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

Tatsuji KOIZUMI* and Gen FURUHASHI

Policy Research Institute, Ministry of Agriculture, Forestry and Fisheries, Tokyo, Japan

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,[1] 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.[2] Japonica

[1] This model covers six regions using Thai FOB and California prices to clear the international rice markets.

[2] Aromatic rice primarily includes basmati and jasmine rice, and typically sells at a premium in world rice markets. Glutinous rice is mostly grown in Southeast Asia and some parts of East Asia, and typically becomes stickier than other kinds of rice when cooked. It is also difficult to classify in rice statistics published by most governments.

*Corresponding author: e-mail koizu@affrc.go.jp
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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.[3] 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[4] (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[5] (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.[6] The RECC model includes equations for projecting rice yield and harvested areas affected by climate change and agricultural investments

[3] Temperate japonica rice varieties are mainly produced in China's Heilongjiang, Jilin and Liaoning provinces, and 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

(1,000t)

	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	7,792	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	59,019	63,108	63,873	65,608	65,488	65,795	67,875	69,286	1.8%
China	34,626	39,913	41,528	42,663	44,429	45,228	45,501	46,461	47,267	2.2%
Japan	8,148	8,001	8,124	8,151	8,089	8,275	8,304	8,197	8,259	0.1%
South Korea	4,512	5,093	4,783	4,286	4,370	4,041	4,175	4,651	4,755	0.4%
Egypt	3,225	3,278	3,294	4,035	3,967	3,966	3,800	4,199	4,351	2.2%
EU28	0	0	1,377	1,206	1,258	1,288	1,280	1,380	1,473	-
USA	749	457	744	635	842	307	588	642	643	−1.1%
Thailand	0	0	0	2	5	1	2	5	0	-
Malaysia	0	0	2	2	3	1	0	0	6	-
Japonica Rice Exports										
World	2,067	1,927	3,007	2,615	2,407	2,042	1,749	2,123	2,329	0.9%
USA	506	805	917	815	753	715	685	875	674	2.1%
China	72	185	228	185	193	266	189	355	765	18.3%
EU28	0	0	182	176	209	242	236	280	263	-
South Korea	211	4	3	2	2	2	2	4	63	−8.3%
Japan	230	88	217	123	57	70	50	50	50	−10.3%
Egypt	826	200	600	700	600	250	200	100	50	−18.2%
Thailand	0	0	0	0	0	0	0	0	0	-
Malaysia	0	0	0	0	0	0	0	0	0	-
Japonica Rice Imports										
World	2,067	1,927	3,007	2,615	2,407	2,042	1,749	2,123	2,329	0.9%
Japan	547	389	387	489	365	310	415	406	494	−0.7%
South Korea	193	323	283	307	261	309	275	411	290	2.9%
EU28	0	0	114	121	133	169	166	171	156	-
USA	5	9	13	12	46	42	17	17	19	10.1%
Malaysia	0	0	2	2	3	1	0	0	6	-
China	1	8	5	0	1	1	1	1	1	1.9%
Egypt	0	2	9	0	0	0	0	1	1	-
Thailand	0	0	0	2	5	1	2	5	0	-
Japonica Rice Ending Stocks										
World	14,265	17,857	20,422	22,956	26,549	30,540	34,003	37,779	39,748	7.6%
China	9,870	12,975	15,264	17,461	20,729	23,953	27,388	30,582	33,668	9.2%
Japan	1,778	2,897	2,735	2,857	3,007	2,821	2,552	2,491	2,262	1.7%
Egypt	719	122	487	427	610	924	924	1,426	1,326	4.5%
South Korea	845	1,034	755	780	899	1,406	1,831	1,784	1,228	2.7%
EU28	0	0	550	627	472	410	589	697	615	-
USA	165	419	294	288	262	485	417	402	272	3.6%
Thailand	0	0	0	0	0	0	0	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.

Table 2. Global indica rice markets

(1,000t)

	2010	2014	2015	2016	2017	Growth rate (2010-2017)
Indica Rice Production						
World	390,870	410,287	403,978	415,062	417,349	1.4%
Thailand	20,262	18,750	15,800	19,200	20,370	0.9%
Vietnam	26,371	28,166	27,584	27,400	28,943	2.0%
Indonesia	35,500	35,560	36,200	36,858	37,000	0.4%
Malaysia	1,642	1,800	1,800	1,820	1,820	1.5%
India	95,970	105,482	104,408	109,698	110,000	1.6%
China	95,763	95,843	96,646	94,944	94,873	1.0%
Japan	0	0	0	0	0	-
South Korea	0	0	0	0	0	-
USA	6,218	5,902	4,945	5,633	4,492	−1.0%
EU28		654	521	480	540	-
Cambodia	4,358	4,925	4,931	5,256	5,399	4.4%
Lao PDR	1,400	1,875	1,925	1,950	2,000	3.5%
Myanmar	11,060	12,600	12,160	12,650	13,200	1.5%
Philippines	10,539	11,914	11,008	11,686	12,300	2.1%
Bangladesh	31,700	34,500	34,500	34,578	32,650	1.6%
Brazil	9,300	8,465	7,210	8,383	8,075	−0.5%
Cote d'Ivoire	784	1,335	1,399	1,335	1,377	12.1%
Egypt	0	0	0	0	0	-
Madagascar	3,032	2,546	2,382	2,442	1,984	0.7%
Nepal	2,973	3,190	2,863	3,480	3,310	0.8%
Nigeria	2,818	3,782	3,941	3,780	3,780	5.2%
Pakistan	4,823	7,003	6,802	6,849	7,500	3.2%
Sri Lanka	2,494	2,735	3,294	1,997	2,511	2.0%
Indica Rice Consumption						
World	384,307	406,292	400,671	408,973	412,077	1.0%
Thailand	10,300	9,999	9,098	11,995	11,170	1.2%
Vietnam	19,400	22,000	22,500	22,000	22,100	1.4%
Indonesia	38,044	38,300	37,850	37,800	38,000	0.4%
Malaysia	2,690	2,749	2,700	2,750	2,744	2.2%
India	90,196	98,244	93,568	95,776	97,350	0.9%
China	95,161	95,106	95,298	94,987	95,433	−0.2%
Japan	310	325	296	303	191	1.6%
South Korea	82	156	37	0	120	-
USA	3,872	3,977	2,992	3,588	3,452	1.2%
EU28		2,112	2,270	2,220	2,177	-
Cambodia	3,400	3,900	3,900	4,000	4,100	2.9%
Lao PDR	1,400	1,860	2,050	2,080	2,100	3.9%
Myanmar	10,100	10,500	10,400	10,000	9,900	−0.2%
Philippines	12,900	13,000	12,900	12,900	13,100	1.8%
Bangladesh	32,400	35,100	35,100	35,000	35,200	2.0%
Brazil	8,200	7,925	7,900	8,000	8,025	−0.6%
Cote d'Ivoire	1,450	2,400	2,600	2,800	2,900	7.0%
Egypt	22	34	100	101	49	-
Madagascar	3,172	2,746	2,562	2,772	2,659	2.3%
Nepal	3,006	3,770	3,353	4,010	3,910	2.0%
Nigeria	4,800	6,100	6,400	6,550	6,700	4.4%
Pakistan	2,447	2,600	2,800	3,100	3,200	1.5%
Sri Lanka	2,600	3,000	3,300	3,000	3,025	2.7%
Indica Rice Exports						
World	33,289	41,567	38,552	45,087	45,994	4.3%
Thailand	10,647	9,779	9,867	11,615	10,500	0.3%
Vietnam	7,000	6,606	5,088	6,488	7,000	3.6%
Indonesia	0	0	2	2	2	-
Malaysia	1	73	45	1	50	10.1%
India	2,774	12,238	10,240	11,772	12,800	10.7%
China	315	160	82	450	535	−2.9%
Japan	0	0	0	0	0	-
South Korea	0	0	0	0	0	-
USA	2,711	2,363	2,711	2,770	2,184	−1.8%
EU28		30	36	39	38	-
Cambodia	860	1,150	1,050	1,150	1,250	10.7%
Lao PDR	9	60	75	50	75	-
Myanmar	1,075	1,735	1,300	3,350	3,300	26.0%
Philippines	0	0	0	0	0	-
Bangladesh	0	25	4	4	4	-
Brazil	1,479	931	547	830	850	18.5%
Cote d'Ivoire	24	25	20	30	30	27.5%
Egypt	0	0	0	0	0	-
Madagascar	0	0	0	0	0	-
Nepal	0	0	0	0	0	-
Nigeria	0	0	0	0	0	-
Pakistan	3,385	3,800	4,200	3,516	4,300	6.1%
Sri Lanka	17	6	5	0	5	-

(1,000t)

	2010	2014	2015	2016	2017	Growth rate (2010-2017)
Indica Rice Imports						
World	31,131	39,485	36,587	39,199	45,846	5.1%
Thailand	200	299	298	245	250	-
Vietnam	500	400	300	500	400	2.1%
Indonesia	3098	1350	1050	350	2000	8.4%
Malaysia	1,076	1,050	823	900	894	4.2%
India	0	0	0	0	0	-
China	532	4,699	4,799	5,299	5,499	12.0%
Japan	310	325	296	303	191	1.6%
South Korea	82	156	37	0	120	-
USA	573	741	749	728	838	4.2%
EU28		1,537	1,638	1,670	1,744	-
Cambodia	5	20	30	20	20	−8.1%
Lao PDR	24	214	228	82	100	17.1%
Myanmar	0	11	33	10	10	-
Philippines	1300	1800	1600	1100	1200	−0.5%
Bangladesh	1308	1251	217	75	3200	9.9%
Brazil	632	393	904	614	700	−1.6%
Cote d'Ivoire	850	1300	1250	1300	1500	5.1%
Egypt	22	34	100	101	49	-
Madagascar	140	200	180	330	675	11.3%
Nepal	33	580	490	530	600	43.0%
Nigeria	2400	2600	2100	2500	2600	4.3%
Pakistan	32	30	10	10	0	-
Sri Lanka	20	623	31	550	600	24.2%
Indica Rice Ending Stocks						
World	82,180	97,449	98,791	98,992	104,116	0.6%
Thailand	5,615	11,270	8,403	4,238	3,188	4.6%
Vietnam	1941	1259	1555	967	1210	1.2%
Indonesia	7,131	4,111	3,509	2,915	3,913	−0.2%
Malaysia	733	582	460	429	349	2.4%
India	23,500	17,800	18,400	20,550	20,400	4.6%
China	29,525	45,047	51,112	55,918	60,321	4.2%
Japan	0	0	0	0	0	-
South Korea	0	0	0	0	0	-
USA	1,095	1,067	1,058	1,060	753	1.7%
EU28		741	594	486	555	-
Cambodia	253	236	247	373	442	-
Lao PDR	78	420	448	350	275	12.8%
Myanmar	485	748	1,241	551	561	−7.3%
Philippines	2459	2409	2117	2003	2403	−3.7%
Bangladesh	1,378	1,592	1,205	854	1,500	5.1%
Brazil	803	641	308	475	375	−8.8%
Cote d'Ivoire	236	488	517	322	269	2.5%
Egypt	0	0	0	0	0	-
Madagascar	0	0	0	0	0	-
Nepal	0	0	0	0	0	-
Nigeria	538	1887	1528	1258	938	−0.5%
Pakistan	223	1312	1124	1367	1367	5.6%
Sri Lanka	220	827	847	394	475	31.8%

Note: Indica rice production, consumption and trade balances are calculated as “indica rice terms (production, consumption, and trades) = total rice terms - japonica rice terms,” after the japonica rice terms are estimated.

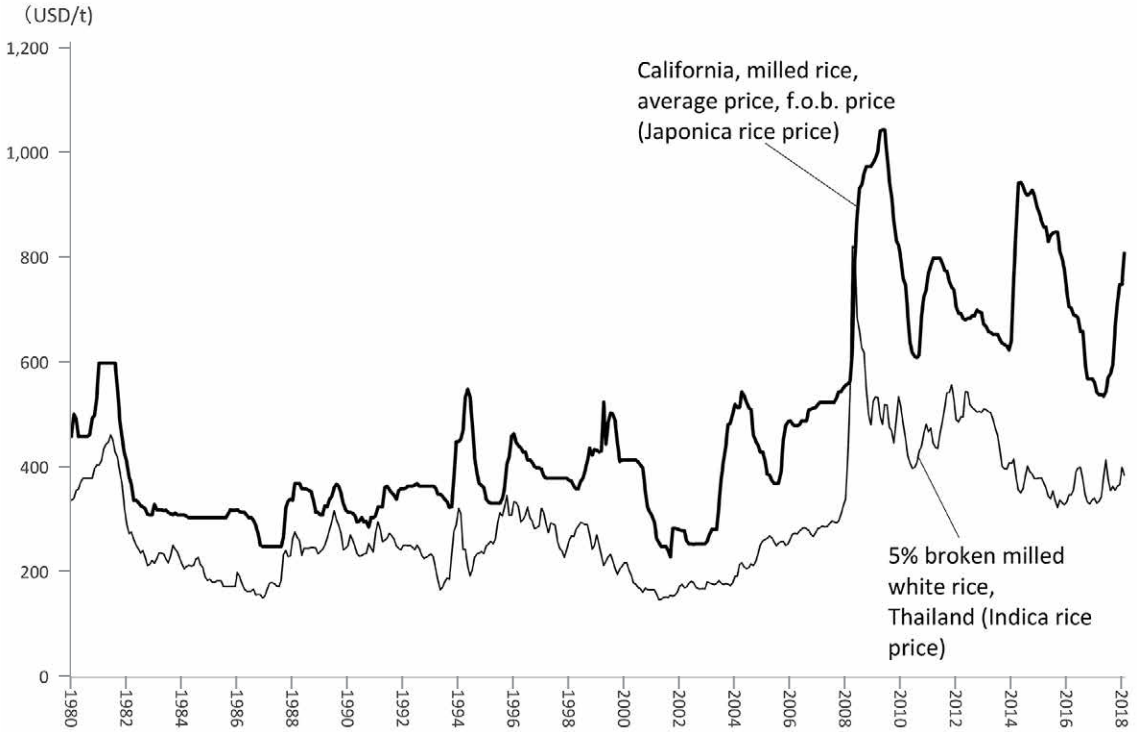

Fig. 1. International indica and japonica export rice prices
Source: Rice Yearbook (USDA-ERS 2018)

(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).

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

where Y is 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 inflastructure, LD denotes investments in land development, AME denotes investments in agricultural machinery/equipment,[7] v is rice variety (japonica or indica), t is time, c denotes the country/region, and $a1$-$a7$ are parameters. Tables A1-1 and A1-2 list these estimated parameters.

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

where APR is the planted area of rice, JRP is the domestic price for japonica rice, IRP is the domestic price for

[7] 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.

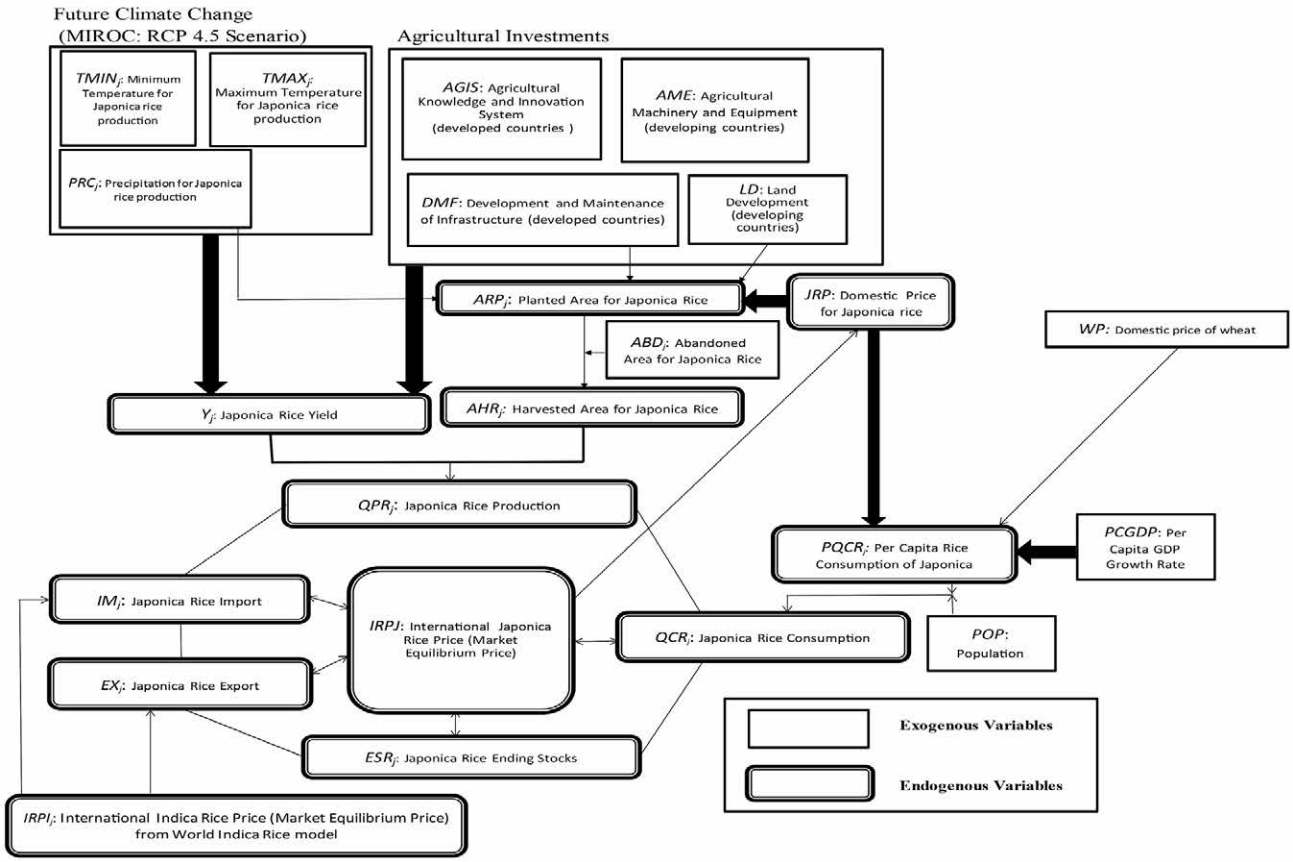

Fig. 2. Structure of the RECC model for the japonica rice market

indica rice,[8] *WP* is the domestic price for wheat, and *a*8-13 are other parameters. Tables A2-1 and A2-2 list these estimated parameters.

$$AHR_{v,t,c} = APR_{v,t,c} - ABD_{v,t,c} \quad 3)$$

where *AHW* is the harvested area and *ABD* is the abandoned area.

$$QPR_{v,t,c} = AHR_{v,t,c} * Y_{v,t,c} \quad 4)$$

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 japonica and indica prices (Eq. 7). Japonica and indica rice exports 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 imports are calculated by the exportable domestic market balance deficit remaining after the domestic market has been satisfied (Eq. 8). Japonica and indica rice ending stocks depend on the domestic japonica and indica rice prices (Eq. 10). The domestic japonica and indica rice prices depend on the international price (Eqs. 11 and 12).

$$QCR_{v,t,c} = PQCR_{v,t,c} * POP_{t,c} \quad 5)$$

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

$$\ln (PQCR_{v,t,c} / PQCR_{v,t-1,c}) = a14 \ln (PCGDP_{t,c} / PCGDP_{t-1,c}) + a15 \ln (JRP_{t,c} / JRP_{t-1,c}) + a16 \ln (IRP_{t,c} / IRP_{t-1,c}) + a17 \ln (WP_{t,c} / WP_{t-1,c}) \quad 6)$$

where *PQCR* is the per capita consumption of japonica and indica rice, *PCGDP* is the per capita GDP, *WP* is the

[8] These domestic prices are derived from the China Statistical Yearbook (National Bureau of Statistics of China 2017), EU Rice Economic Fact Sheet (European Commission 2015), Rice Yearbook (USDA-ERS 2018), and FAOSTAT (FAO 2018).

domestic wheat price, and *a*14-*a*17 are parameters. Tables A3-1 and A3-2 list these estimated parameters.

$$\ln (IMR_{v,t,c} / IMR_{v,t-1,c}) = a18 \ln (JRP_{t,c} / JRP_{t-1,c}) + a19 \ln (IRP_{t,c} / IRP_{t-1,c}) \quad 7)$$

where *IMR* represents rice imports and *a*18-*a*19 represent parameters. Table A4 lists the estimated parameters.

$$QCR_{v,t,c} = QPR_{v,t,c} - EXR_{v,t,c} + IMR_{v,t,c} - (ESR_{v,t,c} - ESR_{v,t-1,c}) \quad 8)$$

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

$$\ln (EXR_{v,t,c} / EXR_{v,t-1,c}) = a20 \ln (IRPJ_{t,c} / IRPJ_{t-1,c}) + a21 \ln (IRPI_{t,c} / IRPI_{t-1,c}) \quad 9)$$

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.

$$\ln (ESR_{v,t,c} / ESR_{v,t-1,c}) = a22 \ln (JRP_{t,c} / JRP_{t-1,c}) + a23 \ln (IRP_{v,t,c} / IRP_{v,t-1,c}) \quad 10)$$

where *a*22-23 are parameters. Tables A6-1 and A6-2 list the estimated parameters.

$$\ln (JRP_{v,t,c} / JRP_{v,t-1,c}) = a24 \ln (IRPJ_{t,c} / IRPJ_{t-1,c}) \quad 11)$$

where *a*24 is a parameter. Table A7-1 lists the estimated parameter.

$$\ln (IRP_{v,t,c} / IRP_{v,t-1,c}) = a25 \ln (IRPI_{t,c} / IRPI_{t-1,c}) \quad 12)$$

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.

$$\sum_c IMR_{v,t,c} = \sum_c EXR_{v,t,c} \quad 13)$$

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 scenarios[11] 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 averaged[13] 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.

Table 3. Standard deviation of annual minimum temperature

(Degree Celsius)

	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)

	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)

	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[14] (IMF 2017). International wheat price is derived from the OECD-FAO Agricultural Outlook 2018-2027[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,[16] and the development and maintenance of infrastructure[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).[18] We also assume that the current growth rate of agricultural machinery/equipment and land development from 2000 to 2007[19] will continue during the projection period. We applied RCP 4.5 as the baseline projection and RCP 8.5[20] as the alternative scenario.

Results

Under the baseline assumptions, the world's japonica rice production is expected to increase at a rate of 0.4%, consumption at 0.6%, exports and imports at 3.0%, and ending stocks at 0.3% per annum during the outlook period (Table 6), while the international japonica rice price is projected to increase from 39.7 USD/cwt in 2015/2017 to 42.1 USD/cwt in 2040. The world's indica rice production and consumption are expected to increase at a rate of 1.3%, exports at 2.4%, imports at 2.6%, and ending stocks at 1.4% per annum during the same period (Table 7). The international indica rice price is projected to increase from 396.9 USD/t in 2015/2017 to 451.6 USD/t in 2040.

Under scenario RCP 8.5, the international japonica rice price is expected to increase by 44.6% and the international indica rice price is expected to increase by 3.5% compared to the baseline projection average from 2018 to 2040. (Table 8). As a result, the coefficient of variation (CV)[21] of the international japonica rice price is calculated as 0.109 during the simulation period (the baseline) and as 0.184 in scenario RCP 8.5 from 2015/17 to 2040, as shown in Table 9. The CV from scenario RCP 8.5 is higher than the baseline. The CV of the international indica rice price is calculated as 0.061 during the simulation period (the baseline), and as 0.062 in scenario RCP 8.5, as shown in Table 9. The CV from scenario RCP 8.5 is higher than that from the baseline.

China is the world's largest japonica rice producer, and is expected to account for 67.1% of total japonica production in 2040. Precipitation is the most significant parameter for japonica rice yield equation in China.[22] The standard deviation of precipitation was projected to increase from 1980-2009 to 2015-2040 in the baseline and scenario RCP 8.5 in China's japonica rice growing region. Therefore, China's precipitation volatility

[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.

[15] International wheat price will increase from 163.8 USD/t in 2015/2017 to 173.0 USD/t in 2027.

[16] The agricultural knowledge and innovation system covers agricultural knowledge generation and knowledge transfer.

[17] The development and maintenance of infrastructure covers hydrological infrastructure, storage, marketing, other physical and institutional infrastructure, and farm restructuring.

[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).

[19] These FAOSTAT data were available until 2007. As for detailed data, please refer to Koizumi and Kanamaru (2016) and Koizumi (2018).

[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^2 and an eventual decline by 2100; RCP 6.0 is defined as stabilization without an overshoot pathway to 6 W/m at stabilization after 2100; and RCP 8.5 is defined as a rising radiative forcing pathway leading to 8.5 W/m^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.

[21] The coefficient of variation (CV) is a measure of relative variability. It is the ratio of standard deviation to the mean.

[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)		
	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%
China	9,181	9,489	0.1%	5.5	5.6	0.1%	50,083	52,827	0.2%
Japan	1,571	1,726	0.4%	4.9	5.1	0.2%	7,679	8,759	0.6%
South Korea	778	772	0.0%	5.4	5.5	0.1%	4,165	4,263	0.1%
USA	188	213	0.5%	6.8	8.4	0.9%	1,280	1,786	1.5%
EU28	337	350	0.2%	4.6	5.5	0.8%	1,541	1,935	1.0%
Egypt	754	746	0.0%	5.8	7.7	1.3%	4,367	5,747	1.2%

	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)
World	67,650	77,021	0.6%	2,067	4,123	3.0%	2,064	4,123	3.0%
China	46,410	52,044	0.5%	436	917	3.3%	1	1	0.0%
Japan	8,254	9,175	0.5%	50	21	−3.8%	439	412	−0.3%
South Korea	4,527	4,483	0.0%	23	31	1.3%	325	274	−0.7%
USA	624	579	−0.3%	744	1,172	2.0%	18	18	−0.1%
EU28	1,378	1,421	0.1%	260	700	4.4%	164	200	0.9%
Egypt	4,116	5,190	1.0%	117	538	6.9%	0	0	-
Malaysia	2	3	1.3%	0	0	-	2	3	1.3%

Table 7. Global indica rice market (the baseline projection)

	Harvested area (1,000ha)			Yield (t/ha)			Production (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)
World	147,286	164,634	0.5%	-	-	-	412,129	555,602	1.3%
Thailand	10,125	15,324	1.8%	1.8	2.0	0.4%	18,457	30,499	2.2%
Vietnam	7,726	8,153	0.2%	3.6	6.0	2.2%	27,976	48,986	2.5%
Indonesia	12,197	14,691	0.8%	3.0	3.1	0.1%	36,686	45,066	0.9%
Malaysia	693	675	−0.1%	2.6	2.6	0.0%	1,813	1,780	−0.1%
India	43,762	48,666	0.5%	2.5	3.2	1.1%	108,035	154,730	1.6%
China	21,007	19,186	−0.4%	4.5	4.8	0.2%	95,488	91,829	−0.2%
Japan	0	0	-	0.0	0.0	-	0	0	-
South Korea	0	0	-	0.0	0.0	-	0	0	-
USA	899	873	−0.1%	5.6	9.9	2.5%	5,023	8,681	2.4%
EU28	99	73	−1.3%	5.2	5.6	0.3%	514	406	−1.0%
Cambodia	3,100	3,308	0.3%	1.7	2.1	1.0%	5,195	6,940	1.3%
Lao PDR	972	980	0.0%	2.0	3.0	1.7%	1,958	2,898	1.7%
Myanmar	7,010	7,495	0.3%	1.8	2.4	1.3%	12,670	18,271	1.6%
Philippines	4,700	5,048	0.3%	2.5	3.3	1.3%	11,665	16,835	1.6%
Bangladesh	11,595	14,493	1.0%	2.9	4.0	1.4%	33,909	57,750	2.3%
Brazil	1,984	2,322	0.7%	4.0	4.1	0.1%	7,889	9,425	0.8%
Cote d'Ivoire	887	994	0.5%	1.5	1.9	0.8%	1,370	1,854	1.3%
Egypt	0	0	-	0.0	0.0	-	0	0	-
Madagascar	1,450	1,590	0.4%	1.6	2.0	1.2%	2,269	3,250	1.6%
Nepal	1,451	1,703	0.7%	2.2	3.2	1.6%	3,218	5,467	2.3%
Nigeria	3,106	3,259	0.2%	1.2	1.5	0.7%	3,834	4,759	0.9%
Pakistan	2,754	3,172	0.6%	2.6	3.2	1.0%	7,050	10,297	1.7%
SriLanka	925	1,174	1.0%	2.8	3.2	0.5%	2,601	3,716	1.6%

	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)
World	407,240	549,770	1.3%	43,211	74,724	2.4%	40,544	74,724	2.7%
Thailand	10,754	10,958	0.1%	10,661	19,405	2.6%	264	22	−10.2%
Vietnam	22,200	31,407	1.5%	6,192	17,081	4.5%	400	474	0.7%
Indonesia	37,883	48,129	1.0%	2	2	0.0%	1,133	3,143	4.5%
Malaysia	2,731	3,719	1.4%	32	0	-	872	1,945	3.6%
India	95,565	134,634	1.5%	11,604	19,323	2.2%	0	0	-
China	95,239	102,126	0.3%	356	337	−0.2%	5,199	12,305	3.8%
Japan	263	209	−1.0%	0	200	-	263	768	4.8%
South Korea	52	52	0.0%	0	0	-	52	52	0.0%
USA	3,344	4,135	0.9%	2,555	3,752	1.7%	772	786	0.1%
EU28	2,222	1,575	−1.5%	37	41	0.5%	1,684	1,208	−1.4%
Cambodia	4,000	6,423	2.1%	1,150	478	−3.7%	23	25	0.3%
Lao PDR	2,077	4,162	3.1%	67	0	−100.0%	137	1,270	10.2%
Myanmar	10,100	12,503	0.9%	2,650	5,757	3.4%	18	0	-
Philippines	12,967	20,473	2.0%	0	0	-	1,300	3,677	4.6%
Bangladesh	35,100	62,055	2.5%	4	10	4.1%	1,164	4,332	5.9%
Brazil	7,975	12,343	1.9%	742	751	0.1%	739	3,674	7.2%
Cote d'Ivoire	2,767	7,595	4.5%	27	0	−100.0%	1,350	5,755	6.5%
Egypt	84	120	1.6%	0	0	-	84	120	1.6%
Madagascar	2,664	6,838	4.2%	0	0	-	395	3,587	10.1%
Nepal	3,758	7,373	3.0%	0	0	-	540	1,905	5.6%
Nigeria	6,550	13,691	3.3%	0	0	-	2,400	8,956	5.9%
Pakistan	3,033	5,827	2.9%	4,005	4,465	0.5%	7	27	6.0%
SriLanka	3,108	5,790	2.7%	3	0	-	394	2,091	7.5%

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.[23] 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.

[23] Please refer to Koizumi and Kanamaru (2016).

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References

Calpe, C. (2006) *Rice International Commodity Profile*. http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Rice/Documents/.

Chen, B. and Shaghoian, S. (2016) Market Integration and Price Transmission in the World Rice Export Markets. *Journal of Agricultural and Resource Economics*, **41**, 444-457.

China's National Statistical Bureau and China National Grain and Oils Information Center (2018) *Statistics.* http://www.grain.gov.cn/ [In Chinese].

Climate Research Unit (CRU) at the University of East Anglia, Climate Research Unit (CRU) *Time-series datasets of variations in climate with variations in other phenomena*, http://catalogue.ceda.ac.uk/uuid/3f8944800cc48e1cbc29a5ee12d8542d.

European Commission (2015) *EU Rice Economic Fact Sheet (Agriculture and rural development -Cereals, oilseeds and protein crops, rice-).* https://ec.europa.eu/agriculture/cereals/trade_en.

Eurostat (2018) *Comet database -International trade in goods-*. https://ec.europa.eu/eurostat/web/international-trade-in-goods/data.

FAO (2018) *FAOSTAT.* http://www.fao.org/faostat/en/#home.

Intergovernmental Panel on Climate Change (IPCC) (2018) *Data Distribution Centre*, http://www.ipcc-data.org/.

International Monetary Fund (IMF) (2017) *World Economic Outlook Database.* IMF.

John, A. (2014) Price relations between international rice markets. *Agricultural and Food Economics*, **2**, 1-16.

Koizumi, T. (2018) The Contribution of Agricultural Investments to Food Loss and the World Rice Market in Asian Countries. *JARQ*, **52**, 181-196.

Koizumi, T. and Kanamaru, H. (2016) Contribution of Agricultural Investments to Stabilizing International Rice Price Volatility under Climate Change -Simulation for eight ASEAN countries-. *JARQ*, **50**, 267-284.

National Bureau of Statistics of China (2017) *China's Statistical Yearbook.* National Bureau of Statistics of China.

OECD (2018) *General Service Support Estimates (GSSE).* https://stats.oecd.org/glossary/detail.asp?ID=1100.

OECD-FAO (2018) *OECD-FAO Agricultural Outlook 2018-2027, Cereals.* http://www.agri-outlook.org/commodities/cereals.html.

United Nations, Department of Economics and Social Affairs

(2017) *World Population Prospects, the 2017 Revision.* http://esa.un.org/unpd/wpp/.

United Nations, Statistics Division (2018) *UN Comtrade Database - International Trade Statistics, Import / Export Data*. http://comtrade.un.org/.

United States Department of Agriculture, Economic Research Service (USDA-ERS) (2018) *Rice Yearbook*. https://www.ers.usda.gov/data-products/rice-yearbook/.

United States Department of Agriculture, Foreign Agricultural Service (USDA-FAS) (2018a) *Global Agricultural Trade System, Standard Query.* https://apps.fas.usda.gov/gats/default.aspx.

United States Department of Agriculture, Foreign Agricultural Service (USDA-FAS) (2018b) *PS&D.* https://apps.fas.usda.gov/psdonline/app/index.html#/app/home.

United States Department of Agriculture, National Agricultural Statistics Service (USDA-NASS) (2018) *Data & Statistics, Statistics by State, California Field Office*. https://www.nass.usda.gov/Statistics_by_State/.

Wails E. J. and Chavez, E. (2011) *Updated Arkansas Global Rice Model*. http://ageconsearch.umn.edu/bitstream/102650/2/AGRM%20MODEL%20DOCUMENTATION_revised%20April%2013%202011.pdf.

Appendix

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

	China	*t statistics (Year for dummy)*	USA	*t statistics (Year for dummy)*	Japan	*t statistics (Year for dummy)*	South Korea	*t statistics (Year for dummy)*	Italy (EU)	*t statistics (Year for dummy)*	Egypt	*t statistics (Year for dummy)*
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*	−1.1702	*−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-1/t-2)	0.0338	*1.8814*	0.0173	*1.2457*	0.0387	*1.2056*	0.0262	*1.8237*	0.0420	*1.5363*	-	-
a5, Development and maintenance of infrastructure (t-1/t-2)	0.0160	*1.5202*	-	-	-	-	-	-	-	-	-	-
a6, Land development (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.1247	*0.4864*
a7, Agricultural machinery/ equipment (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	-	-
Constant	0.2709	*1.5835*	7.6937	*6.2351*	1.6983	*38.0499*	0.8507	*2.8064*	5.6783	*2.4615*	1.7579	*42.6056*
Dummy 1	0.0680	*3.9705 (2004)*	0.0946	*2.1995 (1991)*	−0.2822	*−9.3115 (1993)*	−0.0693	*−1.8079 (1993)*	0.0938	*2.0177 (1989)*	0.0118	*0.3213 (1991)*
Dummy 2	0.0338	*2.2144 (2006)*	−0.0132	*−2.1146 (1996)*	-	-	0.1108	*2.9072 (1996)*	0.1253	*2.8682 (2000)*	-	-
Dummy 3	0.0306	*1.9145 (2011)*	−0.0092	*−3.0901 (2005)*	-	-	0.0534	*1.4927 (2015)*	-	-	-	-
Sample	2002-2015		1988-2016		1988-2016		1986-2016		1988-2016		1990-2016	
R-squared	0.9793		0.7896		0.9017		0.7811		0.7538		0.9563	
Adjusted R-squared	0.9327		0.6535		0.8689		0.6543		0.6024		0.9324	
Durbin-Watson stat	2.0467		1.6684		1.9312		2.0773		2.0047		1.4704	

Note: Each dummy year is 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)

	China	*t statistics (Year for dummy)*	USA	*t statistics (Year for dummy)*	Japan	*t statistics (Year for dummy)*	South Korea	*t statistics (Year for dummy)*	Italy (EU)	*t statistics (Year for dummy)*	Egypt	*t statistics (Year for dummy)*
a8, Domestic japonica rice price (t-1/t-2)	0.0247	*3.2955*	0.2261	*4.6244*	0.0999	*2.2610*	0.0439	*3.9954*	0.0887	*3.2216*	0.2819	*2.0266*
a9, Domestic indica rice price (t-1/t-2)	-	-	-	-	-	-	-	-	-	-		
a10, Domestic wheat price (t-1/t-2)	-	-	-	-	-	-	-	-	−0.2549	*−4.7606*	−0.0907	*−0.8014*
a11, Precipitation (t-1/t-2)	0.0323	*2.0808*	0.1014	*3.3569*	0.0486	*1.6532*	−0.0478	*−1.8494*	0.0523	*1.3779*	0.0388	*1.8207*
a12, Development and maintenance of infrastructure (t-1/t-2)	-	-	0.0194	*1.5405*	0.0486	*1.6532*	0.0252	*1.1919*	0.1819	*3.1644*	-	-
a13, Land development (t-1/t-2)	-	-	-	-	-	-	-	-	-	-	0.6774	*1.2648*
Constant	−2.1899	*−1.003*	4.2090	*7.765*	8.8826	*81.4821*	8.9447	*178.8160*	0.0458	*1.5743*	6.0186	*83.1899*
Dummy 1	−0.1554	*−4.0702 (2003)*	−0.0962	*−2.4936 (1998)*	0.0492	*2.4501 (2006)*	−0.0361	*−4.0058 (2000)*	−0.1175	*−3.6864 (2000)*	−0.1187	*−1.7197 (1998)*
Dummy 2	−0.0162	*−2.7619 (2005)*	−0.1635	*−2.7136 (2008)*	0.0539	*2.4858 (2016)*	−0.0316	*−3.3177 (2003)*	0.1420	*1.9470 (2012)*	0.1317	*1.8797 (2000)*
Dummy 3	0.0104	*1.8506 (2011)*	−0.2960	*−6.5629 (2015)*	-	-	0.0384	*5.3772 (2009)*	−0.1041	*−2.9990 (2014)*	-	-
Dummy 4	−0.0262	*−3.8759 (2014)*	-	-	-	-	−0.0102	*−1.5525 (2011)*	-	-	-	-
Sample	2003-2016		1992-2016		2003-2016		2000-2016		1992-2016		1990-2008	
R-squared	0.9996		0.9334		0.9826		0.9982		0.8603		0.8821	
Adjusted R-squared	0.9986		0.8859		0.9677		0.9965		0.7605		0.8071	
Durbin-Watson stat	2.0360		1.9164		2.3874		1.8367		1.9913		1.5835	

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

Table A2-2. Estimation of parameters (Planted Area: Indica rice)

	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	*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)*	Egypt	*t statistics (Year for dummy)*
a14, Income; Per capita GDP growth ratio (t/t-1)	0.1566	*1.6533*	−0.1628	*−1.0518*	−0.0872	*−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	−0.1167	*−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	*−7.0048 (2000)*	0.0880	*2.2635 (2001)*	0.0531	*2.6594 (2005)*	−0.1770	*−2.8921 (1990)*
Dummy 2	−0.0231	*−2.0547 (2002)*	−0.5909	*−3.2982 (2005)*	−0.0050	*−5.1603 (2003)*	0.1199	*3.4131 (2009)*	0.1874	*7.3529 (2008)*	0.0713	*1.2216 (2000)*
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	
R-squared	0.9956		0.9806		0.9716		0.9612		0.9929		0.780958	
Adjusted R-squared	0.9894		0.9028		0.9311		0.9059		0.9669		0.711787	
Durbin-Watson stat	2.2621		2.1898		2.4449		2.3809		2.1345		1.496395	

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	*−2.5335*
a17, Domestic wheat price (t/t-1)	0.0116	*1.7024*	0.2640	*2.5550*	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	*3.0103 (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	*−1.3736 (2001)*	0.7664	*2.5008 (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	
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)	*t statistics (Year for dummy)*	USA (indica)	*t statistics (Year for dummy)*	Egypt	*t statistics (Year for dummy)*
a18, Domestic price for japonica rice (t/t-1)	−0.4482	*−2.8618*	0.0784	*1.7698*	−0.6405	*−1.1145*
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*	4.5568	*8.9970*
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)

	China	*t statistics* (*Year for dummy*)	Japan	*t statistics* (*Year for dummy*)	South Korea	*t statistics* (*Year for dummy*)	EU	*t statistics* (*Year for dummy*)
a20, International japonica rice price (t/t-1)	0.2787	*1.4600*	0.4939	*1.7445*	0.9265	*2.4457*	0.1603	*1.1618*
a21, International indica rice price (t/t-1)	−0.5570	*−2.3779*	-	-	-	-	−0.3347	*−4.9208*
Constant	2.7782	*5.8599*	6.3202	*11.5383*	4.3062	*6.2682*	5.0005	*5.9274*
Dummy 1	−0.5911	*−3.2975 (2000)*	−1.1117	*−3.2592 (1998)*	−1.2535	*−3.6147 (2003)*	0.4688	*3.4722 (2001)*
Dummy 2	0.9572	*5.1908 (2011)*	0.4458	*1.5409 (2000)*	−4.4899	*−12.9711 (2007)*	−0.2994	*−2.5058 (2006)*
Dummy 3	0.9869	*5.4830 (2016)*	1.0020	*3.5933 (2011)*	1.2669	*3.8054 (2016)*	−0.3785	*−3.3494 (2007)*
Sample	1998-2016		1997-2016		2002-2016		2001-2016	
R-squared	0.9389		0.9035		0.9906		0.9576	
Adjusted R-squared	0.8900		0.8472		0.9835		0.9205	
Durbin-Watson stat	2.2591		2.1711		2.2875		1.2026	

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	*t statistics* (*Year for dummy*)	EU	*t statistics* (*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	*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)*	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	*−1.1428*	−0.0867	*−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	*28.0485*	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	*−2.9958 (1994)*	−0.2360	*−6.1701 (2005)*	0.6777	*1.7417 (2001)*
Dummy 2	-	-	−0.2312	*−2.7982 (2000)*	−2.2282	*−12.9509 (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 (2000)*
Sample	2008-2016		2000-2016		1991-2016		1981-2016		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)

	China	*t statistics (Year for dummy)*	USA	*t statistics (Year for dummy)*	EU	*t statistics (Year for dummy)*
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	*−2.0153*	−0.3417	*−3.3925*	−0.4764	*−3.0241*
Constant	−0.0593	*−1.1986*	17.5461	*6.3267*	−11.5403	*−2.0820*
Dummy 1	−0.1549	*−4.4383 (2003)*	−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.

Table A7-1. Estimation of parameters (Price transmission: Japonica rice)

	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)

	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

	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

(million USD)

		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)