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The Impact of COVID-19 on Global Indica and Japonica Rice Markets: Examining by an Endogenous Agricultural Investment Model

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Abstract

Indica and japonica rice are commonly subjected to different market structures, and the international prices for both subspecies display different trends. The global indica and japonica rice markets in the mid and long term under climate change conditions were projected by the Rice Economy Climate Change (RECC) model. Additionally, endogenous agricultural investments were incorporated into the projections. A COVID-19 pandemic scenario was stimulated to observe its impact on the global indica and japonica rice markets. The results indicated that agricultural investments are expected to decrease in many indica rice-producing countries, whereas the investments will increase in many japonica rice-producing countries in the long term. Therefore, the global indica rice production will decrease due to its investment reduction; however, global japonica rice production will increase in the mid and long term. Due to the COVID-19 scenario, the international indica and japonica rice prices would decrease in 2020 due to the unprecedented shrinking economies worldwide, but the prices would increase from 2021 to 2040 compared with the baseline average of the price projections with the RECC model. The scenario simulation results reveal that the japonica rice markets are projected to have less impact than the indica rice markets from the COVID-19 pandemic.

Discipline: Social Science
Additional key words: agricultural knowledge and innovation system, development and maintenance of infrastructure, pandemic scenario, agricultural commodity prices, gross domestic product growth rate

Introduction

Indica and japonica rice[1] are commonly subjected to different market structures, and the international prices for both subspecies display different trends in the global markets. Koizumi & Furuhashi (2020) predicted and simulated the future global indica and japonica rice markets in the mid and long term under climate change by developing their partial equilibrium model. Moreover, Koizumi & Furuhashi (2021) projected and simulated how agricultural investments contributed to stabilizing the global indica and japonica rice prices in the mid- and long-term periods. However, the latter study set agricultural investment as exogenous variables and determined that the more optimistic growth rates in the model, which most international organizations expected as economic prospects for the future before the COVID-19 pandemic started, will continue for the projection period.

Pandey et al. (2010) mentioned that agricultural R&D remains underinvested and has decreased in Asia in actual terms during a declining trend in rice prices before the 2000s. Furthermore, public sector investment in agricultural infrastructure, such as irrigation similarly decreased (Pandey et al. 2010). Zepeda (2001) reported that the public R&D and infrastructure have a detrimental long-term effect on productivity growth because of public budget adjustments and reform in the long term since the public budget would be frequently required to restrain and restructure its allocation according to the circumstances. Technological changes in agriculture as influenced by investments in agricultural research, irrigation, roads, and other factors are also crucial (Rosegrant et al. 2001). Hayami & Kikuchi (1978) verified that irrigation was

[1] In this study, temperate japonica rice is considered as japonica rice, whereas indica, *Oryza glaberrima*, and other rice subspecies are categorized as indica rice (Koizumi & Furuhashi 2020).

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decided by the international rice price in the case of the Philippines. Kikuchi (1988) determined that the variation in international rice price was a positive correlation with the number of rice research articles in the world. Yuize (1979) demonstrated that agricultural land and building investment were decided by Gross National Products, agricultural price index, and other factors in the case of Japan. Based on these previous studies, we hypothesized in this study that the demand for infrastructural stock of agricultural knowledge, as a part of the factor of rice production, would increase when rice price increases.[2] The supply of infrastructural stock of agricultural knowledge will increase to satisfy the input demand. Additionally, infrastructural investment of agricultural knowledge can be a part of all investments. Moreover, it was hypothesized that infrastructural investments of agricultural knowledge as the investment in the macroeconomic frameworks for gross rice production will increase when the gross domestic product (GDP) increases.[3] In the long term, these agricultural investment variables would be affected by the agricultural commodity prices and GDP growth rates. Therefore, GDP and agricultural commodity prices were incorporated into explanatory variables for agricultural investments and have established these agricultural investment variables as endogenous variables in the Rice Economy Climate Change (RECC) model.

The most significant uncertainty in 2020, since World War II, was the plunging of the global economy and agricultural commodity markets into a severe contraction due to the COVID-19 pandemic. The OECD-FAO (2020) examined how the COVID-19 pandemic has negatively affected global agricultural markets in the short term and revealed that the international rice price would decrease in 2020, but increase in 2022. OECD (2020b) examined how COVID-19 would impact the global agricultural markets till the year 2029 and concluded that agricultural prices would gradually recover from 2022, after a fall in prices in the short run.[4] The OECD-FAO predicted the global rice market for the next decade but did not divide its market into indica and japonica rice markets. Strictly speaking, rice in the global market is not a homogeneous commodity.[5] The two major types of rice commonly traded on the global market are indica and japonica. Their production zones, consumer preferences, and policies are mostly distinguished by the rice type with their different market structures. The international rice market would be mainly separated into japonica and indica rice markets. Furthermore, climate change, agricultural investments, and policies would commonly have different impacts on both rice markets. Therefore, the global indica and japonica rice markets should be divided for assessing the effects of market performances, when we examine how climate change, agricultural investment, and policy impact these rice markets. This study does not intend to focus on the genetic strictness of rice types but explores the conventional major rice types, indica and japonica rice, based on practical rice market features. Both rice markets would perform differently behind domestic demand-oriented markets due to their consumption in regions and countries where consumers' rice preferences differ substantially. Accordingly, the COVID-19 pandemic impacting both rice markets differently was hypothesized. In this study, we examined how the COVID-19 pandemic would impact the global indica and japonica rice markets. A partial equilibrium model—RECC model—was developed in addition to incorporating endogenous agricultural investments into the model under climate change.

Agricultural investment and prices

The OECD classifies "agricultural knowledge and innovation systems and development and maintenance of infrastructure" as agricultural investments. Here, we also followed its investment. "The agricultural knowledge and innovation system" cover the generation of new agricultural knowledge and the transfer of this knowledge.[6] "Development and maintenance of infrastructure" cover hydrological infrastructure, storage, marketing, other physical and institutional infrastructures, and farm

[2] The hypothesis that increasing infrastructural stock of agricultural knowledge is derived from applying the profit-maximizing measures with rice price was assumed.

[3] The hypothesis that increasing rice production is derived from applying the macroeconomic frameworks with infrastructural agricultural investment as a substitution of investment was assumed.

[4] It showed FAO price index, but did not show the rice price.

[5] For detailed information, refer to Koizumi & Furuhashi (2020).

[6] The agricultural knowledge and innovation systems covers agricultural knowledge generation and transfer. Agricultural knowledge generation covers budgetary transfers that finance research and development (R&D) activities related to agriculture, irrespective of the institution (private or public, ministry, university, research center, or producer groups). Agricultural knowledge transfer covers budgetary expenditure to finance agricultural vocational schools and agricultural programs at high education levels, generic training and advice to farmers (e.g., accounting rules, pesticide application), and data collection and information dissemination networks related to agricultural production and marketing (OECD 2020a).

restructuring.[7] This study applied the General Service Support Estimate (GSSE) data to agricultural investment data.[8] Although GSSE covers China, Japan, South Korea, India, the U.S., the EU, Vietnam, and the Philippines as a single country in the RECC model, it does not cover other countries and regions. Therefore, FAOSTAT investment stock data, which is defined as "Land development and agricultural machinery & equipment," is applied to the other countries and regions in this study.[9]

Based on these previous studies, it was hypothesized that the increase in agricultural commodity prices and economic growth can correlate positively with increase in the agricultural investments. As shown in Appendix Table A-1–A-4, agricultural investments, consisting of agricultural knowledge and innovation systems, and development and maintenance of infrastructure had positive correlations with a lagged indica and japonica rice prices. The other agricultural investments, i.e., land development and agricultural machinery & equipment, in the other major rice-producing countries also have positive correlations with a lagged domestic indica and japonica rice prices, as shown in Appendix Table A-5–A-12.

Higher agricultural commodity prices for indica and japonica rice are a crucial incentive to increase the agricultural investments in major rice-producing countries with a time lag[10] in the mid- and long-term periods. The assessed parameters of agricultural investments as responses to these prices would depend on the features of indica and japonica rice prices and the relationship among other agricultural commodity prices[11] in these countries and regions.[12] Furthermore, the GDP growth rate as a substitution variable for economic growth can affect the quantity and change in agricultural investment from the viewpoint of macroeconomic indicators. The agricultural investments (agricultural knowledge and innovation systems, development and maintenance of infrastructure, land development, and agricultural machinery & equipment) correlated positively with GDP, as shown in Appendix Table A-1–A-12. Raising agricultural commodity prices and the GDP growth rate would principally bring agricultural investment to its increment, with the premise of certain constant labor input in the agricultural sector.[13] This study additionally covered the endogenous variables for the agricultural investments with constant agricultural labor input and exogenous GDP growth rate. The agricultural investments depend on indica and japonica, the other agricultural commodity prices, and the GDP growth rate in major rice-producing countries. Koizumi & Furuhashi (2021) applied agricultural investments as an exogenous indicator to the RECC model. Developing the RECC model from Koizumi & Furuhashi (2021), this study can evaluate how agricultural commodity prices and GDP growth rate would affect agricultural investments via endogenous changes in major rice-producing countries.

[7] The development of maintenance of infrastructure includes physical infrastructures and institutional infrastructures. The physical infrastructures cover irrigation, drainage networks, silos harbor facilities (docks and elevators), etc. The institutional infrastructures cover land cadasters, machinery user groups, seed and species registries, development of rural finance networks, support to farm organizations, etc. (OECD 2020a).

[8] GSSE data cover rice and other crops. Therefore, the GSSE data were divided by the rice production value ratio of total agricultural production value in each country/region and each year. Agricultural production value data are derived from FAOSTAT (FAO 2020). As for the EU, the rice ratio in Italy is applied for japonica rice production, and the rice ratio in Spain is applied for indica rice production. The data indicate the total amount of investment value for indica and japonica rice in all countries/region.

[9] GSSE data were updated annually from OECD member countries and secretariat. However, FAOSTAT data were not updated after 2007. Therefore, we gave priority to using GSSE data in this study and apply FAOSTAT data for the countries, which GSSE data do not cover. FAOSTAT data cover rice and other crops. Therefore, the data were divided by the rice production value ratio of total agricultural production value in each country and each year. Agricultural production value data are derived from FAOSTAT (FAO 2020).

[10] Agricultural production will grow when the agricultural commodity prices rise, and then, agricultural investment would be needed to increase. We assume a year-lag as an explanatory variable in this study because agricultural investment of the rice sector in the world had accumulated for the past several decades until the present period.

[11] They depend on the crucial commodities in the country.

[12] The parameter estimations show that the indica rice price elasticity of the agricultural knowledge and innovation system in the Philippines is much higher than those in other countries and regions. They also show that the indica rice price elasticities of the development and maintenance of infrastructure in Vietnam and India are much higher than those in other countries and regions. The japonica rice price elasticity is higher than the indica rice price elasticity of both agricultural investments in the EU. However, there are few differences between indica and japonica rice price elasticities of both agricultural investments in other countries. For detailed parameter estimation, refer to Appendix Table A-1–A-12.

[13] It is very difficult to obtain reliable and common category of time-series data for labor inputs in 24 countries and regions. Therefore, we assume that labor inputs will be constant in this study.

Methods and data

1. Estimation of agricultural investments

Rice markets in 24 countries and regions[14] are covered by the RECC model, which also represents the entire global rice market. The RECC model includes equations for projecting rice yield and harvested areas affected by climate change and agricultural investments. Herein, the base year of the projection and simulation was 2015/17 (a 3-year average for 2015-2017),[15] and we predicted and simulated from 2018 to 2040.[16] Each country or regional market consists of production, consumption, exports, imports, and ending stock for indica and japonica rice up to the year 2040. For detailed model structures, refer to Koizumi & Furuhashi (2020) and Koizumi & Furuhashi (2021). Endogenous agricultural investment variables (agricultural knowledge and innovation systems, development and maintenance of infrastructure, land development, and agricultural machinery and equipment) into the RECC model in this study were incorporated. This study assumes that the prices of these variables would impact the rice yields of both types (Fig. 1).

Agricultural investment depends on the lagged indica and japonica rice prices, other agricultural prices, and GDP in the following equation.

$$\ln(AGIV_{v,t,c}/AGIV_{v,t-1,c}) = a1\ln(IRP_{t-1,c}/IRP_{t-2,c}) + a2\ln(JRP_{t-1,c}/JRP_{t-2,c}) + a3\ln(WP_{t-1,c}/WP_{t-2,c}) + a4\ln(MAP_{t-1,c}/MAP_{t-2,c}) + a5\ln(SOYP_{t-1,c}/SOY_{t-2,c}) + a6\ln(VOP_{t-1,c}/VOP_{t-2,c}) + a7\ln(SCA_{t-1,c}/SCA_{t-2,c}) + a8\ln(ETAP_{t-1,c}/ETAP_{t-2,c}) + a9\ln(COTP_{t-1,c}/COTP_{t-2,c}) + a10\ln(RTP_{t-1,c}/RTP_{t-2,c}) + a11\ln(GDP_{t-1,c}/GDP_{t-2,c})$$

where *AGIV* is the agricultural investment (agricultural knowledge and innovation systems, development and maintenance of infrastructure, land development, and agricultural machinery & equipment), *v* is a variety of agricultural investments, *t* is the time, *c* is the country or region, *IRP* is the domestic price of indica rice, *JRP* is the domestic price of japonica rice, *WP* is the domestic price of wheat, *MAP* is the domestic price of corn, *SOYP* is the domestic price of soybeans, *VOP* is the domestic price of vegetable oil, *SCA* is the domestic price of sugar cane, *ETAP* is the domestic price of ethanol, *COTP* is the domestic price of cotton, *RTP* is the domestic price of roots and tubers, *GDP* is the GDP, and *a1–11* are parameters. Appendix Table A-1–A-12 lists these estimated parameters. These equations and parameters were applied to the projection.

Refer to Koizumi & Furuhashi (2020) for historical annual data for this model.

2. Baseline assumptions

The baseline scenario (referred to as baseline hereafter) adopts a set of assumptions for the general economy, agricultural policies, and technological changes without shocks induced by policy changes during the projection period. Economic conditions and projections before 2020 as a baseline assumption were applied. Therefore, we did not cover the impact of COVID-19 on global indica and japonica rice markets as a baseline projection. The climate variables (minimum/maximum temperatures and precipitation) in each country and region are exogenous to the model, and all climate variables for both the baseline and Representative Concentrated Pathway (RCP) 4.5 scenarios[17] are derived from future climate change projections by the Model for Interdisciplinary Research on Climate (MIROC).[18]

Population data for all countries were obtained from the 2019 revision (medium variant) of the World Population Prospects, United Nations (2019). Real GDP was also treated as an exogenous variable, and real GDP growth rate assumptions were set based on IMF World Economic Outlook (2019)[19] (Table 1). International and domestic wheat, corn, soybeans, vegetable oil, sugar cane, ethanol, and cotton prices were derived from the OECD-FAO Agricultural Outlook 2020-2029[20] (OECD & FAO 2020). The present agricultural and trade policies were assumed to continue for the projection period of this study. Based on these assumptions and exogenous

[14] Thailand, Vietnam, Indonesia, Malaysia, the Philippines, Cambodia, Lao PDR, Myanmar, China, Japan, South Korea, India, the U.S., the EU, Bangladesh, Sri Lanka, Nepal, Pakistan, Brazil, Côte d'Ivoire, Egypt, Madagascar, Nigeria, and the rest of the world.

[15] These are historical data.

[16] The estimated time periods for each parameter depend on the country and region. Appendix Table A-1–A-12 lists them.

[17] RCPs are time and space dependent trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCP 4.5 is defined as stabilization without overshoot pathway to 4.5 W/m at stabilization before 2100 (IPCC 2018).

[18] The Model for Interdisciplinary Research on Climate (MIROC), which is the coupled general circulation model, consists of five component models: atmosphere, land, river, sea ice, and ocean. The atmospheric component interacts with the land and sea ice components. The air–sea exchange is realized exclusively between the atmosphere and sea ice components, not directly between the atmosphere and ocean components, and the ocean component interacts only with the sea ice component (Hiroyasu & Emori 2004).

[19] The GDP growth rates are available until the year 2023. This study assumes that the average GDP growth rates from 2017 to 2023 in each country will continue in 2024-2040.

[20] Refer to Appendix Table A-14.

variables for GDP, per capita GDP,[21] population, and agricultural commodity prices, we projected the baseline projection from 2018 to 2040.

3. Scenario of spreading COVID-19

The following alternative scenario was applied as a sensitivity analysis. We applied economic conditions and projections after 2020 and assume that the COVID-19 pandemic will impact global indica and japonica rice markets as an alternative scenario. The impact of COVID-19 on world indica and japonica rice markets was evaluated. The scenario uses projections from the World Economic Outlook (2020) of the IMF for GDP growth. The global economy will decline by 4.4% in 2020, which is larger than the decline during the 2008-2009 financial crisis. The global GDP will grow by 5.2% in 2021 and will recover in the mid–long term (Table 1). International and domestic wheat, corn, soybeans, vegetable oil, sugar cane, ethanol, and cotton prices are derived from OECD-FAO Agricultural Outlook 2021-2030 (OECD & FAO 2021).

[21] It applies for per capita indica and japonica rice consumption. Appendix Table A-13 shows it.

Results

1. Baseline projection for agricultural investments

Agricultural knowledge and innovation systems in Vietnam, India, China, the U.S., the EU, the Philippines, Japan, and South Korea, in the baseline, are expected to increase by 0.1%-3.9% per annum during the projection period (Table 2). In these countries and regions, the development and maintenance of infrastructure are expected to increase by 0.2%-3.0% per annum during the same period. Land development in other countries is expected to increase by 0.3%-2.3% per annum during the same period. Agricultural machinery & equipment in other countries are expected to increase by 0.2%-2.8% per annum during the same period.

2. Baseline projection for global indica and japonica rice markets

The world's indica rice production is expected to increase at a rate of 1.1%, consumption at 1.1%, exports at 1.7%, imports at 1.9%, and ending stocks at 1.6% per annum during the same period (Table 3). The international

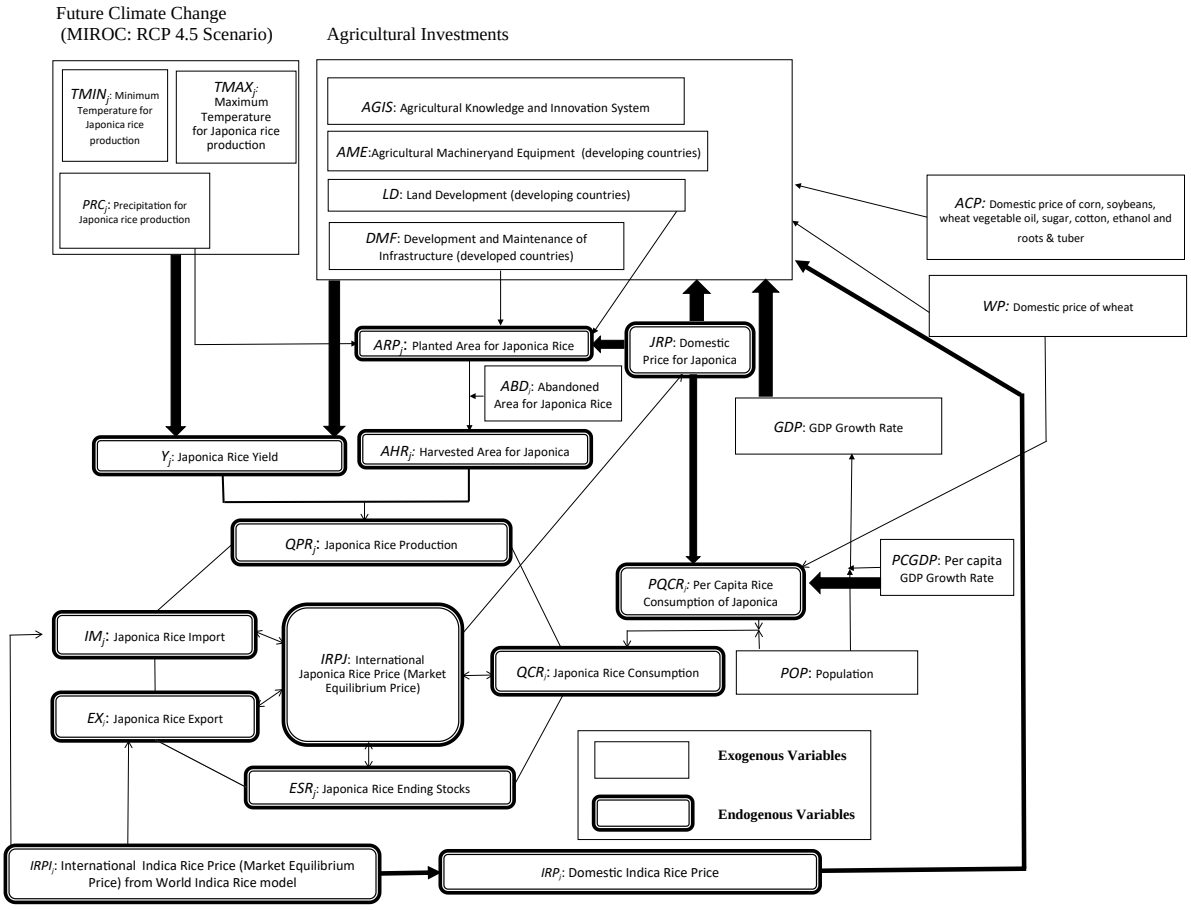

Fig. 1. Structure of the RECC model in the case of japonica rice market

Table 1. Growth rate of GDP (real) (baseline and COVID-19 scenario)

	Baseline		COVID-19 Scenario	
	2020	2021-2040	2020	2021-2040
Thailand	5.3%	5.9%	–6.3%	5.5%
Vietnam	8.9%	8.5%	3.4%	9.3%
Indonesia	8.4%	7.3%	–2.8%	7.1%
Malaysia	4.4%	7.3%	–7.8%	9.0%
India	9.1%	9.7%	–9.6%	8.8%
China	8.0%	8.3%	3.2%	9.2%
Japan	5.0%	3.7%	–3.3%	4.1%
South Korea	–0.2%	5.1%	–3.6%	5.1%
The U.S.	4.1%	3.7%	–2.9%	4.4%
The EU	2.5%	4.1%	–4.4%	6.4%
Cambodia	8.4%	8.5%	–1.5%	8.9%
Lao PDR	10.9%	8.8%	–2.1%	6.4%
Myanmar	9.3%	9.2%	3.3%	9.2%
The Philippines	7.5%	9.3%	–2.5%	9.0%
Bangladesh	9.6%	9.4%	5.0%	9.0%
Brazil	2.5%	4.9%	–5.8%	2.4%
Côte d'Ivoire	8.8%	9.0%	5.0%	9.9%
Egypt	5.9%	6.0%	–0.3%	5.8%
Madagascar	8.7%	7.8%	0.5%	8.6%
Nepal	13.8%	9.1%	4.8%	7.9%
Nigeria	10.8%	11.4%	–1.1%	11.7%
Pakistan	2.4%	2.7%	–4.5%	3.9%
Sri Lanka	6.4%	7.6%	–3.4%	7.3%
Iran	1.0%	5.5%	4.6%	4.6%

Source: IMF (2019) and IMF (2020)
Note: The number of 2020 means the growth rate of 2020. The number of 2021-2040 means the average of changing rate from 2021 to 2040.

price of indica rice is projected to decrease from 396.9 USD/t in 2015/17 to 366.5 USD/t in 2040. In contrast, global japonica rice production is expected to increase at a rate of 0.5%, consumption at 0.7%, exports and imports at 1.6%, and ending stocks at 0.1% per annum during the outlook period (Table 4). The international price of japonica rice is projected to decrease from 670.2 USD/t in 2015/17 to 586.5USD/t in 2040[22]. Future climate change is projected to impact indica and japonica rice production differently.[23]

[22] The international price is real value.

[23] Koizumi & Furuhashi (2020) projected and simulated the future global japonica and indica rice markets under climate change in the long term. The simulation results suggested 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. In the previous study, the coefficient of variation (CV) of indica rice price was 0.1083, and that of japonica rice price was 0.1776 during 2015/17 to 2040 in baseline projection (RCP 4.5) (Koizumi & Furuhashi 2021). As a result of this study, the CVs of international indica and japonica rice prices are 0.2502 and 0.4124 from 2015/17 to 2040, respectively.

Table 2. Agricultural investments (baseline projection)

	Agricultural knowledge and innovation system (USD million)			Development and maintenance of infrastructure (USD million)		
	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)
Vietnam	77	106	1.4%	426	509	0.8%
India	76,103	100,238	1.2%	153,313	299,767	3.0%
China	7,582	10,717	1.5%	9,124	15,604	2.4%
The U.S.	2,043	2,912	1.6%	3,016	4,749	2.0%
The EU	5,552	7,715	1.4%	2,020	2,217	0.4%
The Philippines	258	617	3.9%	852	1,129	1.2%
Japan	985	1,255	1.1%	7,393	8,565	0.6%
South Korea	799	812	0.1%	1,292	1,343	0.2%

	Land development (USD million)			Agricultural machinery & equipment (USD million)		
	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)
Thailand	13,040	21,934	2.3%	1,763	2,464	1.5%
Indonesia	21,124	31,726	1.8%	9,363	14,218	1.8%
Malaysia	1,250	1,331	0.3%	1,430	2,257	2.0%
Cambodia	2,081	3,231	1.9%	296	411	1.4%
Lao PDR	991	1,302	1.2%	86	111	1.1%
Myanmar	8,317	10,917	1.2%	1,430	2,709	2.8%
Bangladesh	9,244	11,864	1.1%	1,292	2,314	2.6%
Brazil	43,779	55,745	1.1%	28,546	30,207	0.2%
Côte d'Ivoire	1,328	1,890	1.5%	213	342	2.1%
Egypt	26,835	33,056	0.9%	1,439	2,173	1.8%
Madagascar	8,230	10,860	1.2%	284	431	1.8%
Nepal	2,878	3,510	0.9%	447	742	2.2%
Nigeria	23,850	26,299	0.4%	1,592	1,731	0.4%
Pakistan	50,210	61,364	0.9%	3,443	5,541	2.1%
Sri Lanka	1,753	2,131	0.9%	198	250	1.0%
Iran (Rest of the world)	53,208	87,290	2.2%	10,352	11,642	0.5%

3. Impact of spreading COVID-19 on agricultural investments

Because of setting a COVID-19 scenario, agricultural knowledge and innovation systems in Vietnam are expected to increase by 7.4%, and those in the EU, China, U.S., India, and Japan are expected to increase by 0.1%-4.8% from 2020 to 2040 compared with the baseline average (Table 5). The increased GDP

Table 3. Global indica rice market (baseline projection)

	Harvested area (1,000 ha)			Yield (t/ha)			Production (1,000t)		
	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)
World	147,286	170,655	0.6%	-	-	-	412,129	534,873	1.1%
Thailand	10,125	12,809	1.0%	2.8	2.8	0.1%	18,457	23,996	1.1%
Vietnam	7,726	9,535	0.9%	5.7	5.9	0.1%	27,976	35,620	1.1%
Indonesia	12,197	13,686	0.5%	5.1	5.7	0.5%	36,686	45,842	1.0%
Malaysia	693	684	–0.1%	4.2	4.5	0.3%	1,813	1,926	0.3%
India	43,762	51,287	0.7%	3.7	4.4	0.8%	108,035	152,043	1.5%
China	21,007	19,302	–0.4%	6.5	6.8	0.2%	95,488	91,629	–0.2%
Japan	0		-	0.0	0.0	-	0	0	-
Korea	0		-	0.0	0.0	-	0	0	-
The U.S.	899	1,208	1.3%	8.0	8.3	0.2%	5,023	7,012	1.5%
The EU	99	88	–0.5%	7.5	8.2	0.4%	514	501	–0.1%
Cambodia	3,100	3,962	1.1%	2.7	3.5	1.1%	5,195	8,535	2.2%
Lao PDR	972	974	0.0%	3.4	4.4	1.2%	1,958	2,567	1.2%
Myanmar	7,010	8,153	0.7%	2.9	4.2	1.7%	12,670	21,499	2.3%
The Philippines	4,700	5,443	0.6%	3.8	4.3	0.6%	11,665	15,572	1.3%
Bangladesh	11,595	13,642	0.7%	4.4	5.2	0.8%	33,909	47,657	1.5%
Brazil	1,984	2,215	0.5%	5.8	7.3	1.0%	7,889	10,981	1.4%
Côte d'Ivoire	887	1,190	1.3%	2.4	3.8	2.1%	1,370	2,935	3.4%
Egypt	0	0	-	0.0	0.0	-	0	0	-
Madagascar	1,450	1,892	1.2%	2.4	3.1	1.0%	2,269	3,761	2.2%
Nepal	1,451	2,017	1.4%	3.3	4.0	0.8%	3,218	5,340	2.2%
Nigeria	3,106	4,089	1.2%	2.0	2.6	1.2%	3,834	6,577	2.4%
Pakistan	2,754	3,263	0.7%	3.8	4.9	1.1%	7,050	10,624	1.8%
Sri Lanka	925	1,047	0.5%	4.1	4.4	0.3%	2,601	3,152	0.8%

	Consumption (1,000 t)			Imports (1,000 t)			Exports (1,000 t)		
	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)
World	407,240	525,695	1.1%	40,544	63,099	1.9%	43,211	63,099	1.7%
Thailand	10,754	11,066	0.1%	264	336	1.1%	10,661	12,556	0.7%
Vietnam	22,200	26,637	0.8%	400	529	1.2%	6,192	9,476	1.9%
Indonesia	37,883	48,219	1.1%	1,133	2,819	4.0%	2	2	0.0%
Malaysia	2,731	3,317	0.8%	872	1,405	2.1%	32	0	-
India	95,565	126,849	1.2%	0	0	-	11,604	21,180	2.7%
China	95,239	96,703	0.1%	5,199	8,301	2.1%	356	291	–0.9%
Japan	263	201	–1.2%	263	201	–1.2%	0	200	-
Korea	52	55	0.3%	52	55	0.3%	0	0	-
The U.S.	3,344	3,879	0.6%	772	800	0.2%	2,555	3,821	1.8%
The EU	2,222	1,637	–1.3%	1,684	1,178	–1.5%	37	40	0.3%
Cambodia	4,000	6,364	2.0%	23	23	0.0%	1,150	2,032	2.5%
Lao PDR	2,077	2,978	1.6%	137	437	5.2%	67	0	-
Myanmar	10,100	15,124	1.8%	18	18	0.0%	2,650	6,376	3.9%
The Philippines	12,967	18,499	1.6%	1,300	3,094	3.8%	0	0	-
Bangladesh	35,100	49,545	1.5%	1,164	1,919	2.2%	4	10	4.1%
Brazil	7,975	11,462	1.6%	739	1,242	2.3%	742	751	0.1%
Côte d'Ivoire	2,767	4,767	2.4%	1,350	1,977	1.7%	27	0	-
Egypt	84	120	1.6%	84	120	1.6%	0	0	-
Madagascar	2,664	4,517	2.3%	395	756	2.9%	0	0	-
Nepal	3,758	6,903	2.7%	540	1,563	4.7%	0	0	-
Nigeria	6,550	11,194	2.4%	2,400	4,748	3.0%	0	0	-
Pakistan	3,033	7,293	3.9%	7	27	6.0%	4,005	3,121	–1.1%
Sri Lanka	3,108	4,054	1.2%	394	1,061	4.4%	3	0	-

growth rate contributes to increasing the agricultural knowledge and innovation systems in Vietnam, the EU, and China. The increased japonica rice and corn prices contribute to increasing the agricultural knowledge and innovation systems in the U.S..[24] The increased indica and japonica rice price contributes to increasing the agricultural knowledge and innovation systems in India and Japan. The agricultural knowledge and innovation systems in the Philippines and South Korea are expected to decrease by 0.4%-1.5% due to decreasing GDP growth rate.

The development and maintenance of infrastructure in China, the U.S., Vietnam, and the EU are expected to increase by 5.5%-7.9% from 2020/21 to 2040 compared with the baseline average (Table 5). The increased GDP growth rate contributes to increasing the development and maintenance of infrastructure in these countries and regions. The development and maintenance of infrastructure in India, the Philippines, Japan, and South Korea are expected to decrease by 0.1%-3.3% due to decreasing GDP growth rate.

The land development in Lao PDR, Bangladesh, Thailand, Sri Lanka, Brazil, Nepal, Cambodia, Myanmar, and Egypt is expected to decrease by 0.1%-5.3%. The decreased GDP contributes to decreasing the land development in these countries. The land development in Côte d'Ivoire, Indonesia, Pakistan, Madagascar, Nigeria, and Malaysia is expected to increase by 0.1%-7.4% due to the high GDP growth rates in these countries. The increased vegetable oil and rice prices contributed to increasing the land development in Indonesia. The agricultural machinery & equipment in Lao PDR, Nepal, Bangladesh, Thailand, Brazil, Sri Lanka, Indonesia, Cambodia, Myanmar, and Egypt are decreased by 0.3%-4.1% because of the high GDP growth rates in these countries. The agricultural machinery & equipment in Côte d'Ivoire, Madagascar, Pakistan, Malaysia, and Nigeria are expected to increase by 1.1%-6.8% because of the high GDP growth rates in these countries. The increased wheat and vegetable oil prices contribute to increasing the agricultural machinery & equipment in Nigeria.

[24] Japonica rice and corn are normally produced in the different geographical areas in the U.S. Therefore, these agricultural commodities are not competed to increase the agricultural knowledge and innovation systems.

4. Impacts of spreading COVID-19 on indica rice markets

Due to setting a COVID-19 scenario, the world indica rice consumption is expected to decrease by 0.1%, its production by 0.0%, and its imports and exports by 2.5% compared with the baseline in 2020 (Table 6). The income elasticities of per capita indica rice consumption are positive in most of the countries, except for Japan, South Korea, the EU, and Thailand.[25] Because of decreasing per capita real GDP growth rate, the indica rice consumption in India, China, Indonesia, and the Philippines is projected to decrease by 0.6%-1.3%. Therefore, world

[25] For income elasticity of indica rice, please refer to Koizumi & Furuhashi (2020).

Table 4. Global japonica rice market (baseline projection)

	Harvested area (1,000 ha)			Yield (t/ha)			Production (1,000t)		
	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)
World	13,160	13,568	0.1%	-	-	-	70,721	79,550	0.5%
China	9,181	9,652	0.2%	7.8	8.5	0.4%	50,083	57,493	0.6%
Japan	1,571	1,365	–0.6%	6.7	6.9	0.1%	7,679	7,982	0.2%
South Korea	778	753	–0.1%	7.1	7.4	0.2%	4,165	4,188	0.0%
The U.S.	188	211	0.5%	9.7	10.4	0.3%	1,280	1,550	0.8%
The EU	337	350	0.2%	6.6	6.6	0.0%	1,541	1,611	0.2%
Egypt	754	796	0.2%	8.4	9.5	0.6%	4,367	5,244	0.8%

	Consumption (1,000 t)			Imports (1,000 t)			Exports (1,000 t)		
	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)	2015-17	2040	Annual growth rate (2015/17-2040)
World	67,650	79,443	0.7%	2,064	2,999	1.6%	2,067	3,001	1.6%
China	46,410	56,688	0.9%	1	1	0.0%	436	764	2.5%
Japan	8,254	7,579	–0.4%	439	700	2.0%	50	71	1.5%
South Korea	4,527	4,412	–0.1%	325	270	–0.8%	23	23	0.0%
The U.S.	624	606	–0.1%	18	20	0.5%	744	929	1.0%
The EU	1,378	1,501	0.4%	164	211	1.1%	260	298	0.6%
Egypt	4,116	4,785	0.7%	0	0	-	117	458	6.1%

indica rice consumption is projected to decrease in 2020. Due to the decreasing rice consumption, the indica rice imports in China, Indonesia, and the Philippines are projected to decrease by 9.2%-16.4%. The decreasing of total excess demand in the global indica rice market in 2020 is more than the decreasing of total excess supply in its global market as the equilibrium process of the model projection. As a result, the international price of indica rice is expected to decrease by 2.8% compared with the baseline in 2020.

The world's indica rice consumption and production are expected to decrease by 0.8% compared with the baseline average from 2021 to 2040. The indica rice consumption in India and Bangladesh is expected to decrease by 2.0% and 4.0%, respectively due to the decreasing GDP growth rate. Overall, India and Bangladesh have contributed in decreasing the global indica rice consumption. Most of the rice-producing countries are expected to decrease, and India contributes to decreasing global indica rice production, and its production is projected to decrease by 3.5% due to the decreasing of development and maintenance of infrastructure.[26] The global indica rice imports and exports are expected to decrease by 2.3% compared with the baseline average from 2021 to 2040. Most of the rice imports are expected to decrease because of decreasing rice consumption in many countries and regions. The indica rice imports in the Philippines, Nepal, Bangladesh, and Nigeria are projected to decrease by 6.1%-31.0%. The rice export in India is projected to decrease by 9.9% because the decreasing rate of indica rice production is higher than that of rice consumption. The decreasing of total excess supply in the global indica rice market in the projection period to 2040 is more than the decreasing of total excess demand in its global market as the equilibrium process. Consequently, the international price of indica rice is predicted to increase by 10.3% from 2021 to 2040 compared with the baseline average.

Table 5. Scenario impacts on agricultural investments (scenario/baseline: 2020-2040)

	Agricultural knowledge and innovation system	Development and maintenance of infrastructure
Vietnam	7.4%	7.1%
India	2.4%	–3.3%
China	3.1%	7.9%
The U.S.	2.6%	7.3%
The EU	4.8%	5.5%
The Philippines	–1.5%	–0.9%
Japan	0.1%	–0.9%
South Korea	–0.4%	–0.1%

	Land development	Agricultural machinery & equipment
Thailand	–1.9%	–2.8%
Indonesia	3.2%	–1.1%
Malaysia	0.1%	3.0%
Cambodia	–0.2%	–0.9%
Lao PDR	–5.3%	–4.1%
Myanmar	–0.2%	–0.4%
Bangladesh	–2.8%	–3.4%
Brazil	–1.7%	–1.3%
Côte d'Ivoire	7.4%	6.8%
Egypt	–0.1%	–0.3%
Madagascar	1.7%	4.0%
Nepal	–1.1%	–3.6%
Nigeria	0.3%	1.1%
Pakistan	1.1%	2.3%
Sri Lanka	–1.9%	–2.0%

Note: These numbers show the changing rate from 2020 to 2040 average on the scenario and baseline projection.

[26] The parameter estimate shows that the magnitude of the development and maintenance of infrastructure in India is much higher than that of the agricultural knowledge and innovation system in the indica rice yield equation.

Table 6. Scenario impacts on world rice markets (scenario/baseline)

	2020	2040	2020	2021-2040
	(1,000 t, USD/t)		(1,000 t, USD/t)	
Indica rice market				
Production	419,567	522,757	0.0%	–0.8%
Consumption	415,320	516,347	–0.1%	–0.8%
Imports	34,802	57,944	–2.5%	–2.3%
Exports	34,049	57,944	–2.5%	–2.3%
International indica rice price	588.5	453.9	–2.8%	10.3%
Japonica rice market				
Production	72,309	80,279	0.0%	0.5%
Consumption	72,179	80,175	–0.001%	0.5%
Imports	2,911	2,947	7.7%	1.6%
Exports	2,913	2,950	7.7%	1.6%
International japonica rice price	436.6	670.8	–0.3%	6.9%

Note: The number of 2021-2040 means the changing rate from 2021 to 2040 average on the scenario and baseline projection.

5. Impact of spreading COVID-19 on japonica rice market

In 2020, the world's japonica rice consumption is expected to decrease by 0.001%, its production is not expected to change, compared with the baseline (Table 6). The income elasticity of japonica rice per capita consumption is positive in China and Egypt, but negative in Japan, South Korea, the EU, and the U.S.[27] Due to the decreasing GDP growth rate, japonica rice consumption is predicted to decrease by 0.4% in China. It contributes to decreasing world japonica rice consumption in 2020. Domestic rice production in China is not projected to change, and domestic consumption is projected to decrease. Therefore, the japonica rice exports are projected to increase by 19.5% in China. The decreasing of total excess demand in the global japonica rice market is more in 2020 than the decreasing of total excess supply in its global market as the equilibrium process. Accordingly, the international price of japonica rice is expected to decrease by 0.3% compared with the baseline in 2020.

The world's japonica rice consumption and production are expected to increase by 0.5% compared with the baseline average from 2021 to 2040 (Table 6). In China, the japonica rice consumption is expected to increase by 0.5% due to the increasing GDP growth rate, and its production is projected to increase by 0.6% because of the increasing of the agricultural knowledge and innovation systems and the development and maintenance of infrastructure. The increasing of consumption and production in China, the world's largest japonica rice-producing and consuming country, will contribute to increasing the global japonica rice production and consumption. The global japonica rice imports and exports are expected to increase by 1.6% compared with the baseline average from 2021 to 2040. Rice consumption in Japan is projected to increase due to decreasing GDP growth rate.[28] As a result, the japonica rice import in Japan is predicted to increase. The increasing rate of japonica rice production is higher than that of consumption in China. Therefore, the japonica rice exports in China are projected to increase. China is one of the world's largest japonica rice exporters, and its exports will contribute to increasing the global japonica rice exports. The increasing of total excess supply in the global japonica rice market in the projection period to 2040 is lower than the increasing of total excess demand in its global market as the equilibrium process. Consequently, compared with the baseline average, the international price of japonica rice is expected to increase by 6.9% from 2021 to 2040.

Due to the COVID-19 scenario, the international indica and japonica rice prices are projected to decrease in 2020, but they are projected to increase from 2021 to 2040 compared with the baseline average. The simulation results show that the indica and japonica rice markets are projected to have different impacts. The changing rate of international indica rice price is projected to be higher than that of international japonica rice price from the COVID-19 impact, depending on the income and price elasticity of both per capita rice consumptions and parameters of GDP, rice, and other agricultural commodity prices of agricultural investments.

Conclusions

The model had shown the projection results for global indica and japonica rice markets by incorporating agricultural investments, such as endogenous effects of climate change. Here, we have evaluated how agricultural commodity prices and the GDP growth rate will certainly affect the agricultural investments in the major rice-producing countries represented in the model. The projection suggests how the COVID-19 pandemic will impact the global indica and japonica rice markets in the long term. Because of the COVID-19 scenario, agricultural investments are expected to decrease in the long term in many indica rice-producing countries due to the falling GDP growth rate. In contrast, agricultural investments are expected to increase in the long term in many japonica rice-producing countries due to the increasing GDP growth rate. The increased indica and japonica rice prices also contribute to increasing the agricultural investments, mainly for agricultural knowledge and innovation system. Our findings suggest that the declining agricultural investments will decrease indica rice production, but the increasing agricultural investments will induce increasing japonica rice production. The changing of real per capita GDP growth rate due to the COVID-19 pandemic will decrease the global indica rice consumption but increase the global japonica rice consumption in the long term. Due to the COVID-19 scenario, the international indica and japonica rice prices are projected to decrease in 2020, but they are projected to increase from 2021 to 2040 compared with the baseline average. The simulation results indicate that the japonica rice markets are projected to have less impact than the indica rice markets from COVID-19. The difference between both rice markets is derived

[27] For income elasticity of japonica rice, refer to Koizumi & Furuhashi (2020).

[28] The income elasticities of demand are higher than the own price elasticity in Japan. For these elasticities, refer to Koizumi & Furuhashi (2020).

from the income and own-price elasticity of both rice consumptions. Furthermore, parameters of GDP, rice price, and other agricultural commodity prices of agricultural investment functions affect this result.

We apply IMF's real GDP projection data to the baseline and scenario projections. The IMF data are updated twice a year. Furthermore, these data are used for the assumptions of projected agricultural commodity prices from OECD & FAO. However, these data do not cover the future climate change impact. As the future direction of this study, we continually seek to derive GDP projection data incorporating climate change impacts for the long term and carefully update it regularly. The agricultural investment depends on total GDP, year-lagged indica and japonica rice prices, and other agricultural prices in this study.[29] We recognize that a part of GDP can affect agricultural investments, and the increasing of rice price can contribute to increasing the GDP growth rate in some rice-producing countries. We have not covered these structures in our model yet. Furthermore, the agricultural investment might require more years to obtain its elicit effects for rice production in general, and then these issues are also considered in the next step of this further study. As another issue, the simulated indica and japonica rice prices will increase by the year 2040. However, the other exogenous agricultural commodity prices, which apply the scenario, will decrease by 2030. These exogenous prices are derived from OECD & FAO (2021). The OECD-FAO's Aglink-Cosimo model does not cover endogenous agricultural investments and climate change impact. We must develop a global wheat and other commodity market model incorporating endogenous agricultural investments and climate change impact, which is also the future direction of this study. We recognize that we should incorporate fertilizer and pesticide prices and knowledge infrastructure capital prices into the model as agricultural investment variables. Additionally, more time-series data for agricultural investments and inputs need to be obtained.

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[29] Refer to the agricultural investment equation in the Methods and Data chapter.

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Table A-1. Estimation of parameters for agricultural knowledge and innovation system (1)

	China	t statistics (Year for dummy)	Japan	t statistics (Year for dummy)	South Korea	t statistics (Year for dummy)	Vietnam	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	-	-	-	-	-	-	0.2028	2.5456
a2, domestic price of japonica (t-1/t-2)	0.3837	1.0873	0.0456	1.0468	0.3302	2.2548	-	-
a3, domestic price of wheat (t-1/t-2)	0.2932	1.9193	-	-	-	-	-	-
a4, domestic price of maize (t-1/t-2)	0.2655	1.6526	-	-	-	-	-	-
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	-	-	0.3493	3.7862	0.1642	1.4151	0.2424	1.1822
Constant	6.2007	13.2863	24.2055	94.0602	–22.4565	2.9462	–0.1728	–1.0289
Dummy 1	–0.2710	–2.6579(2008)	0.2770	1.7783(2008)	0.5577	2.4281(1998)	0.1329	2.3031(2010)
Dummy 2	–0.2559	–2.5669(2009)	0.0834	2.6919(2011)	–0.2532	–1.6530(2006)	–0.0745	–1.2292(2014)
Dummy 3	–0.3598	–0.3598(2017)	0.1718	1.1161(2013)	0.2612	2.6518(2001)	–	-
Sample	2003-2018		1987-2018		1988-2009		2003-2015	
R-squared	0.9813		0.8361		0.9216		0.9905	
Adjusted R-squared	0.9767		0.7791		0.8627		0.9837	
Durbin-Watson stat	1.4397		1.5736		2.1765		1.8315	

Note 1: (t-1) and (t-2) means time. Domestic prices and real GDP data are USD based. Variables for a1–a11 are all levels and apply logarithmic transformation.

Note 2: Each dummy year is utilized for excluding political, speculative, and other factors that impact on rice markets.

Table A-2. Estimation of parameters for agricultural knowledge and innovation system (2)

	The Philippines	t statistics (Year for dummy)	India	t statistics (Year for dummy)	The U.S.	t statistics (Year for dummy)	The EU	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.5758	2.9429	0.2916	1.6415	-	-	0.1251	1.9075
a2, domestic price of japonica (t-1/t-2)	-	-	0.2899	4.2680	0.0843	1.8384	0.2866	2.6654
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	0.0807	1.5858	0.2032	2.3341
a4, domestic price of maize (t-1/t-2)	-	-	0.1408	1.6402	0.3223	5.6097	0.2421	1.9377
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	0.0783	1.1953	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	0.1441	2.8093
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.3524	1.0336	-	-	0.3978	1.8563	0.2117	1.4762
Constant	–5.6881	–9.1267	3.8496	12.4889	4.9458	5.6093	5.7763	3.0978
Dummy 1	0.9680	5.3626(2003)	0.6451	3.4896(2010)	–0.0634	–1.9101(1988)	–0.0997	–1.2609(2000)
Dummy 2	0.4023	2.3466(2004)	0.4812	2.5341(2011)	–0.2184	–4.2794(1996)	–0.2580	–3.2899(2002)
Dummy 3	–0.2391	–1.7085(2007)	–0.2765	–1.4921(2016)	–0.0733	–1.5029(2000)	0.2452	3.0615(2013)
Sample	2003-2015		2001-2018		1988-2018		1990-2018	
R-squared	0.9891		0.9195		0.9782		0.9894	
Adjusted R-squared	0.9781		0.8756		0.9637		0.9729	
Durbin-Watson stat	1.7332		1.7662		2.1213		1.7774	

Table A-3. Estimation of parameters for development and maintenance of infrastructure (1)

	China	t statistics (Year for dummy)	Japan	t statistics (Year for dummy)	South Korea	t statistics (Year for dummy)	Vietnam	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	-	-	-	-	-	-	0.3746	2.0586
a2, domestic price of japonica (t-1/t-2)	0.3253	1.4960	0.0485	1.4748	0.1323	1.0861	-	-
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	-	-	-	-
a4, domestic price of maize (t-1/t-2)	0.2288	1.5418	-	-	-	-	-	-
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.2718	18.4467	0.1679	1.0495	-	-	0.1745	1.8242
Constant	6.9657	25.4309	–1.1678	–1.1967	11.3194	6.3945	0.5640	1.3638
Dummy 1	0.3894	2.5771(1998)	–0.2862	–2.8793(2006)	0.5683	3.6121(1996)	–0.3600	–2.4894(2012)
Dummy 2	–0.0167	–0.9339(2007)	0.2988	2.9251(2011)	0.5195	3.2733(1997)	–0.3924	–2.5643(2016)
Dummy 3	–0.2958	–2.0126(2018)	0.2294	2.2216(2012)	–0.3942	–2.3912(2011)	-	-
Sample	1996-2018		1997-2018		1989-2018		2003-2016	
R-squared	0.9683		0.8566		0.8337		0.9594	
Adjusted R-squared	0.9535		0.7992		0.7703		0.9341	
Durbin-Watson stat	1.4542		2.0035		2.1765		2.2128	

Note 1: (t-1) and (t-2) means time. Domestic prices and real GDP data are USD based. Variables for a1–a11 are all levels and apply logarithmic transformation.

Note 2: Each dummy year is utilized for excluding political, speculative, and other factors that impact on rice markets.

Table A-4. Estimation of parameters for development and maintenance of infrastructure (2)

	The Philippines	t statistics (Year for dummy)	India	t statistics (Year for dummy)	The U.S.	t statistics (Year for dummy)	The EU	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.1301	1.5231	0.3422	5.7149	0.2811	2.3350	0.0880	0.9550
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	0.3056	2.1135
a3, domestic price of wheat (t-1/t-2)	-	-	0.2825	2.5605	0.5223	3.5437	0.2614	2.0413
a4, domestic price of maize (t-1/t-2)	-	-	0.2288	1.7735	0.8308	0.9863	0.0758	0.9426
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	0.1223	0.9365	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	0.2427	3.9943
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.1998	1.0883	0.2718	1.2288	0.2689	1.1582	0.1343	1.1027
Constant	–3.3674	–5.9783	5.1907	32.2339	–56.3263	–11.4877	–14.4919	–6.2381
Dummy 1	–0.3737	–2.0635(2006)	–0.2943	–3.5815(2002)	–2.2927	–5.5895(2007)	0.4595	3.9979(2013)
Dummy 2	–0.1875	–1.0381(2011)	0.1963	2.4127(2007)	1.6329	3.5988(2010)	–0.6395	–5.6268(2016)
Dummy 3	0.3609	1.5962(2012)	0.3212	3.9898(2009)	–1.2704	–3.0214(2018)	–0.8085	–7.6719(2017)
Sample	2004-2016		2001-2017		1987-2018		1990-2018	
R-squared	0.9836		0.9899		0.9844		0.9821	
Adjusted R-squared	0.9673		0.9839		0.9731		0.9545	
Durbin-Watson stat	1.6055		2.5635		1.6891		2.2092	

Table A-5. Estimation of parameters for land development (1)

	Thailand	t statistics (Year for dummy)	Indonesia	t statistics (Year for dummy)	Malaysia	t statistics (Year for dummy)	Cambodia	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.2957	1.7175	0.1570	1.4823	0.0388	1.2495	0.1943	3.2224
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	-	-	-	-
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	-	-
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	0.2381	0.9705	0.0224	1.6305	-	-
a7, domestic price of sugar cane (t-1/t-2)	0.0173	1.6711	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.2428	1.7227	-	-	-	-	0.1629	1.1428
Constant	8.9902	165.5831	8.5941	21.0268	7.3843	54.2724	7.7922	50.5442
Dummy 1	–0.0169	–1.8394(1992)	–0.1896	–2.8300(1994)	0.0425	1.6289(1992)	0.2474	3.7537(1981)
Dummy 2	–0.0361	–3.8630(1994)	–0.1691	–2.4337(1996)	0.0585	2.2605(1993)	–0.1019	–2.0238(1985)
Dummy 3	0.0320	3.0014(2007)	0.1375	1.8915(2004)	0.0332	1.2989(1995)	0.0658	1.3141(1991)
Sample	1981-2007		1980-2007		1983-2007		1981-2007	
R-squared	0.9890		0.8045		0.9681		0.9737	
Adjusted R-squared	0.9841		0.7221		0.9454		0.9595	
Durbin-Watson stat	1.5371		1.1314		1.7301		1.8320	

Note 1: (t-1) and (t-2) means time. Domestic prices and real GDP data are USD based. Variables for a1–a11 are all levels and apply logarithmic transformation.
Note 2: Each dummy year is utilized for excluding political, speculative, and other factors that impact on rice markets.

Table A-6. Estimation of parameters for land development (2)

	Lao PDR	t statistics (Year for dummy)	Myanmar	t statistics (Year for dummy)	Bangladesh	t statistics (Year for dummy)	Brazil	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.1302	1.3804	0.1467	7.7120	0.0530	1.9113	0.0474	2.1476
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	-	-	-	-
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	0.0538	2.2864
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	0.0573	1.5280
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	0.0492	1.7810
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.1467	14.7454	0.1302	1.4661	0.2379	8.3889	0.0393	1.7922
Constant	3.0661	16.1613	8.3332	166.9293	0.3252	5.0536	8.3104	29.3232
Dummy 1	–0.1061	–2.6122(1996)	0.1385	2.5206(1982)	0.1386	4.2482(1980)	0.0380	2.3971(1983)
Dummy 2	–0.1001	–2.5218(1997)	–0.1073	–2.2613(2006)	–0.0494	–2.1253(1987)	–0.0254	–1.7406(1986)
Dummy 3	0.1002	2.4049(2000)	0.1510	2.8649(2007)	–0.0473	–2.0727(1994)	0.0602	2.9109(2002)
Sample	1981-2007		1982-2007		1980-2007		1982-2007	
R-squared	0.9769		0.8733		0.9916		0.9956	
Adjusted R-squared	0.9683		0.8240		0.9886		0.9901	
Durbin-Watson stat	1.7473		1.5605		1.4797		2.1799	

Table A-7. Estimation of parameters for land development (3)

	Côte d'Ivoire	t statistics (Year for dummy)	Egypt	t statistics (Year for dummy)	Madagascar	t statistics (Year for dummy)	Nepal	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.0288	1.7005	-	-	0.0483	1.7918	0.0336	1.0960
a2, domestic price of japonica (t-1/t-2)	-	-	0.0449	0.9823	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	-	-	0.0453	0.9047
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	-	-
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	0.0217	1.3774	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.1698	1.7795	0.1212	1.2595	0.2852	17.1299	0.0855	2.2625
Constant	5.9478	13.9443	9.1586	22.8642	9.9367	41.9731	7.0631	43.1394
Dummy 1	–0.0669	–2.0019(1983)	–0.1197	–2.3967(1988)	–0.0460	–2.0824(1988)	–0.0342	–1.3589(1983)
Dummy 2	0.1385	3.9279(1994)	–0.1142	–2.1917(1989)	0.0408	1.8476(1992)	0.0866	3.1472(1993)
Dummy 3	0.1624	3.6371(1995)	0.0653	1.2149(1995)	0.0474	2.1311(1993)	0.0906	3.0711(1995)
Sample	1980-2007		1981-2007		1982-2007		1980-2007	
R-squared	0.9698		0.9315		0.9811		0.9847	
Adjusted R-squared	0.9520		0.8813		0.9704		0.9757	
Durbin-Watson stat	1.5321		1.5908		1.9174		1.5895	

Note 1: (t-1) and (t-2) means time. Domestic prices and real GDP data are USD based. Variables for a1–a11 are all levels and apply logarithmic transformation.
Note 2: Each dummy year is utilized for excluding political, speculative, and other factors that impact on rice markets.

Table A-8. Estimation of parameters for land development (4)

	Nigeria	t statistics (Year for dummy)	Pakistan	t statistics (Year for dummy)	Sri Lanka	t statistics (Year for dummy)	Iran (Rest of the world)	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.0396	1.8264	-	-	0.0245	1.9366	0.0842	2.7742
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	0.0811	2.2132	0.0245	1.0606	-	-	0.0187	1.6633
a4, domestic price of maize (t-1/t-2)	0.0294	0.9696	-	-	-	-	0.1084	3.1205
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.0266	1.3383	0.2148	8.2282	0.1359	8.3090	0.2471	1.6540
Constant	8.5629	95.9335	9.6570	92.9855	6.6847	100.4712	10.1136	83.5820
Dummy 1	0.0375	2.2200(1990)	–0.0313	–2.7142(1990)	0.0281	2.5408(1992)	0.0641	3.2631(1985)
Dummy 2	0.0436	2.5071(1992)	0.0232	0.0231(1998)	–0.0320	–2.9038(2004)	0.0640	3.2805(1986)
Dummy 3	0.0469	2.3734(1993)	-	-	–0.0287	–2.4392(2007)	–0.0995	–3.7968(1995)
Sample	1980-2007		1992-2007		1981-2007		1981-2007	
R-squared	0.9780		0.9819		0.9670		0.9863	
Adjusted R-squared	0.9649		0.9735		0.9571		0.9762	
Durbin-Watson stat	1.9376		1.7117		1.7729		1.8025	

Table A-9. Estimation of parameters for agricultural machinery & equipment (1)

	Thailand	t statistics (Year for dummy)	Indonesia	t statistics (Year for dummy)	Malaysia	t statistics (Year for dummy)	Cambodia	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	-	-	0.1391	2.6089	0.0890	1.1122	0.0196	3.1975
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	-	-	-	-
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	-	-
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	0.1198	3.4756	0.1722	2.1224	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.2452	7.0341	0.2579	2.2397	0.2852	3.8668	0.1629	13.8051
Constant	4.5542	18.3809	9.9675	19.1272	5.1372	18.2615	3.7090	74.8231
Dummy 1	–0.0807	–1.9765(1991)	–0.2183	–3.5703(1995)	–0.1156	–1.7799(1993)	0.0368	5.9949(1991)
Dummy 2	0.0874	1.9894(1996)	0.1569	2.6518(2004)	–0.1489	–2.2958(1995)	0.0100	2.3216(2001)
Dummy 3	–0.1635	–2.1447(2013)	0.1904	2.9199(2006)	0.1411	2.1227(2000)	0.0169	3.4494(2007)
Sample	1981-2007		1983-2007		1981-2007		1991-2007	
R-squared	0.9860		0.8795		0.9513		0.9992	
Adjusted R-squared	0.9798		0.7934		0.9255		0.9986	
Durbin-Watson stat	1.7316		1.4201		1.4414		2.1798	

Note 1: (t-1) and (t-2) means time. Domestic prices and real GDP data are USD based. Variables for a1–a11 are all levels and apply logarithmic transformation.
Note 2: Each dummy year is utilized for excluding political, speculative, and other factors that impact on rice markets.

Table A-10. Estimation of parameters for agricultural machinery & equipment (2)

	Lao PDR	t statistics (Year for dummy)	Myanmar	t statistics (Year for dummy)	Bangladesh	t statistics (Year for dummy)	Brazil	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.0696	1.1856	0.0696	1.7231	0.0271	2.5590	0.0466	1.4254
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	-	-	-	-	-	-	-	-
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	-	-
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	-	-	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.1320	14.1225	0.3209	3.7438	0.2786	11.9788	0.0304	0.9892
Constant	2.2085	44.0984	6.2974	106.8299	6.8387	116.4868	9.6867	138.6705
Dummy 1	0.0765	4.8523(1980)	0.2426	2.6190(1980)	0.0264	3.2412(1990)	0.1120	5.0042(1997)
Dummy 2	–0.0311	–2.7701(1986)	0.2372	3.0495(2001)	0.0248	3.0422(1991)	0.0458	2.5332(2000)
Dummy 3	-	-	0.3135	3.4810(2002)	–0.0164	–2.0525(1996)	0.0738	3.4010(2004)
Sample	1980-2007		1980-2007		1982-2007		2002-2016	
R-squared	0.9976		0.9338		0.9883		0.9586	
Adjusted R-squared	0.9971		0.9007		0.9829		0.9172	
Durbin-Watson stat	1.5392		1.6239		1.4788		1.7055	

Table A-11. Estimation of parameters for agricultural machinery & equipment (3)

	Côte d'Ivoire	t statistics (Year for dummy)	Egypt	t statistics (Year for dummy)	Madagascar	t statistics (Year for dummy)	Nepal	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	0.0258	0.9014	-	-	0.0765	2.0919	0.0455	2.0415
a2, domestic price of japonica (t-1/t-2)	-	-	0.0369	1.1000	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	0.0359	0.9457	-	-	-	-	0.0203	0.9502
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	0.0665	3.2806
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	0.0277	1.7306	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	-	-	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.2497	3.8911	0.2846	9.0669	0.1285	11.9909	0.2570	14.1619
Constant	3.8773	13.5033	2.7619	7.2619	2.1897	9.6167	2.7735	17.8826
Dummy 1	0.0626	2.3099(1993)	0.0154	5.4894(1993)	–0.0620	–2.1921(1987)	–0.0263	–1.8428(1985)
Dummy 2	0.0900	2.6479(1995)	0.2108	5.9538(1994)	–0.0837	–2.8350(1988)	–0.0432	–2.5955(1995)
Dummy 3	–0.0374	–1.5068(2004)	0.2191	3.7666(1996)	–0.0803	–3.0055(1990)	–0.0296	–1.9975(2001)
Sample	1980-2007		1981-2007		1980-2007		1981-2007	
R-squared	0.9727		0.9943		0.9872		0.9979	
Adjusted R-squared	0.9566		0.9880		0.9808		0.9961	
Durbin-Watson stat	1.5056		1.5187		1.6994		2.1985	

Note 1: (t-1) and (t-2) means time. Domestic prices and real GDP data are USD based. Variables for a1–a11 are all levels and apply logarithmic transformation.
Note 2: Each dummy year is utilized for excluding political, speculative, and other factors that impact on rice markets.

Table A-12. Estimation of parameters for agricultural machinery & equipment (4)

	Nigeria	t statistics (Year for dummy)	Pakistan	t statistics	Sri Lanka	t statistics (Year for dummy)	Iran (Rest of the world)	t statistics (Year for dummy)
a1, domestic price of indica (t-1/t-2)	-	-	0.0663	1.1654	0.0837	1.5195	0.1723	1.9044
a2, domestic price of japonica (t-1/t-2)	-	-	-	-	-	-	-	-
a3, domestic price of wheat (t-1/t-2)	0.1205	2.0521	0.0854	1.4269	-	-	0.1238	1.0334
a4, domestic price of maize (t-1/t-2)	-	-	-	-	-	-	0.2728	2.2721
a5, domestic price of soybeans (t-1/t-2)	-	-	-	-	-	-	-	-
a6, domestic price of vegetable oils (t-1/t-2)	0.0606	1.1665	-	-	-	-	-	-
a7, domestic price of sugar cane (t-1/t-2)	-	-	-	-	-	-	-	-
a8, domestic price of ethanol (t-1/t-2)	-	-	-	-	-	-	-	-
a9, domestic price of cotton (t-1/t-2)	-	-	-	-	-	-	-	-
a10, domestic price of roots and tubers (t-1/t-2)	0.0397	0.9578	-	-	-	-	-	-
a11, GDP (t-1/t-2)	0.3942	18.5591	0.3308	1.3908	0.1554	9.3099	0.3886	9.5572
Constant	8.5750	46.7255	11.1303	8.8931	3.2014	16.2566	8.8236	22.0311
Dummy 1	0.0790	1.7992(1982)	-	-	0.0837	1.8153(1983)	–0.2551	–3.5610(1982)
Dummy 2	0.0529	1.4570(1986)	-	-	–0.0746	–2.0834(1996)	–0.2615	–4.0321(1983)
Dummy 3	0.1505	2.5657(1997)	-	-	0.0770	2.1222(2002)	0.1470	2.0105(2007)
Sample	1982-2007		1988-2007		2002-2016		1982-2007	
R-squared	0.9777		0.9759		0.9586		0.9812	
Adjusted R-squared	0.9628		0.9585		0.9172		0.9687	
Durbin-Watson stat	1.9450		1.7307		1.7055		2.1460	

Table A-13. Exogenous variables for per capita GDP growth rate (real)

	Baseline		COVID-19 Scenario	
	2020	2021-2040	2020	2021-2040
Thailand	5.2%	5.8%	–6.6%	5.4%
Vietnam	7.8%	7.5%	2.4%	8.3%
Indonesia	7.2%	6.1%	–3.8%	6.1%
Malaysia	3.1%	5.9%	–8.9%	7.7%
India	7.7%	8.2%	–10.5%	7.8%
China	7.7%	8.0%	2.9%	9.0%
Japan	5.4%	4.1%	–3.0%	4.6%
South Korea	–0.6%	4.7%	–3.8%	5.0%
The U.S.	3.6%	3.1%	–3.4%	3.9%
The EU	3.5%	3.5%	–6.5%	4.8%
Cambodia	6.8%	6.9%	–3.0%	7.3%
Lao PDR	9.3%	7.2%	–3.5%	4.9%
Myanmar	8.5%	8.5%	2.6%	8.6%
The Philippines	5.8%	7.6%	–4.0%	7.3%
Bangladesh	8.5%	8.3%	4.0%	7.9%
Brazil	1.4%	1.7%	–6.4%	1.8%
Côte d'Ivoire	6.1%	6.2%	2.3%	7.2%
Egypt	4.0%	4.3%	–0.3%	3.4%
Madagascar	5.8%	5.0%	–2.0%	6.0%
Nepal	12.3%	7.7%	3.4%	6.5%
Nigeria	8.0%	8.7%	–3.6%	9.0%
Pakistan	0.5%	2.7%	–3.4%	2.0%
Sri Lanka	5.2%	6.4%	–4.0%	6.6%
Iran	–0.1%	4.5%	3.5%	3.6%

Source: IMF (2020)

Table A-14. Exogenous variables for growth rate of agricultural commodity prices

(USD/t)

	Baseline			COVID-19 Scenario	
	2015/17	2020	2040	2020	2040
Wheat	213	212	207	246	212
Maize	160	165	161	199	167
Soybeans	401	386	387	490	413
Vegetable oil	762	759	751	941	841
White sugar	429	390	382	409	394
Ethanol	44	39	42	38	43
Cotton	1,773	1,621	1,514	1,650	1,606
Roots & tubers	371	473	458	470	468

Sources: OECD-FAO (2020) and OECD-FAO (2021)