             | 264                |
| Vietnam        | 22,200                   | 31,407         | 1.5%            | 6,192                | 17,081              | 4.5%             | 400                |
| Indonesia      | 37,883                   | 48,129         | 0.7%            | 2                     | 2                    | 0.0%             | 1,133              |
| Malaysia       | 2,731                    | 3,719          | 1.4%            | 32                   | 0                    | -                | 872                |
| India          | 95,565                   | 134,634        | 1.5%            | 11,604               | 19,323              | 2.2%             | 5,199              |
| China          | 95,239                   | 102,126        | 0.3%            | 356                  | 337                 | -0.2%            | 13,205             |
| Japan          | 263                      | 209            | -1.0%           | 0                    | 200                 | -                | 263                |
| South Korea    | 52                       | 52             | 0.0%            | 0                    | 0                   | -                | 52                 |
| USA            | 3,344                    | 4,135          | 0.9%            | 2,555                | 3,752               | 1.7%             | 772                |
| EU28           | 2,222                    | 1,575          | -1.5%           | 37                   | 41                  | 0.5%             | 1,684              |
| Cambodia       | 4,000                    | 6,423          | 2.1%            | 1,150                | 478                 | -3.7%            | 23                 |
| Lao PDR        | 2,077                    | 4,162          | 3.1%            | 67                   | 0                   | -100.0%          | 137                |
| Myanmar        | 10,100                   | 12,503         | 0.9%            | 2,650                | 5,757               | 3.4%             | 18                 |
| Philippines    | 12,967                   | 20,473         | 2.0%            | 0                    | 0                   | -                | 1,300              |
| Bangladesh     | 35,100                   | 62,055         | 2.5%            | 0                    | 0                   | -                | 1,164              |
| Brazil         | 7,975                    | 12,343         | 1.9%            | 742                  | 751                 | 0.1%             | 739                |
| Cote d'Ivoire  | 2,767                    | 7,595          | 4.5%            | 27                   | 0                   | -100.0%          | 1,350              |
| Egypt          | 84                       | 120            | 1.6%            | 0                    | 0                   | -                | 84                 |
| Madagascar     | 2,664                    | 6,838          | 4.2%            | 0                    | 0                   | -                | 395                |
| Nepal          | 3,758                    | 7,373          | 3.0%            | 0                    | 0                   | -                | 540                |
| Nigeria        | 6,550                    | 13,691         | 3.3%            | 0                    | 0                   | -                | 2,400              |
| Pakistan       | 3,033                    | 5,827          | 2.9%            | 4,005                | 4,465               | 0.5%             | 7                  |
| SriLanka       | 3,108                    | 5,790          | 2.7%            | 3                    | 0                   | -                | 394                |
### Table 8. Average changing rate between the scenario and baseline from 2018 to 2040

|                         | Changing rate between RCP 8.5 scenario and Baseline projection from 2018-2040 (%) |
|-------------------------|-----------------------------------------------------------------------------------|
| **Japonica**            |                                                                                   |
| World Production        | -2.3%                                                                              |
| China                   | -3.5%                                                                              |
| USA                     | 5.9%                                                                               |
| World Consumption       | -2.3%                                                                              |
| World Export            | -6.1%                                                                              |
| China                   | -37.5%                                                                             |
| USA                     | 10.3%                                                                              |
| World Import            | -6.1%                                                                              |
| International rice price| 44.6%                                                                              |
| **Indica**              |                                                                                   |
| World Production        | -0.2%                                                                              |
| World Consumption       | -0.2%                                                                              |
| World Export            | 2.7%                                                                               |
| World Import            | 2.7%                                                                               |
| International rice price| 3.5%                                                                               |

### Table 9. Scenario impact on international japonica and indica rice prices (2015/17-2040)

|                                | Coefficient of variation | Standard Deviation | Mean  |
|--------------------------------|--------------------------|--------------------|-------|
| **International japonica rice price** |                          |                    |       |
| Baseline (RCP 4.5)             | 0.109                    | 4.445              | 40.718|
| RCP 8.5 scenario               | 0.184                    | 10.587             | 57.562|
| **International indica rice price** |                          |                    |       |
| Baseline (RCP 4.5)             | 0.061                    | 27.174             | 448.924|
| RCP 8.5 scenario               | 0.062                    | 28.607             | 463.741|
contributed to international japonica rice volatility. India is the world’s largest indica rice producer, and is expected to account for 27.8% of total Indica production in 2040. Minimum temperature and precipitation are the significant parameters for the indica rice yield equation in India. The standard deviation of minimum temperature and precipitation are projected to increase from 1980-2009 to 2015/17-2040 in the baseline and scenario RCP 8.5 in India’s indica rice growing region. Therefore, India’s minimum temperature and precipitation volatility contributed to international japonica rice volatility.

**Conclusion**

We projected and simulated the future global japonica and indica rice markets under climate change in the long term, by utilizing a partial equilibrium model. Future climate change is projected to have different impacts on both japonica and indica rice production. As a result of the baseline projection and simulations, the international japonica rice price is more volatile than the international indica price. The international japonica rice price in scenario RCP 8.5 is more volatile than the baseline, because unstable precipitation in China in scenario RCP 8.5 contributed to the increased volatility. The international indica rice price in scenario RCP 8.5 is more volatile than the baseline, because India’s minimum temperature and precipitation volatility in scenario RCP 8.5 contributed to the increased volatility. Consequently, the simulation results suggest that the international japonica rice price will be more volatile than the international indica price, and that both prices will show different trends due to the long-term impact of climate change. The international japonica rice price volatility mainly results from unstable precipitation changes, especially in China. Therefore, the mitigation of precipitation change in the northern provinces of China will be crucial to stabilizing the international japonica rice market. This study applied a linear function to japonica and indica rice yields. However, the parameter-variable yield function, which has an inverse-u-shaped relation between the yield and temperatures, would be required for long-term projections. This could be a future direction of this study. Although this study utilized a limited number of time-series data for regression in the model, it did not cover feed use for the japonica and indica rice markets, given the difficult challenge of obtaining reliable time-series data in each country, especially China. However, we must meet this challenge to obtain such time-series data for the regression of both rice types and the feed use incorporated in the model, both of which would be also future directions of this study.

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## Appendix

### Table A1-1. Estimation of parameters (Japonica rice yield)

| Parameter                                                                 | China (t statistics) | USA (t statistics) | Japan (t statistics) | South Korea (t statistics) | Italy (EU) (t statistics) | Egypt (t statistics) | Dummy 1 | Dummy 2 | Dummy 3 | Sample 2002-2015 | R-squared | Adjusted R-squared | Durbin-Watson stat |
|---------------------------------------------------------------------------|-----------------------|--------------------|----------------------|-----------------------------|-----------------------------|----------------------|--------|--------|--------|-----------------|-----------|------------------|-------------------|
| a1, Minimum Temperature (t\(t-1\))                                       | -0.0085 -1.5919      | -0.0266 -1.1347    | -0.2212 -2.1952       | -0.1311 -2.1268             | -0.0472 -1.8938         | -1.702 -1.7861       |
| a2, Maximum Temperature (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\(t-1/t-2\))         | 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\(t-1/t-2\))        | 0.0160 1.5202        | -        -           | -                    | -                            | -               -       |
| a6, Land development (t\(t-1/t-2\))                                     | -         -            | -                    | -                    | -                            | -               -       |
| a7, Agricultural machinery/equipment (t\(t-1/t-2\))                    | -         -            | -                    | -                    | -                            | -               -       |
| Constant                                                                 | 0.2709 1.5833        | 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 (1999)  | 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 1.9345 (2011) | -0.0092 -3.0901 (2095) | -        -            | 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 utilized to exclude political, speculative and other factors impacting the rice markets.
### Table A1-2. Estimation of parameters (Indica rice yield)

|                  | China      | t statistics (Year for dummy) | USA        | t statistics (Year for dummy) | Spain (EU) | t statistics (Year for dummy) |
|------------------|------------|-------------------------------|------------|-------------------------------|------------|-------------------------------|
| a1, Minimum Temperature (t/t-1) | -0.0136    | -3.4886                       | -0.3059    | -1.1570                       | -0.5888    | -3.9044                       |
| a2, Maximum Temperature (t/t-1)  | -          | -                             | -          | -                             | -          | -                             |
| a3, Precipitation (t/t-1)        | 0.0202     | 4.5773                        | 0.0431     | 1.7579                        | 0.0872     | 2.1734                        |
| a4, Agricultural knowledge and innovation system (t-1/t-2) | 0.0284     | 1.4355                        | -          | -                             | 0.0300     | 1.6100                        |
| a5, Development and maintenance of infrastructure (t-1/t-2) | -          | -                             | 0.0197     | 1.3966                        | -          | -                             |
| a6, Land development (t-1/t-2)   | -          | -                             | -          | -                             | -          | -                             |
| a7, Agricultural machinery/equipment (t-1/t-2) | -          | -                             | -          | -                             | -          | -                             |
| Constant          | 1.7058     | 138.6705                      | 7.9385     | 94.0602                       | 4.9422     | 2.9462                        |
| 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  |                               |            |                               |
| R-squared         | 0.9586     |                               | 0.9075     |                               | 0.9216     |                               |
| Adjusted R-squared| 0.9172     |                               | 0.8679     |                               | 0.8627     |                               |
| Durbin-Watson stat| 1.7055     |                               | 1.8108     |                               | 2.1765     |                               |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A2-1. Estimation of parameters (Planted Area: Japonica rice)

| Country       | a8, Domestic japonica rice price (t-1/t-2) | a9, Domestic indica rice price (t-1/t-2) | a10, Domestic wheat price (t-1/t-2) | a11, Precipitation (t-1/t-2) | a12, Development and maintenance of infrastructure (t-1/t-2) | a13, Land development (t-1/t-2) | Constant | Dummy 1 | Dummy 2 | Dummy 3 | Dummy 4 | Sample | R-squared | Adjusted R-squared | Durbin-Watson stat |
|---------------|--------------------------------------------|----------------------------------------|-----------------------------------|----------------------------|-------------------------------------------------------------|-------------------------------|----------|---------|---------|---------|---------|--------|-----------|---------------------|-------------------|
| China         | 0.0247                                     |                                        | 3.2935                            | 0.2261                     | 4.6244                                                      | 0.0999                        | 2.2610   | 0.0439  | 3.9954  | 0.0887  | 3.2216  | 0.2819 | 2.0266    | 0.0247              | 3.2935             |
| USA           |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| Japan         |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| South Korea   |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| Italy (EU)    |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| Egypt         |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| USA           |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| Japan         |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| South Korea   |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| Italy (EU)    |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |
| Egypt         |                                            |                                        |                                   |                            |                                                             |                               |          |         |         |         |         |        |           |                     |                   |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A2-2. Estimation of parameters (Planted Area: Indica rice)

| Parameter | China t statistics (Year for dummy) | USA t statistics (Year for dummy) | Spain (EU) t statistics (Year for dummy) |
|-----------|-------------------------------------|----------------------------------|----------------------------------------|
| 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 |
| a10, Domestic wheat price (t-1/t-2) | - | - | - | - | -0.2567 | -2.7875 |
| a11, Precipitation (t-1/t-2) | 0.0113 | 5.9696 | 0.3180 | 4.4243 | 0.1681 | 2.3952 |
| a12, Development and maintenance of infrastructure (t-1/t-2) | 0.0203 | 2.3380 | 0.0586 | 4.7911 | 0.0916 | 1.8861 |
| a13, Land development (t-1/t-2) | - | - | - | - | - |
| Constant | 6.2608 | 9.6184 | 3.5982 | 2.0112 | 1.2137 | 5.2479 |
| Dummy 1 | -0.8025 | -2.5460 (2004) | -0.1343 | -2.7169 (1996) | -0.8025 | -13.7030 (1993) |
| Dummy 2 | -0.2525 | -1.0200 (2006) | 0.1690 | 3.6979 (1999) | -0.2525 | -4.3355 (1995) |
| Dummy 3 | 0.0941 | 1.8521 (2013) | -0.1684 | -2.4798 (2008) | 0.0941 | 1.6073 (2007) |
| Dummy 4 | - | - | - | - | 0.1747 | 3.1062 (2011) |
| Sample | 2003-2016 | 1991-2016 | 1993-2016 |
| R-squared | 0.9874 | 0.8534 | 0.9761 |
| Adjusted R-squared | 0.9672 | 0.7361 | 0.9541 |
| Durbin-Watson stat | 1.7733 | 1.7521 | 1.9941 |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A3-1. Estimation of parameters (Per capita consumption for japonica rice)

|                | China     | USA       | Japan     | South Korea | EU         | Egypt     | Notes                                      |
|----------------|-----------|-----------|-----------|-------------|------------|-----------|--------------------------------------------|
|                | t statistics (Year for dummy) | t statistics (Year for dummy) | t statistics (Year for dummy) | t statistics (Year for dummy) | t statistics (Year for dummy) | t statistics (Year for dummy) | Notes                                      |
| a14, Income; Per capita GDP growth ratio (t/t-1) | 0.1566 | 1.6533 | -0.1628 | -1.0518 | -2.1557 | -0.0886 | -1.0325 | 0.2284 | 2.7558 | 0.1441 | 2.1030 |                          |
| a15, Domestic price for japonica rice (t/t-1) | -0.0411 | -3.5940 | -0.2496 | -1.8288 | -0.0382 | -2.7586 | -0.0699 | -2.2205 | -0.1283 | -4.3873 | -0.0649 | -0.9673 |                          |
| a16, Domestic price for indica rice (t/t-1) | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - |                          |
| a17, Domestic wheat price (t/t-1) | 0.0991 | 5.0434 | 0.2822 | 1.4081 | - - - - - | - - - - - | - - - - - | - | 0.1829 | 2.7452 |                          |
| Constant       | -0.3167 | -1.5919 | 1.0833 | 5.7261 | 0.8958 | 1.2816 | 3.9659 | 4.7922 | 3.9531 | 26.4899 | 3.6079 | 89.1119 |                          |
| Dummy 1        | -0.0428 | -3.7366 (2000) | -0.9231 | -5.6703 (2001) | -0.0899 | -7.0648 (2000) | 0.0880 | 2.2635 (2001) | 0.0531 | 2.6594 (2005) | -0.1770 | -2.8921 (1998) |                          |
| Dummy 2        | -0.0231 | -2.5547 (2002) | -0.5909 | -5.2982 (2005) | -0.0050 | -5.1603 (2003) | 0.1199 | 3.4131 (2009) | 0.1874 | 7.5529 (2008) | 0.0713 | 1.2216 (2009) |                          |
| Dummy 3        | 0.0115 | 1.0897 (2014) | -0.1334 | -1.1019 (2012) | 0.0293 | 3.1294 (2011) | -0.1135 | -3.5472 (2013) | -0.1551 | -5.8993 (2015) | - | - |                          |
| Dummy 4        | - - - - - | -0.9634 | -6.2216 (2014) | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - | - - - - - |                          |
| Sample         | 1999-2016 | 2001-2016 | 1999-2016 | 1998-2015 | 2001-2015 | 1990-2015 | 1999-2016 | 2001-2015 | 1990-2015 | 1990-2015 |                          |
| R-squared      | 0.9956 | 0.9806 | 0.9716 | 0.9612 | 0.9259 | 0.780958 |                          |
| Adjusted R-squared | 0.9894 | 0.9028 | 0.9311 | 0.9069 | 0.9669 | 0.711787 |                          |
| Durbin-Watson stat | 2.2621 | 2.1898 | 2.4449 | 2.3809 | 2.1345 | 1.498395 |                          |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
### Table A3-2. Estimation of parameters (Per capita consumption for indica rice)

|                | 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) | EU | t statistics (Year for dummy) |
|----------------|-------|-------------------------------|-----|-------------------------------|-------|-------------------------------|-------------|-------------------------------|----|-------------------------------|
| a14, Income; Per capita GDP growth ratio (t/t-1) |       | 0.1170                        |     | 2.3536                        | -0.0912 | -3.6380                        | -0.8141     | -1.5025                      | -0.2361 | -1.7035                      | -0.3671 | -2.5647                      |
| a15, Domestic price for japonica rice (t/t-1)   |       | 0.0128                        |     | 0.8964                        | -      | -                             | -           | -                             | -      | -                             | -      | -                            |
| a16, Domestic price for indica rice (t/t-1)     |       | -0.0420                       |     | -2.4488                       | -0.2199 | -2.7048                        | -0.3720     | -1.4657                      | -2.3627 | -4.3763                      | -0.1796 | -2.5355                      |
| a17, Domestic wheat price (t/t-1)              |       | 0.0116                        |     | 1.7024                        | 0.2640  | 2.5559                        | 0.3556      | 1.4891                       | -      | -                             | -      | -                            |
| Constant                                        |       | 1.8706                        |     | 3.2362                        | 3.7220  | 7.7816                        | -0.5974     | -3.2020                      | -0.7980 | -1.9167                      | 0.3715  | 2.1493                       |
| Dummy 1                                         |       | 0.0299                        |     | 2.4584 (2001)                 | 0.1891  | 3.00103 (2005)                | 1.0281      | 4.3274 (1999)                | -0.4674 | -1.5572 (2007)               | -0.0108 | -1.5520 (2008)               |
| Dummy 2                                         |       | -0.0217                       |     | -2.0447 (2005)                | -0.1874 | -2.5781 (2011)                | -0.2371     | -1.3716 (2001)               | 0.7664  | 2.5088 (2011)                | -0.0506 | -1.8034 (2010)               |
| Dummy 3                                         |       | -0.0380                       |     | -3.4855 (2006)                | 0.2047  | 3.0002 (2014)                 | 0.6172      | 2.6537 (2005)                | 1.7962  | 6.2948 (2012)                | -      | -                            |
| Dummy 4                                         |       | -                              |     | -                             | -      | -                             | 0.4433      | 2.7984 (2010)                | -      | -                             | -      | -                            |
| Sample                                         |       | 1999-2016                     |     | 2001-2016                     | 1999-2016 | 2005-2016                     | 2001-2015 | 2005-2016                     | 2001-2015 | 2005-2016                     | 2001-2015 | 2005-2016                     |

R-squared                          |       | 0.9844                        |     | 0.9121                        | 0.9599  | 0.9738                        | 0.9774      |
| Adjusted R-squared                 |       | 0.9621                        |     | 0.7363                        | 0.8865  | 0.8689                        | 0.9547      |
| Durbin-Watson stat                 |       | 2.2578                        |     | 2.3077                        | 2.3372  | 1.7678                        | 1.9408      |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A4. Estimation of parameters (Japonica and indica rice imports)

|                | USA (japonica) | USA (indica) | Egypt | Egypt |
|----------------|----------------|--------------|-------|-------|
|                | t statistics   | t statistics |       |       |
|                | (Year for dummy) | (Year for dummy) |       |       |
| a18, Domestic price for japonica rice (t/t-1) | -0.4482 | -2.8618 | 0.0784 | 1.7698 |
| a19, Domestic price for indica rice (t/t-1) | 0.2827 | 0.9584 | -0.2653 | -1.1035 |
| Constant       | 3.7115 | 3.2035 | 4.4539 | 4.4963 |
| Dummy 1        | -0.3536 | -2.4749 (2004) | -0.1541 | -1.4677 (2004) | -1.4409 | -3.2679 (2000) |
| Dummy 2        | -0.2854 | -2.3814 (2006) | 0.2332 | 2.8594 (2006) | 2.5189 | 6.2342 (2011) |
| Dummy 3        | 0.2820 | 1.8873 (2013) | 0.3831 | 2.4927 (2007) | 1.4042 | 3.3953 (2015) |
| Sample         | 2001-2016 | 2001-2016 |       | 1998-2016 |
| R-squared      | 0.9250 | 0.9263 |       | 0.9083 |
| Adjusted R-squared | 0.8593 | 0.8617 |       | 0.8166 |
| Durbin-Watson stat | 2.4095 | 1.8686 |       | 1.8850 |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
| Table A5-1. Estimation of parameters (Japonica rice exports) |
|----------------------------------------------------------|
|                                                        |
|                                                        |
| a20, International japonica rice price (t/t-1)           |
| China: 0.2787                                           |
| t statistics 1.4600 (Year for dummy)                    |
| Japan: 0.4939                                           |
| t statistics 1.7445 (Year for dummy)                    |
| South Korea: 0.9265                                      |
| t statistics 2.4457 (Year for dummy)                    |
| EU: 0.1603                                              |
| t statistics 1.1618 (Year for dummy)                    |
|                                                        |
| a21, International indica rice price (t/t-1)             |
| constant: −0.5570                                        |
| t statistics −2.3779 (Year for dummy)                    |
| constant: 2.7782                                         |
| t statistics 5.8599 (Year for dummy)                    |
| Constant: 6.3202                                         |
| t statistics 11.5383 (Year for dummy)                   |
| Constant: 4.3062                                         |
| t statistics 6.2682 (Year for dummy)                    |
| Constant: 5.0005                                         |
| t statistics 5.9274 (Year for dummy)                    |
| Dummy 1: −0.5911                                         |
| t statistics −3.2975 (2000)                             |
| Dummy 1: −3.2975                                         |
| t statistics −1.1117 (2000)                             |
| Dummy 1: −1.1117                                         |
| t statistics −3.2592 (1998)                             |
| Dummy 1: −3.2592                                         |
| t statistics −1.2535 (2003)                             |
| Dummy 1: −1.2535                                         |
| t statistics −3.6147 (2003)                             |
| Dummy 1: −3.6147                                         |
| t statistics 0.4688 (2001)                              |
| Dummy 2: 0.9572                                          |
| t statistics 5.1908 (2011)                              |
| Dummy 2: 5.1908                                          |
| t statistics 0.4458 (2000)                              |
| Dummy 2: 0.4458                                         |
| t statistics 1.5409 (2000)                              |
| Dummy 2: 1.5409                                         |
| t statistics −4.4899 (2007)                             |
| Dummy 2: −4.4899                                        |
| t statistics −12.9711 (2007)                            |
| Dummy 2: −12.9711                                        |
| t statistics −0.2994 (2006)                             |
| Dummy 2: −0.2994                                        |
| t statistics −2.5058 (2006)                             |
| Dummy 2: −2.5058                                        |
| t statistics −0.3785 (2007)                             |
| Dummy 2: −0.3785                                        |
| t statistics −3.3494 (2007)                             |
| Dummy 3: 0.9869                                          |
| t statistics 5.4830 (2016)                              |
| Dummy 3: 5.4830                                         |
| t statistics 1.0020 (2011)                              |
| Dummy 3: 1.0020                                         |
| t statistics 3.5933 (2011)                              |
| Dummy 3: 3.5933                                         |
| t statistics 1.2669 (2016)                              |
| Dummy 3: 1.2669                                         |
| t statistics 3.8054 (2016)                              |
| Dummy 3: 3.8054                                         |
| t statistics −0.3785 (2007)                             |
| Dummy 3: −0.3785                                        |
| t statistics −3.3494 (2007)                             |
|                                                        |
| Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets. |
Table A5-2. Estimation of parameters (Indica rice exports)

|                  | China          |   | EU            |   |
|------------------|----------------|---|---------------|---|
|                  | $t$ statistics |   | $t$ statistics|   |
|                   | (Year for dummy) | | (Year for dummy) |   |
| a20, International japonica rice price (t/t-1) | $-0.1721$ | $1.3456$ | $-0.3542$ | $-1.6664$ |
| a21, International indica rice price (t/t-1)   | $0.9770$ | $1.4790$ | $0.7169$ | $2.0049$ |
| Constant         | $4.3023$ | $2.0650$ | $-0.8166$ | $-1.7506$ |
| Dummy 1          | $-0.7161$ | $-1.5389$ (2015) | $0.6836$ | $3.2592$ (1998) |
| Dummy 2          | $1.5049$ | $2.9102$ (2016) | $-0.5301$ | $-2.9575$ (2006) |
| Dummy 3          | -              | -              | -              | -              |
| Sample           | 1998-2016     |   | 2002-2016     |   |
| R-squared        | $0.9202$       |   | $0.9167$      |   |
| Adjusted R-squared | $0.8694$   |   | $0.8543$      |   |
| Durbin-Watson stat | $2.1710$   |   | $1.7793$      |   |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A6-1. Estimation of parameters (Ending stocks: Japonica rice)

|                  | China | USA | Japan | South Korea | EU | Egypt |
|------------------|-------|-----|-------|-------------|----|-------|
| **t statistics (Year for dummy)** |       |     |       |             |    |       |
| a22, Domestic price for japonica rice (t/t-1) | -0.2512 | -1.7120 | -0.2596 | -2.2921 | -0.1699 | -1.6278 | -0.0592 | -2.1869 | -0.3098 | -0.7544 |
| a26, Domestic rice production (t/t-1) |       |     |       |             |    |       |
| a23, Domestic price for indica rice (t/t-1) | - | - | - | - | - | - | - | - | - | - |
| Constant | 3.1072 | 3.9588 | 20.3505 | 8.1652 | 6.7708 | 20.0485 | 2.4049 | 3.8473 | 2.8817 | 3.7860 | 5.3096 | 12.71756 |
| Dummy 1 | -0.0363 | -1.5034 (2012) | 0.1924 | 2.9621 (2005) | -2.2962 | -13.6709 (1991) | -0.6299 | -2.9558 (1994) | -0.2360 | -6.1701 (2005) | 0.6777 | 1.7471 (2001) |
| Dummy 2 | - | - | -0.2312 | -2.7982 (2000) | -2.2282 | -12.9369 (1992) | -0.4788 | -2.2481 (2002) | 0.2339 | 5.3141 (2007) | -1.6111 | -4.2162 (2010) |
| Dummy 3 | - | - | 0.1784 | 2.4167 (2015) | -4.6233 | -26.1276 (1993) | -0.4087 | -1.9083 (2011) | -0.0834 | -2.1493 (2013) | 0.6932 | 1.7513 (2009) |
| Sample | 2008-2016 | 2000-2016 | 1991-2016 | 1983-2016 | 2001-2016 | 1996-2015 |
| R-squared | 0.9989 | 0.9217 | 0.9873 | 0.8306 | 0.9551 | 0.6872 |
| Adjusted R-squared | 0.9977 | 0.8608 | 0.9832 | 0.7882 | 0.9252 | 0.5428 |
| Durbin-Watson stat | 2.0192 | 2.1386 | 1.9330 | 1.6350 | 2.1736 | 2.5219 |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A6-2. Estimation of parameters (Ending stocks: Indica rice)

| Parameter Description                                      | China                     | USA                      | EU                       |
|-------------------------------------------------------------|---------------------------|--------------------------|--------------------------|
| a22, Domestic price for japonica rice (t/t-1)                | -                         | -                        | -                        |
| a26, Domestic rice production (t/t-1)                        | -                         | -                        | -                        |
| a23, Domestic price for indica rice (t/t-1)                  | -0.0785                   | -0.3417                  | -0.4764                  | -3.0241                  |
| Constant                                                    | -0.0593                   | 17.5461                  | -11.5403                 | -2.0820                  |
| Dummy 1                                                     | -0.1549                   | -0.2492                  | -3.5595 (2001)           | -                        |
| Dummy 2                                                     | -                         | -0.1606                  | -2.3193 (2010)           | -                        |
| Dummy 3                                                     | -                         | -0.3049                  | -4.6571 (2014)           | -                        |
| Sample                                                      | 2002-2016                 | 2000-2016                | 2012-2016                |
| R-squared                                                   | 0.9924                    | 0.9019                   | 0.9213                   |
| Adjusted R-squared                                          | 0.9893                    | 0.7757                   | 0.6853                   |
| Durbin-Watson stat                                          | 1.8974                    | 1.5532                   | 2.4475                   |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
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### Table A7-1. Estimation of parameters (Price transmission: Japonica rice)

| Parameter                        | China  | t statistics | EU (Italy) | t statistics (Year for dummy) | Egypt  | t statistics (Year for dummy) |
|----------------------------------|--------|--------------|------------|--------------------------------|--------|--------------------------------|
| a24, International japonica rice price (t/t-1) | 0.2663 | 1.5782       | 0.9370     | 5.2493                         | 0.2091 | 1.9487                         |
| Constant                         | 1.3347 | 1.9281       | 2.8123     | 4.1300                         | -      | -                              |
| Dummy 1                          | -0.0701| -1.0805 (2013)| 1.2936    | 7.9300 (2001)                  | -      | -                              |
| Dummy 2                          | 0.0762 | 1.1989 (2015)| -0.4411   | -2.8494 (2003)                 | -      | -                              |
| Dummy 3                          | -      | -            | -0.2996   | -2.4100 (2013)                 | -      | -                              |
| Sample                           | 2009-2016 | 2001-2016  | 1992-2016 |                                |        |                                |
| R-squared                        | 0.9577 | 0.8968       | 0.8838     |                                |        |                                |
| Adjusted R-squared               | 0.8519 | 0.8280       | 0.8664     |                                |        |                                |
| Durbin-Watson stat               | 2.0410 | 1.9708       | 1.6500     |                                |        |                                |

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

### Table A7-2. Estimation of parameters (Price transmission: Indica rice)

| Parameter                        | China  | t statistics (Year for dummy) | Spain (EU) | t statistics (Year for dummy) |
|----------------------------------|--------|--------------------------------|------------|--------------------------------|
| a25, International indica rice price (t/t-1) | 0.5982 | 11.7600                        | 0.2255     | 1.5389                         |
| Constant                         | 3.2532 | 8.2672                         | 4.2835     | 5.1342                         |
| Dummy 1                          | 0.0434 | 2.7376 (2013)                  | -0.4766    | -5.5867 (2004)                 |
| Dummy 2                          | -      | -                              | -0.3468    | -3.5454 (2005)                 |
| Dummy 3                          | -      | -                              | 0.2669     | 3.1706 (2011)                  |
| Dummy 4                          | -      | -                              | -0.0561    | -1.6790 (2011)                 |
| Sample                           | 2009-2016 | 2001-2016  |            |                                |
| R-squared                        | 0.9978 | 0.9106                         |            |                                |
| Adjusted R-squared               | 0.9948 | 0.8324                         |            |                                |
| Durbin-Watson stat               | 2.2408 | 1.8542                         |            |                                |

Note: Each dummy year is utilized to exclude political, speculative and other factors impacting the rice markets.
Table A8. Exogenous variables for population and per capita GDP growth rate

| Country           | Per capita GDP growth rate (2018-2040) (%) | Population (1,000) |
|-------------------|-------------------------------------------|--------------------|
|                   |                                           | 2015/17            | 2040               |
| Thailand          | 4.7                                       | 68,853             | 68,338             |
| Vietnam           | 6.6                                       | 94,560             | 111,229            |
| Indonesia         | 6.5                                       | 261,090            | 312,134            |
| Malaysia          | 9.7                                       | 31,178             | 39,668             |
| Cambodia          | 7.5                                       | 15,762             | 20,592             |
| Lao PDR           | 9.2                                       | 6,760              | 8,728              |
| Myanmar           | 9.6                                       | 52,887             | 61,489             |
| Philippines       | 9.2                                       | 103,318            | 139,448            |
| India             | 8.3                                       | 1,324,135          | 1,605,356          |
| China             | 8.5                                       | 1,403,349          | 1,417,473          |
| Japan             | 3.4                                       | 127,736            | 115,212            |
| South Korea       | 6.7                                       | 50,789             | 52,409             |
| USA               | 3.8                                       | 322,189            | 374,069            |
| EU28              | 3.6                                       | 508,210            | 509,687            |
| Italy             | 3.2                                       | -                  | -                  |
| Spain             | 3.9                                       | -                  | -                  |
| Bangladesh        | 8.1                                       | 162,941            | 196,294            |
| Sri Lanka         | 8.4                                       | 20,796             | 21,398             |
| Nepal             | 5.5                                       | 28,981             | 35,068             |
| Pakistan          | 8.1                                       | 193,200            | 277,495            |
| Brazil            | 4.6                                       | 207,634            | 231,602            |
| Madagascar        | 4.0                                       | 24,900             | 44,368             |
| Egypt             | 6.3                                       | 95,673             | 137,066            |
| Cote d'Ivoire     | 7.5                                       | 23,700             | 41,796             |
| Nigeria           | 2.6                                       | 186,019            | 333,172            |
| Iran (Rest of the World) | 6.3                                       | 2,152,084          | 3,056,246          |

Sources: IMF (2017) and United Nations (2017)
### Table A9. Exogenous variables for developed countries and China

|                | 1995  | 2000  | 2005  | 2010  | 2015  | 2016  | Growth rate (2010-2016) |
|----------------|-------|-------|-------|-------|-------|-------|-------------------------|
| **USA**        |       |       |       |       |       |       |                         |
| Agricultural knowledge and innovation system for rice | 17.5  | 18.7  | 22.7  | 30.6  | 22.1  | 24.8  | −3.4%                  |
| Development and maintenance of infrastructure for rice | 0.3   | 0.4   | 11.9  | 49.7  | 25.1  | 36.2  | −5.1%                  |
| **China**      |       |       |       |       |       |       |                         |
| Agricultural knowledge and innovation system for rice | 72.2  | 164.8 | 252.3 | 640.2 | 935.5 | 855.8 | 5.0%                   |
| Development and maintenance of infrastructure for rice | 181.2 | 438.0 | 476.7 | 653.7 | 1113.6 | 1042.4 | 8.1%                  |
| **Japan**      |       |       |       |       |       |       |                         |
| Agricultural knowledge and innovation system for rice | 213.8 | 160.8 | 150.9 | 220.7 | 151.0 | 126.0 | −8.9%                  |
| Development and maintenance of infrastructure for rice | 4127.4 | 2025.8 | 1360.7 | 1105.0 | 1037.9 | 977.8 | −2.0%                  |
| **South Korea** |       |       |       |       |       |       |                         |
| Agricultural knowledge and innovation system for rice | 81.0  | 44.1  | 86.3  | 104.9 | 126.7 | 130.0 | 3.6%                   |
| Development and maintenance of infrastructure for rice | 398.8 | 369.5 | 322.5 | 248.6 | 234.1 | 228.1 | −1.4%                  |
| **EU28**       |       |       |       |       |       |       |                         |
| Agricultural knowledge and innovation system for rice | 8.9   | 8.7   | 16.5  | 20.8  | 19.1  | 19.3  | −1.2%                  |
| Development and maintenance of infrastructure for rice | 5.2   | 5.1   | 10.5  | 12.5  | 8.2   | 7.1   | −8.9%                  |

Source: Estimation from OECD (2018)