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Impact of Agricultural Investments on World Wheat Market under Climate Change: Effects of Agricultural Knowledge and Innovation System, and Development and Maintenance of Infrastructure

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Abstract

The role of agricultural investment growth in alleviating climate risks for wheat production systems and markets was examined using a partial equilibrium model, the Wheat Economy Climate Change (WECC) model, which covers the wheat markets of 10 countries and two regions. This study examines how future agricultural investments will affect the world wheat market. The volatility of international wheat prices at baseline is expected to increase in 2014-2016 and until 2040 because of climate change. However, a constant increase in agricultural investments in major producing countries will contribute to international wheat price stability. In particular, agricultural investments in Russia are crucial for stabilizing international wheat prices in mid-long term under future climate change conditions.

Discipline: Agricultural economics
Additional key words: partial equilibrium model, wheat price, price stability in mid-long term, Russia and Ukraine

Introduction

The increase in global mean surface temperatures in 2081-2100 relative to 1986-2005 is estimated between 0.3°C and 4.8°C, depending on representative concentration pathways (RCPs). Agricultural production will thus be affected by this climate change in different ways, including changes in yield and harvested area. Numerous studies exist on how future climate change could impact global agricultural production. For instance, Lobel (2007) examined the changes in diurnal temperature range and national cereal yield, and Furuya et al. (2015) developed yield-response functions for the world food model to evaluate climate change effects by incorporating a crop model into the yield-trend functions[1]. Moreover, Furuya and Koyama (2005) examined how climate change will impact world grain markets, and Koizumi and Kanamaru (2016) examined how agricultural investments, based on FAO data, will impact rice price volatility under climate change. After remaining at historic lows for decades, food prices have significantly increased and become more volatile since 2007. Price volatility has a strong impact on food security in developing countries (Food and Agriculture Organization, FAO 2011). Moreover, the coefficient of variation (CV) for international wheat prices was 0.1664 from 1985 to 1995, 0.2425 from 1996 to 2005, and 0.2645 from 2006 to 2015[2]; therefore, the volatility is increasing. FAO (2011) concluded that agricultural investments could reduce food price volatility through increased productivity and improved technical management of production risk, especially in the face of climate change. This report was based on policy implications for policy makers and did not conduct simulation analysis. Koizumi and Kanamaru

[1] For further studies, please refer to Koizumi and Kanamaru (2016).

[2] Calculated from the monthly wheat price (Wheat, No. 1 Hard Red Winter, ordinary protein, Kansas City).

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(2016) were the first to evaluate how future agricultural investments will impact the world rice market, especially the volatility of international rice prices, by factoring in future climate change. This study examines how agricultural investment will contribute to stabilizing world wheat market by factoring future climate change. This study utilizes Organisation of Economic Co-Operation and Development (OECD)-based agricultural investment data on developed countries and FAO-based data on developing countries to conduct simulations for alleviating climate risks for wheat production systems and markets through a partial equilibrium model.

Structure of the WECC model and data for regression

The Wheat Economy Climate Change (WECC) model covers the wheat markets in 10 countries and two regions (EU28, China, India, USA, Russia, Ukraine, Canada, Australia, Argentina, Indonesia, Egypt, and the rest of the world). The model also covers Germany, France, and other EU production to aggregate EU wheat production. The base year range is 2014-2016 (3-year average for 2014-2016). Each country's market consists of production, consumption, exports, imports, and ending stock until 2040. The WECC model covers equations for projecting wheat yield and planted area affected by climate change (Fig. 1). This study applied an Error Correction Model in order to evaluate the long-run equilibrium relationships among economic variables.

The wheat yield equation for developed countries depends on annual flowering season averages of temperature, precipitation, amount of solar radiation, and lagging investments[3]. The wheat-planted area

[3] Constant term and time trend are estimated; however they are not applied for projections. Instead of statistically estimated constant term and time trend, this study applied a coefficient of calibration to improve reality for the model projection activity. The coefficient of calibration obtained to correct each market activity of the first projection year (2017) is equivalent to the updated estimation data (2017) published by USDA-FAS (2017).

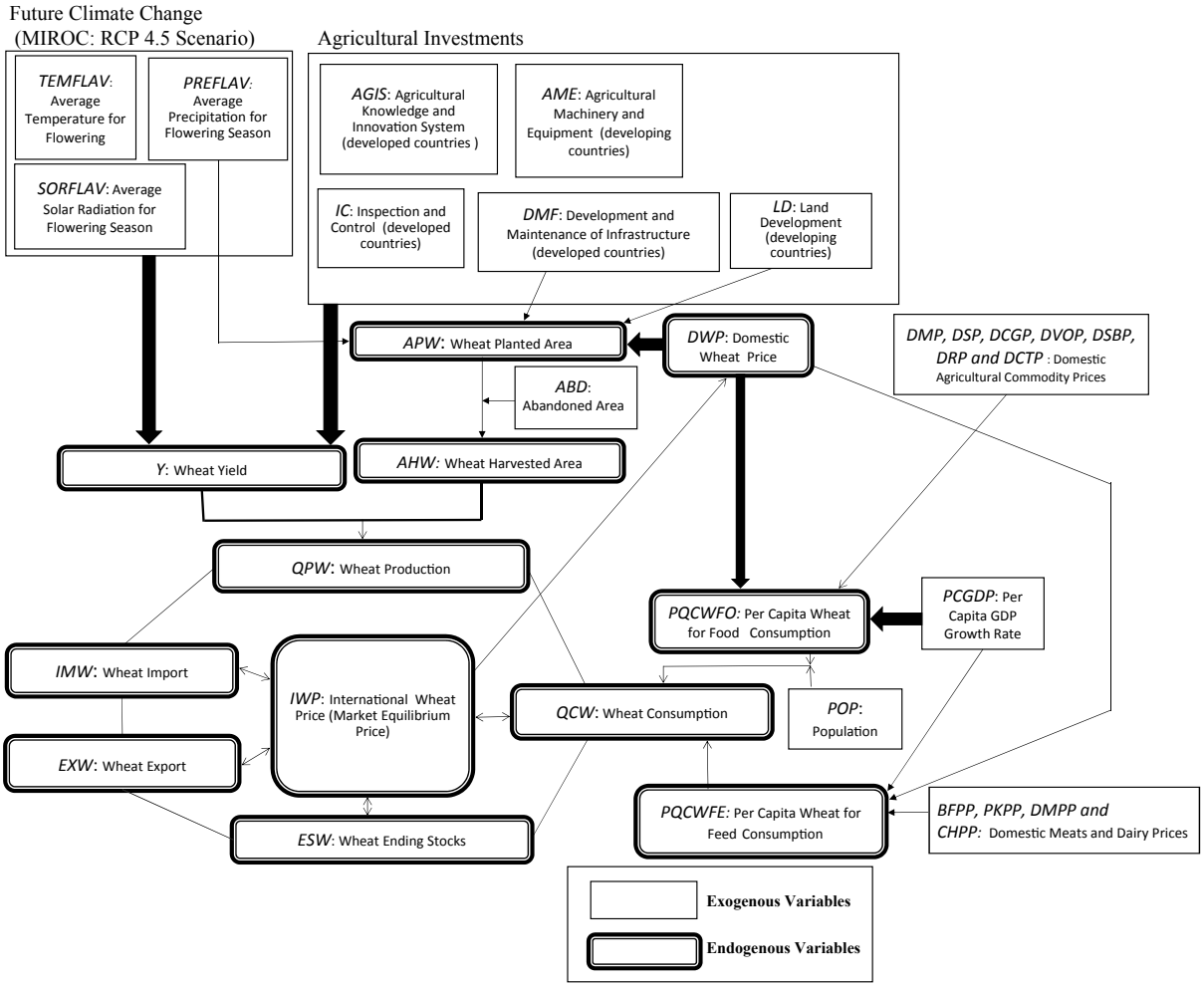

Fig. 1. Structure of the WECC model

equation depends on the domestic prices of wheat, competitive commodity prices, precipitation, and lagging investments. Changing rate from current to previous year of climate variables and price variables effect on wheat yield and wheat-planted area. The lagged changing rate of agricultural investment variables effect on wheat yield and wheat-planted area. They mean that agricultural investments can impact wheat yield and wheat-planted area with a lag, different from climate and price variables. The WECC model is developed as a new model to cover agricultural investment variables derived from both OECD and FAO. The model also covers different climate variables from a rice model (RECC model)[4]. Consequently, the model approach is different from Koizumi and Kanamaru (2016), and the model has originality to differ from the previous model approaches.

The wheat-harvested area is derived from the difference between the planted and abandoned areas. Further, wheat production is calculated by multiplying the harvested area and wheat yield as follows:

$$\ln(Y_{t,c}/Y_{t-1,c}) = a1 \ln(TEMFLAV_{t,c}/TEMFLAV_{t-1,c}) + a2 \ln(PREFLAV_{t,c}/PREFLAV_{t-1,c}) + a3 \ln(SORFLAV_{t,c}/SORFLAV_{t-1,c}) + a4 \ln(AGIS_{t-1,c}/AGIS_{t-2,c}) + a5 \ln(DMF_{t-1,c}/DMF_{t-2,c}) + a6 \ln(IC_{t-1,c}/IC_{t-2,c}) + a7 \ln(LD_{t-1,c}/LD_{t-2,c}) + a8 \ln(AME_{t-1,c}/AME_{t-2,c})^{5} \quad 1)$$

$$\ln(APW_{t,c}/APW_{t-1,c}) = a9 \ln(DWP_{t,c}DWP_{t-1,c}) + a10 \ln(PRCAV_{t,c}/PRCAV_{t-1,c}) + a11 \ln(DMP_{t,c}/DMP_{t-1,c}) + a12 \ln(DSP_{t,c}/SP_{t-1,c}) + a13 \ln(DCGP_{t,c}/DCGP_{t-1,c}) + a14 \ln(DVOP_{t,c}/DVOP_{t-1,c}) + a15 \ln(DSBP_{t,c}/DSBP_{t-1,c}) + a16 \ln(DRP_{t,c}/DRP_{t-1,c}) + a17 \ln(DMF_{t-1,c}/DMF_{t-2,c}) + a18 \ln(DCTP_{t,c}/DCTP_{t-1,c}) + a19 \ln(LD_{t-1,c}/LD_{t-2,c})^{6} \quad 2)$$

$$AHW_{t,c} = APW_{t,c} - ABD_{t,c}^{7} \quad 3)$$

$$QPW_{t,c} = AHW_{t,c} * Y_{t,c}^{8} \quad 4)$$

The per capita wheat consumption for food depends on income, domestic prices of wheat and rice, and time trend. The per capita wheat consumption for feed depends on income, domestic wheat price, beef, pork, and cheese prices[9].

$$\ln(PQCWFO_{t,c}/PQCWFO_{t-1,c}) = a20 \ln(PCGDP_{t,c}/PCGDP_{t-1,c}) + a21 \ln(DWP_{t,c}/DWP_{t-1,c}) + a22 \ln(DRP_{t,c}/DRP_{t-1,c})^{10} \quad 5)$$

$$QCWFO_{t,c} = PQCWFO_{t,c} * POP_{t,c}^{11} \quad 6)$$

$$\ln(QCWFE_{t,c}/QCWFE_{t-1,c}) = a23 \ln(GDP_{t,c}/GDP_{t-1,c}) + a24 \ln(DWP_{t,c}/DWP_{t-1,c}) + a25 \ln(BFPP_{t,c}/BFPP_{t-1,c}) + a26 \ln(PKPP_{t,c}/PKPP_{t-1,c}) + a27 \ln(CHPP_{t,c}/CHPP_{t-1,c})^{12} \quad 7)$$

$$QCW_{t,c} = QCWFO_{t,c} + QCWFE_{t,c}^{13} \quad 8)$$

For net wheat exporting countries, wheat imports are based on domestic wheat price. Wheat exports are calculated by the exportable domestic market balance

[4] In the RECC model, the paddy rice yield equation depends on the annual averages of minimum temperature, maximum temperature, precipitation, lagging investments in land development and agricultural machinery & equipment, and time trend (Koizumi and Kanamaru 2016).

[5] *Y* is wheat yield, *TEMFLAV* is the average temperatue of the flowering season, *PREFLAV* is the average precipitation of the flowering season, *SORFLAV* is the average of the amount of solar radiation of the flowering season, *AGIS* is the investment amount of agricultural knowledge and innovation system, *DMF* is that of development and maintenance of infrastructure, *IC* is that of inspection and control, *LD* denotes that of agricultural land development, *AME* denotes that of agricultural machinery/equipment, *c* denotes countries/region, and a1-a8 are parameters. Tables A1-1, A1-2, and A1-3 list these estimated parameters.

[6] *APW* is the planted area of wheat, *DWP* is the domestic wheat price, *PRCAV* is the average precipitation, *DMP* is the domestic corn price, *DSP* is the domestic soybean price, *DCGP* is the domestic coarse grain price, *DVOP* is the domestic vegetable oil price, *DSBP* is the domestic white sugar price, *DRP* is the domestic rice price, *DCTP* is the domestic cotton price, *LD* is the lagging investment in agricultural land development, and a9-19 are parameters. Tables A2-1, 2-2, and 2-3 list these estimated parameters.

[7] *AHW* is the harvested area, and *ABD* is the abandoned area. The abandoned area is an exogenous variable and will be utilized for simulation in future studies.

[8] This equation is a feed demand element function for livestock production; however, the impact of income elasticity is bigger than that of price elasticity. Consequently, income elasticity is incorporated into this equation.

[9] This equation is a feed demand element function for livestock production; however, the impact of income elasticity is bigger than that of price elasticity. Consequently, income elasticity is incorporated into this equation.

[10] *PQCWFO* is the per capita wheat consumption for food, *PCGDP* is the per capita GDP (constant price), and a20-a22 are parameters. Tables 3-1, 3-2, and 3-3 list these estimated parameters.

[11] *QCWFO* is the wheat consumption for food, and *POP* is the population.

[12] *QCWFE* is the wheat consumption for feed, *GDP* is the GDP (constant price), *BFPP* is the domestic beef price, *PKPP* is the domestic pork price, *CHPP* is the domestic cheese price, and a23-a27 are parameters. Tables 4-1 and 4-2 list these estimated parameters.

[13] *QCW* is wheat consumption.

deficit remaining after the domestic market has been satisfied.

$$\ln (IMW_{t,c}/IMW_{t-1,c}) = a28 \ln (DWP_{t,c}/DWP_{t-1,c})^{14} \quad 9)$$

$$EXW_{t,c} = QPW_{t,c} - QCW_{t,c} + IMW_{t,c} - (ESW_{t,c} - ESW_{t-1,c})^{15} \quad 10)$$

For net wheat importing countries, wheat exports depend on international wheat price. Wheat imports are calculated by the exportable domestic market balance deficit remaining after the domestic market has been satisfied as follows:

$$\ln (EXW_{t,c}/EXW_{t-1,c}) = a29 \ln (IWP_t/IWP_{t-1})^{16} \quad 11)$$

$$IMW_{t,c} = QCW_{t,c} - QPW_{t,c} + EXW_{t,c} + (ESW_{t,c} - ESW_{t-1,c}) \quad 12)$$

Wheat ending stocks depend on domestic wheat price. The domestic wheat price is based on the international wheat price as follows:

$$\ln (ESW_{t,c}/ESW_{t-1,c}) = a30 \ln (DWP_{t,c}/DWP_{t-1,c})^{17} \quad 13)$$

$$\ln (DWP_{t,c}/DWP_{t-1,c}) = a31 \ln (IWP_{t,c}/IWP_{t-1,c})^{18} \quad 14)$$

The model determines the production, consumption, imports, and ending stocks for each simulation year. The wheat market clearing price is obtained from the following equilibrium conditions using the *Gauss–Seidel algorithm*: Wheat, No. 1 Hard Red Winter, ordinary protein, Kansas City, which refers to the international wheat market clearing price[19].

$$\Sigma \quad IMW_{t,c} = \Sigma \quad EXW_{t,c} \quad 15)$$

Historical temperatures, precipitation, and solar radiation data are derived from CRU TS 3.2 (University of East Anglia). For larger countries, the values for the grids that correspond to major wheat-producing areas are averaged[20]. For the other countries, the values for all grids that cover the entire territory are spatially averaged. The historical yield, planted area, harvested area, production, per capita consumption, imports, exports, and ending stock data for wheat[21] are derived from Production, Supply and Distribution (PS&D) (USDA-FAS 2017). This study defines wheat producer price as the domestic wheat price, derived from FAOSTAT (FAO). These data are used for regression in the time-series analysis.

Baseline assumptions and scenarios

The baseline outlook adopts a set of assumptions for the general economy, agricultural policies, and technological changes without any policy shock during the outlook period. The climate variables (temperatures, precipitation, and amount of solar radiation) for both the baseline outlook and policy scenario come from the climate change projections of the Model for Interdisciplinary Research on Climate (MIROC), a global climate model under the RCP 4.5 scenario. Spatially averaged climate variables for each country are computed similarly to the historical climate data used for regression. The flowering seasons for model covered countries differ as Table 1. The standard deviations for temperature, precipitation, and solar radiation during the flowering season in most analyzed countries are projected to increase in 2017-2040 compared to 1980-2009 (Tables 2, 3, and 4). The exogenous variables for per capita GDP growth rate, population, international commodity prices, and livestock production are listed in Tables A9-1 and A9-2[22]. This study assumes that current agricultural and trade policies will continue, and abandoned areas will become zero in all countries throughout the outlook

[14] *IMW* is wheat import, and a28 is a parameter. Tables A5-1 and 5-2 lists the estimated parameters.

[15] *EXW* denotes wheat exports, and *ESW* is the ending stocks of wheat.

[16] a29 is a parameter. *IWP* is the international wheat price. Table A6 lists the estimated parameters.

[17] a30 is a parameter. Tables A7-1, A7-2, and A7-3 list the estimated parameters.

[18] a31 is a parameter. A8-1 and A8-2 list the estimated parameters.

[19] Wheat is categorized into four types (hard wheat, soft wheat, intermediate quality wheat, and durum) for its application. Among them, hard wheat, especially for *Wheat, No. 1 Hard Red Winter, ordinary protein, Kansas City,* is most typically utilized for world wheat trade.

[20] West Australia for Australia, Saskatchewan State for Canada, Kansas State for USA, Punjab for India, North China Region for China, and Southern Russia (Black Sea Coastal Area) for Russia.

[21] 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.

[22] The population data for all countries were obtained from the 2017 Revision (medium variant) of World Population Prospects, United Nations (2017). The per capita real GDP was also treated as an exogenous variable, and GDP growth rate assumptions were based on World Economic Outlook 2017 (IMF 2017). These GDP growth rates are available up to 2022. This study assumes that the average per capita GDP growth rate from 2017 to 2022 in each country will continue to be the same in 2023-2040. Competing commodity prices and domestic livestock production are derived from OECD-FAO Agricultural Outlook 2017-2026 (OECD-FAO 2017).

Table 1. Planning, Harvesting and flowering seasons for model covered countries

Countries	Planting	Harvesting	Flowering
Germany (EU)	October	August	June to July
France (EU)	October to November	July to August	May to June
Poland (EU)	September to October	July to August	May to June
China	October to November	May to June	April to May
India	October to November	April to May	February to March
USA	September to October	June to August	May to June
Russia	August to September	July to August	June
Ukraine	August to September	July to August	June
Canada	May to June	June to October	June to July
Australia	April to June	October to December	August to September
Argentina	May to July	November to January	September to October
Egypt	September to October	April to August	March to April
Pakistan (The rest of the world)	October to December	March to April	February to March

Table 2. Standard deviations for the average temperature (°C) during the flowering season

	1980-1989	1990-1999	2000-2009	2017-2026 (Projection)	2027-2040 (Projection)
German (EU)	1.1193	0.6820	1.1283	0.4553	0.8672
France (EU)	1.0648	0.7556	0.4560	0.6994	0.7473
Poland (EU)	0.9657	0.9118	1.0141	1.0808	0.9868
China	0.3145	0.8586	0.4877	0.7367	2.2790
India	0.8275	0.7211	0.8361	0.9056	1.1104
USA	1.0382	1.0768	0.5719	0.7718	1.1870
Russia	1.4340	1.2104	0.5957	1.0770	0.8453
Ukraine	1.0610	1.3199	0.9755	1.3926	1.1375
Canada	1.0491	1.0723	1.1027	1.4069	0.7741
Australia	0.7620	0.6974	0.5486	0.6989	0.6632
Argentina	0.4872	0.2416	0.6635	0.9171	0.7326
Egypt	1.0264	0.8066	0.8038	0.9015	1.1727
Pakistan (The rest of the world)	1.0943	0.6800	0.9708	0.8186	1.4280

Table 3. Standard deviations for the average precipitation (mm) during the flowering season

	1980-1989	1990-1999	2000-2009	2017-2026 (Projection)	2027-2040 (Projection)
German (EU)	19.8870	10.6641	16.0834	10.8339	16.4337
France (EU)	18.1433	14.7955	17.4974	10.3621	7.2470
Poland (EU)	7.5331	9.9083	17.2434	18.0844	19.7753
China	12.0804	13.6838	19.5637	10.4693	13.9853
India	5.1607	6.9931	7.2761	8.7790	11.9685
USA	16.4108	17.2637	18.3846	15.1192	23.5297
Russia	9.0648	10.6106	9.4302	13.4176	12.6190
Ukraine	13.5169	18.0339	7.2924	26.9470	28.4940
Canada	10.9840	17.0611	9.7627	11.5968	12.8768
Australia	7.5456	9.9710	7.6615	9.5303	6.3625
Argentina	21.6510	12.5778	25.1198	21.3412	20.1479
Egypt	0.1322	0.4566	0.2514	3.1710	2.2699
Pakistan (The rest of the world)	9.0684	5.0736	13.2703	8.1918	11.9762

period.

This study applies the *Agricultural knowledge and innovation system*[23], *development and maintenance of infrastructure*[24], *and inspection and control*[25] for Australia, Canada, the USA, the EU, Russia, and Ukraine. These time-series data are derived from *OECD General Service Support Estimates* (GSSE) (OECD)[26]. *Land development*[27] and *agricultural machinery and equipment* are applied for other countries (India, China, Egypt, Argentina, and Pakistan (the rest of the world)). Both OECD and FAOSTAT agricultural investment data can be used not only for wheat but also for other crops. However, this study covers major wheat-producing countries. Therefore, it assumes that these agricultural investments will be mainly used for wheat production, and the current growth rate of *agricultural knowledge and innovation system*, *development and maintenance of infrastructure*, and *inspection and control* from 2006 to 2015 for Australia, Canada, the USA, and the EU will continue during the outlook period (2017-2040)[28] (Table 5). We also assume that the current growth rate of *agricultural knowledge and innovation system*, and *development and maintenance of infrastructure* from 2006 to 2011 in Russia and Ukraine will continue during the outlook period[29]. This study also assumes that the current growth rate of *land development* and *agricultural machinery and equipment* from 1990 to 2007 in other countries (India, China, Egypt, Argentina, and Pakistan (the rest of the world)) will continue during the outlook period (Table 6)[30].

This study applied alternative scenarios to the baseline outlook. This study examines the impact of agricultural investment on world wheat markets. Consequently, this study applied the growth rate of agricultural investments will be zero for major producing countries as scenarios. The growth rates of agricultural knowledge and innovation system, and development and maintenance of infrastructure in Australia under scenario 1, that in the USA under scenario 2, that in Russia under scenario 3, and that in Ukraine under

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

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

[25] *Inspection and control* covers agricultural product safety and inspection, pest and disease inspection and control, and input control.

[26] GSSE is summed up by all types of agricultural indicators by OECD and not assumed to have inflation problems for targeted countries (Interviewed from OECD Trade and Agriculture Directorate, 2018.4).

[27] *Land development* is the result of actions leading to major improvements in land quantity, quality, or productivity, or which prevent its deterioration. These time-series data are derived from FAOSTAT (FAO). These data are summed up by the same methods of GSSE and not assumed to have inflation problems.

[28] The growth rates of investments in *development and maintenance of infrastructure* in the USA from 2006 to 2015 were 10.9% on average, which seems too high. Instead, we apply the growth rates from 2012 to 2015 for USA (0.7%) to the baseline outlook period.

[29] The growth rates of investments in *development and maintenance of infrastructure* in Russia from 2006 to 2011 were 18.5%, which seems too high. Instead, we apply the growth rates from 2005 to 2007 for Russia (2.7%) to the projection period.

[30] The growth rates of *agricultural machinery & equipment* in India from 1990 to 2007 were 6.6%, which seems too high. As a result, this study applies the growth rate from 2003 to 2004 for India (2.4%) to the projection period.

Table 4. Standard deviations for the average amount of solar radiation (MJ/day) during the flowering season

	1980-1989	1990-1999	2000-2009	2017-2026 (Projection)	2027-2040 (Projection)
German (EU)	1.5030	0.7520	1.4370	0.7720	0.8888
France (EU)	1.0637	0.8383	1.0883	0.9437	0.7118
Poland (EU)	1.0032	1.2344	0.6923	1.1887	1.0050
China	0.5721	0.9583	1.0214	0.6597	1.4808
India	0.1395	0.2106	0.3365	0.6575	0.7047
USA	0.3528	0.3018	0.3456	0.4609	0.7369
Russia	0.1295	0.4355	0.6760	0.4183	0.3737
Ukraine	0.5686	1.0536	1.0219	0.8330	0.7486
Canada	0.3624	0.5306	0.3086	0.3342	0.5653
Australia	0.2140	0.2179	0.1528	0.3191	0.3578
Argentina	0.3624	0.3466	1.0090	0.7890	0.4236
Egypt	0.1657	0.5272	0.1542	0.6438	0.5546
Pakistan (The rest of the world)	0.1248	0.1807	0.3592	0.5879	0.7519

scenario 4 are hypothesized to be zero from 2017 to 2040. This study focuses on the OECD-based agricultural investment impact on world wheat market and wheat price stability[31], which means that it does not target scenario simulation for FAO-based *land development* and *agricultural machinery, and equipment* in China, India, and Argentina.

[31] Among model covered countries, this study assumes that the *development and maintenance of infrastructure* in Canada will decrease during the projection period. Therefore, Canada is excluded from the scenario targeting countries. The agricultural investment data for EU member countries do not appear in the *OECD General Service Support Estimates* data. This study focuses on the country-based agricultural investment impact on the world wheat market and wheat price volatility. Therefore, it excludes the EU from the scenario simulation countries.

Table 5. Growth rate (%) of agricultural investments in developed countries, Russia and Ukraine

Country	Agricultural investments	1986-1995	1996-2005	2006-2015	2006-2010	2012-2015
Australia	Agricultural knowledge and innovation system	12.7	5.0	1.8	0.4	0.6
	Development and maintenance of infrastructure	-	26.3	2.4	-13.4	8.0
Canada	Agricultural knowledge and innovation system	1.8	1.2	1.4	2.9	0.3
	Development and maintenance of infrastructure	-6.7	2.4	-2.9	-6.0	6.9
USA	Agricultural knowledge and innovation system	3.7	2.5	2.6	-0.3	-0.5
	Development and maintenance of infrastructure	9.0	48.5	10.9	-7.8	0.7
EU	Agricultural knowledge and innovation system	6.9	5.2	3.0	4.0	4.0
	Inspection and control	-0.8	14.4	1.6	-4.4	2.0
	Development and maintenance of infrastructure	4.5	6.0	-0.3	2.8	0.5
		1986-1995	2005-2007	2006-2011	2005-2007	
Russia	Agricultural knowledge and innovation system	34.2	2.3	16.0	2.3	
	Development and maintenance of infrastructure	10.5	18.5	2.7	18.5	
Ukraine	Agricultural knowledge and innovation system	25.2	16.3	2.3	6.9	
	Development and maintenance of infrastructure	12.8	13.2	1.5	15.9	

Table 6. Growth rate (%) of agricultural investments in other countries

Country	Agricultural investments	1975-1985	1985-1995	1996-2007	1990-2007	2003-2004
India	Land Development	1.1	1.2	0.7	0.9	-0.1
	Agricultural machinery & equipment	7.2	5.9	7.4	6.6	2.4
China	Land Development	1.1	1.1	0.8	0.9	2.0
	Agricultural machinery & equipment	7.0	-0.8	7.6	4.4	4.1
Egypt	Land Development	-1.2	2.7	0.6	1.7	0.1
	Agricultural machinery & equipment	6.1	3.9	1.1	2.7	5.9
Argentina	Land Development	2.4	2.2	1.9	1.8	2.2
	Agricultural machinery & equipment	6.0	1.8	-0.1	0.6	-1.3
Pakistan	Land Development	1.2	0.8	0.7	1.0	1.9
(The rest of the World)	Agricultural machinery & equipment	13.6	5.4	0.6	1.4	0.3

Results

Under the baseline assumptions, world wheat production is expected to increase at a rate of 1.3% per annum from 2014-2016 to 2040 (Table 7), and consumption is expected to increase at a rate of 1.4% per annum from 2014-2016 to 2040 (Table 8). World wheat exports and imports are expected to increase at a rate of 2.5% per annum during the same period (Table 8). World wheat ending stocks are expected to decrease at a rate of 0.1% per annum during the same period. The international wheat price is projected to increase from 190.0 USD/t in 2014-2016 to 208.9 USD/t in 2040[32]. The CV of international wheat price from 2014/2016 to 2040 is 0.3159.

Outlooks were made using various agricultural investment scenarios in selected countries for comparison against the baseline outlook. These agricultural investments can be considered to be working as climate change adaptation measures. Under scenario 1, Australian wheat production is expected to decrease

[32] The projected price is constant price.

Table 7. World wheat yield, harvested area and production (baseline outlook)

	Yield (MT/ha)			Harvested area (1,000 ha)			Production (1,000 MT)		
	2014-16	2040 (Projection)	Growth rate (%) (2014/16-2040)	2014-16	2040 (Projection)	Growth rate (%) (2014/16-2040)	2014-16	2040 (Projection)	Growth rate (%) (2014/16-2040)
World	-	-	-	160,386	226,203	1.4	739,981	1,009,417	1.3
EU	-	-	-	26,966	23,367	-0.6	154,364	183,216	0.7
France (EU)	6.8	8.8	1.1	5,436	4,710	-0.6	36,987	41,682	0.5
Germany (EU)	8.1	10.0	0.9	3,235	3,045	-0.3	26,266	30,571	0.6
Other EU	5.0	7.1	1.5	18,295	15,612	-0.7	91,111	110,962	0.8
China	5.3	6.5	0.8	24,133	18,837	-1.0	128,416	121,732	-0.2
India	2.9	3.9	1.2	30,721	28,887	-0.3	89,793	112,411	0.9
USA	3.1	4.3	1.3	18,561	17,092	-0.3	58,041	73,938	1.0
Russia	2.5	4.9	2.8	25,406	29,921	0.7	64,218	145,175	1.0
Ukraina	4.0	3.8	-0.2	6,622	6,699	0.0	26,275	25,315	2.0
Canada	3.2	2.6	-0.8	9,312	15,425	2.1	29,571	40,565	1.3
Australia	2.2	2.8	1.1	12,676	12,190	-0.2	27,673	34,388	0.9
Argentina	3.0	3.2	0.3	4,701	4,384	-0.3	14,243	14,042	2.0
Indonesia	0.0	0.0	-	0	0	-	0	0	-
Egypt	6.3	5.5	-0.6	1,290	1,640	1.0	8,167	9,073	0.4

Table 8. World wheat consumption, exports and imports (baseline outlook)

	Consumption (1,000 MT)			Exports (1,000 MT)			Imports (1,000 MT)		
	2014-16	2040 (Projection)	Growth rate (%) (2014/16-2040)	2014-16	2040 (Projection)	Growth rate (%) (2014/16-2040)	2014-16	2040 (Projection)	Growth rate (%) (2014/16-2040)
World	715,017	1,011,141	1.4	173,103	314,167	2.5	169,391	314,166	2.5
EU	127,676	122,108	-0.2	32,380	66,830	3.1	6,065	5,752	-0.2
China	115,667	195,179	2.2	777	765	-0.1	3,401	74,470	13.7
India	93,051	134,733	1.6	1,646	4,340	4.1	2,139	26,596	11.1
USA	31,649	42,504	1.2	24,469	36,930	1.7	3,466	3,614	0.2
Russia	37,500	35,333	-0.2	25,381	110,075	6.3	550	330	-2.1
Ukraina	11,333	12,506	0.4	15,567	12,769	-0.8	31	24	-1.1
Canada	9,041	13,410	1.7	22,183	28,879	1.1	491	543	0.4
Australia	7,462	7,787	0.2	18,905	26,064	1.3	153	176	0.6
Argentina	6,050	8,461	1.4	8,867	5,596	-1.9	17	17	0.0
Indonesia	8,655	14,091	2.1	286	363	1.0	9,198	14,473	1.9
Egypt	19,333	26,754	1.4	466	966	3.1	11,575	18,658	2.0

by 6.9% and exports by 8.7% compared to the baseline outlook average from 2017 to 2040. Consequently, the international wheat price is expected to increase by 1.6% (Table 9). Under scenario 2, the US wheat production is expected to decrease by 5.3%, and exports by 9.4% compared to the baseline outlook average from 2017 to 2040. Consequently, the international wheat price is expected to increase by 3.0% (Table 9). Under scenario 3, Russian wheat production is expected to decrease by 16.0%, and exports by 27.9% compared to the baseline outlook average from 2017 to 2040. World wheat production and consumption are expected to decrease by 0.6%, and world wheat exports and imports to decrease by 1.8%. Consequently, the international wheat price is expected to increase by 11.0% (Table 9). In scenario 4, Ukrainian wheat production is expected to decrease by 18.8%, and exports by 31.5% compared to the baseline outlook average from 2017 to 2040. World wheat production and consumption are expected to decrease by 0.2%, and world wheat exports and imports to decrease by 0.7%. Consequently, the international wheat price is expected to increase by 3.8% (Table 9).

The CVs of the international wheat prices from 2014-2016 to 2040 in all scenarios are higher than those in the baseline outlook (Table 10). As a result, the CV is calculated as 0.3223 during the simulation period (scenario 1), 0.3237 (scenario 2), 0.3278 (scenario 3), and 0.3267 (scenario 4), as shown in Table 10. The CV from scenario 3 is slightly higher than that from scenario 4. Consequently, the impact from scenario 3 on Russia is the most important for stabilizing the international wheat price among the scenario targeted countries.

Conclusion

This study conducted simulations on alleviating climate risks for wheat production systems and markets by utilizing a partial equilibrium model. It examined how future agricultural investments would impact the world wheat market, especially the stability of international

Table 9. Average changing rate (%) between scenarios and baseline from 2017 to 2040

Changing rate between Scenario 1 and Baseline projection from 2017-2040		Changing rate between Scenario 2 and Baseline projection from 2017-2040		Changing rate between Scenario 3 and Baseline projection from 2017-2040		Changing rate between Scenario 4 and Baseline projection from 2017-2040	
Australia		USA		Russia		Ukraine	
Yield	-6.2	Yield	-5.9	Yield	-16.3	Yield	-15.8
Harvested area	-0.8	Harvested area	0.6	Harvested area	0.4	Harvested area	-3.9
Production	-6.9	Production	-5.3	Production	-16.0	Production	-18.8
Export	-8.7	Export	-9.4	Export	-27.9	Export	-31.5
Consumption	-0.4	Consumption	-0.2	Consumption	-1.0	Consumption	-0.3
Import	-0.3	Import	-0.7	Import	-7.3	Import	-3.6
World		World		World		World	
Production	-0.1	Production	-0.2	Production	-0.6	Production	-0.2
Consumption	-0.1	Consumption	-0.2	Consumption	-0.6	Consumption	-0.2
Export	-0.3	Export	-0.6	Export	-1.8	Export	-0.7
Import	-0.3	Import	-0.6	Import	-1.8	Import	-0.7
International wheat price	1.6	International wheat price	3.0	International wheat price	11.0	International wheat price	3.8

Table 10. Scenario impacts on international wheat price (2014/16-2040)

Scenario/Baseline	Country	Coefficient of variation (CV)	Standard Deviation	Average
Baseline	-	0.3159	96.7592	306.2864
Scenario 1	Australia	0.3223	100.4110	311.5611
Scenario 2	USA	0.3237	102.2517	315.9130
Scenario 3	Russia	0.3278	111.1265	339.0133
Scenario 4	Ukraine	0.3267	104.0369	318.4654

wheat price, by considering future climate change in mid-long term. The simulation results suggest that agricultural investments in major wheat-producing countries will contribute to price stability in mid-long term, by considering climate change. Among scenarios, the changing rates of wheat production and export in scenario 3 (Russia) are higher than those in other scenarios. Russia is projected to become the world's largest wheat exporting country in the baseline outlook, and it means that Russian wheat production and export will the most crucial factor that can impact the world wheat market. As a result of this study, Russian agricultural investment is the biggest factor that can impact the world wheat market. In conclusion, agricultural investments in Russia play a crucial role in stabilizing international wheat prices in mid-long term, as wheat production becomes increasingly affected by climate change. This study applied specific assumptions to baseline and scenario outlooks, but could also apply other macro-assumptions and climate change projections to the baseline and scenario outlooks as a future direction of study. This model may have simultaneous determination bias in each elasticity, and examining and eliminating this bias are also the future direction of this study.

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Table A1-1. Estimation of parameters (yield)

	France (EU)	*t statistics（Year for dummy）*	Germany (EU)	*t statistics（Year for dummy）*	Poland (EU)	*t statistics（Year for dummy）*	China	*t statistics*
a1, Average temperature of flowering season（t/t-1）	-0.4343	*-1.5077*	-1.4726	*-4.3469*	0.2223	*1.8758*	0.5286	*1.9697*
a2, Average precipitation of flowering season（t/t-1）	0.3129	*2.0237*	0.0637	*1.5764*	0.0352	*1.2879*	-0.0754	*-0.7544*
a3, Average amount of solar radiation of flowering season（t/t-1）	1.4029	*1.7599*	1.3150	*3.3314*	0.8123	*1.8774*	-0.7433	*-1.4419*
a4, Agricultural Knowledge and Innovation System (t-1/t-2)	0.5484	*3.1528*	0.1384	*1.7861*	-	-	-	-
a5, Development and maintenance of inflastrucure (t-1/t-2)			0.0479	*1.5242*	0.3376	*2.9232*	-	-
a6, Inspection and Control (t-1/t-2)	0.0855	*1.7621*	-	-	0.2206	*3.1010*	-	-
a7, Land Development (t-1/t-2)	-	-	-	-	-	-	1.6513	*2.0603*
a8, Agricultural machinery and equipment（t-1/t-2）	-	-	-	-	-	-	0.1138	*0.8048*
Time trend (t/t-1)	-0.0299	*-3.0187*	0.0051	*1.3966*	-0.0290	*-3.0998*	-0.0092	*-1.5536*
Constant	11.3424	*109.7778*	11.0244	*84.1370*	10.5611	*102.0242*	0.8610	*24.8950*
Dummy 1	-0.1131	*-2.1125 (2003)*	-0.1185	*-2.4645 (1989)*	0.2632	*3.4369 (2004)*	-	-
Dummy 2	0.1254	*2.68823(2004)*	0.0833	*1.8034 (1991)*	-0.2397	*-3.5579(2006)*	-	-
Dummy 3	-	-	-	-	-	-	-	-
Sample	1988-2009		1989-2009		1987-2009		1980-2007	
R-squared	0.8103		0.9639		0.8567		0.8911	
Adjusted R-squared	0.6681		0.8969		0.6848		0.8600	
Durbin-Watson stat	2.5418		2.3893		2.2120		1.0276	

Table A1-2. Estimation of parameters (yield)

	India	*t statistics（Year for dummy）*	USA	*t statistics（Year for dummy）*	Russia	*t statistics（Year for dummy）*	Ukraine	*t statistics*
a1, Average temperature of flowering season（t/t-1）	-0.5893	*-2.4254*	-0.3429	*-0.8776*	-1.8073	*-2.3514*	-0.6566	*-1.4107*
a2, Average precipitation of flowering season（t/t-1）	-0.0423	*-1.1394*	0.1559	*0.7014*	-0.1654	*-1.0726*	0.9321	*1.5934*
a3, Average amount of solar radiation of flowering season（t/t-1）	0.4962	*1.6522*	1.1075	*1.8940*	1.0910	*1.2158*	1.2205	*0.7054*
a4, Agricultural Knowledge and Innovation System (t-1/t-2)	-	-	0.2081	*1.7935*	0.4003	*1.3750*	0.4853	*2.2011*
a5, Development and maintenance of infrastrucure (t-1/t-2)	-	-	0.8492	*1.2051*	0.2260	*3.2531*	0.2930	*2.1292*
a6, Inspection and Control (t-1/t-2)	-	-	-	-	-	-	-	-
a7, Land Development (t-1/t-2)	0.8988	*1.7776*	-	-	-	-	-	-
a8, Agricultural machinery and equipment（t-1/t-2）	0.1677	*0.6695*	-	-	-	-	-	-
Time trend (t/t-1)	-0.0009	*-0.8526*	-0.0554	*-1.7622*	-0.0088	*-0.7495*	0.1989	*3.5366*
Constant	0.6380	*8.3650*	10.5324	*45.3515*	0.4234	*1.4553*	-2.5890	*-2.6627*
Dummy 1	0.1122	*2.3613 (1997)*	-0.1712	*-2.0667 (2002)*	-0.1786	*-1.9858 (2003)*	-	-
Dummy 2	-	-	-	-	0.1611	*2.2772 (2008)*	-	-
Dummy 3	-	-	-	-	-	-	-	-
Sample	1984-2009		1989-2009		1995-2009		2004-2014	
R-squared	0.9177		0.8088		0.9851		0.9210	
Adjusted R-squared	0.8858		0.6813		0.9303		0.7365	
Durbin-Watson stat	1.3282		1.6593		2.1673		2.1311	

Table A1-3. Estimation of parameters (yield)

	Canada	*t statistics（Year for dummy）*	Australia	*t statistics*	Argentina	*t statistics（Year for dummy）*	Egypt	*t statistics*	Pakistan (The rest of the world)	*t statistics*
a1, Average temperature of flowering season（t/t-1）	-0.5255	*-3.5878*	-0.9388	*-2.8071*	0.8319	*2.9602*	0.3716	*0.8958*	-0.5004	*-3.3184*
a2, Average precipitation of flowering season（t/t-1）	-0.9947	*-3.7729*	0.7958	*1.6348*	0.2956	*1.6727*	0.4205	*1.3738*	0.0251	*1.0764*
a3, Average amount of solar radiation of flowering season（t/t-1）	-	-	1.0524	*1.1440*	1.1461	*0.9515*	0.6350	*0.9601*	1.0496	*1.4823*
a4, Agricultural Machinery and Equipment (t-1/t-2)	0.3005	*0.9529*	0.1905	*1.5337*	-	-	-	-	-	-
a5, Development and maintenance of infrastrucure (t-1/t-2)	0.3453	*1.0864*	0.1923	*1.4126*	-	-	-	-	-	-
a6, Inspection and Control (t-1/t-2)	-	-	-	-	-	-	-	-	-	-
a7, Land Development (t-1/t-2)	-	-	-	-	-	-	-	-	0.5944	*0.8508*
a8, Agricultural machinery and equipment（t-1/t-2）	-	-	-	-	0.7382	*1.2212*	0.9478	*2.0667*	0.0353	*1.5322*
Time trend (t/t-1)	0.0269	*1.8280*	-0.1022	*-1.5361*	-	-	-	-	0.0183	*3.0126*
Constant	5.0738	*1.4393*	0.9127	*1.7718*	8.1923	*77.2851*	1.1565	*15.2572*	0.3290	*13.7801*
Dummy 1	-0.2320	*-2.1384(1988)*	-	-	-0.1720	*-1.7638(1986)*	-	-	-	-
Dummy 2	0.2685	*2.4779 (1990)*	-	-	0.3077	*2.4880(1989)*	-	-	-	-
Dummy 3	-	-	-	-	-0.2751	*-2.5256(1995)*	-	-	-	-
Sample	1988-2009		1996-2009		1982-2009		1981-2009		1982-2009	
R-squared	0.9308		0.9664		0.8447		0.8736		0.9548	
Adjusted R-squared	0.8361		0.8542		0.7005		0.8314		0.9419	
Durbin-Watson stat	2.4808		1.7741		1.9030		1.0626		2.5532	

Table A2-1. Estimation of parameters (planted area: 1)

	France (EU)	*t statistics*（*Year for dummy*）	Germany (EU)	*t statistics*	Poland (EU)	*t statistics*（*Year for dummy*）	China	*t statistics*
a9, Domestic wheat price（t/t-1）	0.4535	*2.3960*	0.5224	*1.2644*	0.3555	*2.4943*	0.1609	*1.8613*
a10, Average precipitation (t/t-1)	-0.0226	*-1.3084*	-0.0504	*-1.5976*	0.2786	*2.7987*	0.1036	*0.9831*
a11, Domestic corn price（t/t-1）	-0.1115	*-1.3937*	-0.0448	*-1.3087*	-0.3260	*-4.2094*	-0.0409	*-1.1838*
a12, Domestic soybean price（t/t-1）	-	-	-	-	-	-	-	-
a13, Domestic coarse grain price（t/t-1）	-0.4946	*-3.4540*	-0.3394	*-0.8505*	-	-	-	-
a14, Domestic vegetable price（t/t-1）	-	-	-0.0134	*-1.2646*	-0.1071	*-2.0530*	-	-
a15, Domestic white sugar price（t/t-1）	-	-	-	-	-0.1603	*-3.5538*	-	-
a16, Domestic rice price（t/t-1）	-	-	-	-	-	-	-	-
a17, Development and maintenance of infrastructure（t-1/t-2）	0.1390	*2.1854*	0.1016	*1.6306*	0.3230	*2.8405*	-	-
a18, Domestic cotton price (t/t-1)	-	-	-	-	-	-	-0.0248	*-1.7963*
a19, Land development（t-1/t-2）	-	-	-	-	-	-	-	-
Time trend (t/t-1)	-0.0142	*-3.4809*	0.0106	*2.9305*	-0.0183	*-4.3856*	0.0160	*1.5346*
Constant	14.7489	*34.572*	13.8143	*32.109*	12.6882	*16.2584*	10.8119	*263.4496*
Dummy 1	-0.1076	*-4.374(1995)*	-	-	-0.1835	*-4.4989(1994)*	-	-
Dummy 2	0.0653	*3.1232(2000)*	-	-	0.0251	*0.0251(2009)*	-	-
Dummy 3	-0.1025	*-3.9195(2003)*	-	-	-	-	-	-
Sample	1995-2010		1991-2009		1992-2009		2002-2016	
R-squared	0.9771		0.9295		0.9396		0.9766	
Adjusted R-squared	0.9140		0.8731		0.8533		0.9532	
Durbin-Watson stat	2.8643		2.7402		2.4796		2.3269	

Table A2-2. Estimation of parameters (planted area: 2)

	India	*t statistics*（*Year for dummy*）	USA	*t statistics*	Russia	*t statistics*（*Year for dummy*）	Ukraine	*t statistics*（*Year for dummy*）
a9, Domestic wheat price（t/t-1）	0.0890	*0.7761*	0.2730	*2.8073*	0.5972	*3.5913*	0.0812	*1.8097*
a10, Average precipitation (t/t-1)	0.0258	*1.2861*	0.0766	*1.7960*	0.2792	*1.4002*	1.2772	*1.8881*
a11, Domestic corn price（t/t-1）	-	-	-	-	-0.1797	*-2.3895*	-0.9451	*-2.3515*
a12, Domestic soybean price（t/t-1）	-	-	-	-	-	-	-	-
a13, Domestic coarse grain price（t/t-1）	-	-	-0.0949	*-0.9848*	-0.1797	*-2.3895*	-0.1399	*-2.2216*
a14, Domestic vegetable price（t/t-1）	-	-	-	-	-0.0517	*-0.8078*	-0.2542	*-0.7470*
a15, Domestic white sugar price（t/t-1）	-	-	-	-	-	-	-0.9979	*-1.9197*
a16, Domestic rice price（t/t-1）	-0.0685	*-1.5290*	-	-	-	-	-	-
a17, Development and maintenance of infrastructure（t-1/t-2）	-	-	0.0135	*1.3526*	0.0653	*1.2677*	0.5139	*4.0651*
a18, Domestic cotton price (t/t-1)	-	-	-	-	-	-	-	-
a19, Land development（t-1/t-2）	0.8588	*0.9740*	-	-	-	-	-	-
Time trend (t/t-1)	-0.0058	*-0.5019*	-0.0239	*-5.6067*	-0.0017	*-1.2830*	0.0067	*1.1433*
Constant	10.1339	*120.618*	10.4352	*136.264*	10.4505	*81.4966*	7.0019	*12.199*
Dummy 1	0.0556	*2.4155(2010)*	-	-	-0.1996	*-4.5187(2003)*	1.3425	*3.0757(2009)*
Dummy 2	0.0566	*2.8485(2011)*	-	-	0.1202	*3.2315(2007)*	-	-
Dummy 3	-0.0766	*-2.0379(2014)*	-	-	0.0253	*1.5101(2014)*	-	-
Sample	2004-2016		1992-2010		2002-2014		2003-2014	
R-squared	0.9066		0.9332		0.9895		0.9839	
Adjusted R-squared	0.7197		0.8998		0.9371		0.8230	
Durbin-Watson stat	2.2063		1.6090		2.2312		2.2186	

Table A2-3. Estimation of parameters (planted area: 3)

	Canada	*t statistics*（*Year for dummy*）	Australia	*t statistics*（*Year for dummy*）	Argentina	*t statistics*（*Year for dummy*）	Egypt	*t statistics*（*Year for dummy*）	Pakistan (The rest of the world)	*t statistics*（*Year for dummy*）
a9, Domestic wheat price（t/t-1）	0.2841	*1.5091*	0.3165	*1.7315*	0.2170	*0.8199*	0.2763	*1.9154*	0.1045	*2.1066*
a10, Average precipitation (t/t-1)	0.1875	*1.2278*	0.3961	*2.7866*	0.0948	*1.3613*	0.1034	*0.9456*	-0.0281	*-1.0221*
a11, Domestic corn prices（t/t-1）	-	-	-	-	-	-	-	-	-	-
a12, Domestic soybean price（t/t-1）	-	-	-	-	-0.6401	*-1.4088*	-	-	-	-
a13, Domestic coarse grain price（t/t-1）	-	-	-0.2511	*-1.3346*	-0.2085	*-1.0986*	-	-	-	-
a14, Domestic vegetable price（t/t-1）	-0.1350	*-1.2537*	-	-	-	-	-	-	-	-
a15, Domestic white sugar price（t/t-1）	-	-	-	-	-	-	-	-	-	-
a16, Domestic rice price（t/t-1）	-	-	-	-	-	-	-	-	-	-
a17, Development and maintenance of infrastructure（t-1/t-2）	0.0640	*1.7063*	0.0385	*0.9520*	-	-	-	-	-	-
a18, Domestic cotton price (t/t-1)	-	-	-	-	-	-	-	-	0.2204	*1.3791*
a19, Land development（t-1/t-2）	-	-	-	-	-	-	0.4696	*0.8886*	-	-
Time trend (t/t-1)	-0.0318	*-7.9997*	0.2091	*1.1895*	1.6420	*2.3818*	0.0102	*1.1665*	-0.2023	*-1.5911*
Constant	9.9310	*106.165*	8.6955	*14.141*	0.6420	*2.3818*	6.5739	*72.582*	9.4134	*37.800*
Dummy 1	-0.1621	*-2.6131(2002)*	0.1067	*2.5694(2003)*	-0.2416	*-2.0984(1995)*	-0.1193	*-1.4756(2002)*	0.0409	*2.5481(2007)*
Dummy 2	-	-	-0.1051	*-2.1938(2006)*	0.0962	*0.8315(2001)*	-0.2826	*-3.1663(2005)*	0.0275	*1.8376(2011)*
Dummy 3	-	-	-	-	-0.1518	*-1.0741(2003)*	-	-	0.0123	*1.6084(2014)*
Sample	1992-2010		1999-2010		1992-2010		2002-2016		2004-2014	
R-squared	0.9131		0.9158		0.8527		0.8988		0.8832	
Adjusted R-squared	0.8577		0.7868		0.6685		0.8230		0.6106	
Durbin-Watson stat	2.3314		2.1684		1.9062		1.9281		1.9491	

Table A3-1. Estimation of parameters (per capita consumption for food: 1)

	EU	*t statistics*	China	*t statistics*	India	*t statistics* (*Year for dummy*)	USA	*t statistics* (*Year for dummy*)
a20, Income: Per capita GDP growth rate (t/t-1)	0.1142	*0.9081*	0.0520	*2.0300*	0.0575	*1.3278*	0.1962	*1.5312*
a21, Domestic wheat price（t/t-1)	-0.1531	*-1.0499*	-0.0169	*-0.9322*	-0.1206	*-2.1239*	-0.0269	*-1.1386*
a22, Domestic rice price（t/t-1)	-	-	0.0290	*3.7580*	0.0296	*1.6767*	0.0428	*2.2423*
Time trend (t/t-1)	0.0161	*2.1857*	-0.0169	*-6.3946*	0.0042	*1.3408*	-0.0143	*-2.9829*
Constant	4.5267	*74.3892*	4.6451	*161.6695*	3.9528	*27.0053*	4.6805	*140.2273*
Dummy 1	-	-	-	-	-0.0480	*-1.054 (2001)*	-0.0797	*-4.1034 (1990)*
Dummy 2	-	-	-	-	0.1069	*2.0858 (2002)*	-0.0728	*-3.6823 (1991)*
Dummy 3	-	-	-	-	0.0934	*1.9998 (2013)*	-	-
Sample	2002-2013		1991-2011		1998-2016		1990-2016	
R-squared	0.9689		0.9858		0.7470		0.9172	
Adjusted R-squared	0.9512		0.9822		0.5447		0.8924	
Durbin-Watson stat	2.1811		1.3961		2.3705		1.1990	

Table A3-2. Estimation of parameters (per capita consumption for food: 2)

	Russia	*t statistics* (*Year for dummy*)	Ukraine	*t statistics* (*Year for dummy*)	Canada	*t statistics*	Australia	*t statistics* (*Year for dummy*)
a20, Income: Per capita GDP growth rate (t/t-1)	-0.0155	*-1.2556*	0.2013	*4.4450*	0.0520	*2.0300*	0.0903	*4.9435*
a21, Domestic wheat price（t/t-1)	-0.0146	*-1.3778*	-0.1813	*-3.3056*	-0.0169	*-0.9322*	-0.0865	*-5.6410*
a22, Domestic rice price（t/t-1)	-	-	-	-	0.0290	*3.7580*	0.1661	*13.3077*
Time trend (t/t-1)	0.0013	*1.8168*	-0.0216	*-6.6982*	-0.0169	*-6.3946*	-0.0018	*-0.8864*
Constant	5.0659	*325.5731*	5.3978	*169.9031*	4.6451	*161.6695*	4.8438	*152.1088*
Dummy 1	-0.0562	*-2.7563 (1994)*	0.1343	*2.6991 (1995)*	-	-	-0.0471	*-6.7059 (2010)*
Dummy 2	-0.0771	*-3.8896 (1995)*	-	-	-	-	-	-
Dummy 3	0.0376	*2.0572 (2004)*	-	-	-	-	-	-
Sample	1992-2015		1985-2009		1991-2011		2003-2014	
R-squared	0.7452		0.7839		0.9857		0.9866	
Adjusted R-squared	0.6337		0.7407		0.9821		0.9754	
Durbin-Watson stat	2.3014		1.1829		1.3961		2.3581	

Table A3-3. Estimation of parameters (per capita consumption for food: 3)

	Argentina	*t statistics* (*Year for dummy*)	Indonesia	*t statistics*	Egypt	*t statistics* (*Year for dummy*)	Pakistan (The rest of the world)	*t statistics* (*Year for dummy*)
a20, Income: Per capita GDP growth rate (t/t-1)	0.1117	*1.2534*	0.3894	*4.5173*	0.0905	*4.8811*	0.1265	*1.5533*
a21, Domestic wheat price（t/t-1)	-0.0608	*-1.3484*	-0.1877	*-2.1849*	-0.0541	*-2.4355*	-0.0300	*-1.6681*
a22, Domestic rice price（t/t-1)	-	-	0.0536	*1.1996*	-	-	0.1265	*1.5533*
Time trend (t/t-1)	0.0034	*1.4022*	0.0021	*1.3883*	0.0007	*0.9176*	-0.0148	*-5.3488*
Constant	4.8364	*19.2548*	2.6434	*27.4364*	5.0477	*518.3757*	5.2101	*149.3880*
Dummy 1	0.0487	*2.1418 (2007)*	-	-	-0.0348	*-4.1310 (2002)*	-0.0563	*-1.4562 (1990)*
Dummy 2	0.0487	*2.2210 (2009)*	-	-	-	-	0.0845	*2.1579 (1998)*
Dummy 3	-	-	-	-	-	-	-	-
Sample	2005-2014		1995-2016		2002-2016		1990-2016	
R-squared	0.8593		0.9289		0.9371		0.8507	
Adjusted R-squared	0.6835		0.9122		0.9120		0.8059	
Durbin-Watson stat	2.1574		1.2178		2.1770		1.0119	

Table A4-1. Estimation of parameters (Consumption for feed: 1)

	EU	*t statistics*	China	*t statistics* (*Year for dummy*)	India	*t statistics*	USA	*t statistics* (*Year for dummy*)
a23, Income: GDP growth rate (t/t-1)	0.1107	*1.9480*	0.4089	*1.9495*	-	-	2.7864	*0.6395*
a24, Domestic wheat price (t/t-1)	-0.8535	*-9.0272*	-0.8833	*-2.0877*	-	-	-0.7196	*-1.4503*
a25, Domestic beef price (t/t-1)	0.6776	*4.9442*	-	-	-	-	1.1048	*1.9973*
a26, Domestic pork price (t/t-1)	0.7429	*4.3202*	1.8173	*2.5514*	-	-	-	-
a27, Domestic cheese price (t/t-1)	-	-	-	-	-	-	-	-
Time trend (t/t-1)	-1.9970	*-6.3948*	0.2263	*0.2068*	-	-	-2.9037	*-1.8394*
Constant	22.3243	*22.5150*	7.1444	*2.5838*	-	-	-	-
Dummy 1	-0.1063	*-2.2728(2000)*	0.4981	*1.5350 (2001)*	-	-	-2.3215	*-5.6328 (2007)*
Dummy 2	0.2513	*4.3108 (2007)*	-0.6425	*-2.0521(2005)*	-	-	-0.6487	*-1.8221 (2010)*
Dummy 3	-	-	-0.7988	-	-	-	0.8585	-
Sample	2000-2013		1991-2016		-		1992-2015	
R-squared	0.9921		0.8739		-		0.8455	
Adjusted R-squared	0.9743		0.8145		-		0.7632	
Durbin-Watson stat	2.2791		1.6080		-		2.4977	

Table A4-2. Estimation of parameters (Consumption for feed: 2)

	Russia	*t statistics*	Ukraine	*t statistics* (*Year for dummy*)	Canada	*t statistics* (*Year for dummy*)	Australia	*t statistics* (*Year for dummy*)	Egypt	*t statistics* (*Year for dummy*)
a23, Income: GDP growth rate (t/t-1)	0.3537	*2.2448*	2.0753	*2.7036*	1.0033	*1.8421*	0.9790	*2.0232*	0.3367	*1.2055*
a24, Domestic wheat price (t/t-1)	-0.4776	*-2.5290*	-0.2675	*-1.1826*	-0.1745	*-1.6587*	-0.6887	*-2.4727*	-0.7608	*-1.7769*
a25, Domestic beef price (t/t-1)	1.1609	*3.2602*	-	-	-	-	0.9390	*1.5969*	-	-
a26, Domestic pork price (t/t-1)	-	-	-	-	-	-	-	-	-	-
a27, Domestic cheese price (t/t-1)	0.2519	*1.9821*	-	-	-	-	-	-	0.5264	*1.8784*
Time trend (t/t-1)	-1.2558	*-5.4487*	-3.3132	*-4.2001*	-1.2909	*-2.0897*	-2.2728	*-1.2699*	0.2854	*1.6924*
Constant	12.1926	*25.7531*	14.7687	*10.7618*	11.4889	*8.1082*	15.3470	*2.8555*	5.5207	*5.4662*
Dummy 1	0.4959	*4.2396 (2007)*	-0.7341	*-1.5916 (1999)*	-0.4024	*-2.1384 (1992)*	0.1209	*1.7283 (2007)*	-1.9164	*-6.0759 (1994)*
Dummy 2	0.1140	*1.2046 (2013)*	-1.2240	*-2.2687 (2003)*	-0.6398	*-4.0925 (2007)*	-0.6455	*-5.1718 (2009)*	-0.7756	*-2.2465 (2001)*
Dummy 3	0.3696	*3.5413 (2014)*	0.7432	-	-0.3581	*-2.3038 (2009)*	-	-	0.4981	*1.5909 (2009)*
Sample	1999-2016		1997-2015		1992-2015		2000-2014		1990-2014	
R-squared	0.9102		0.8265		0.8033		0.8998		0.8952	
Adjusted R-squared	0.8093		0.6877		0.6768		0.7662		0.8428	
Durbin-Watson stat	1.9972		2.3428		2.3056		1.4615		1.8162	

Table A5-1. Estimation of parameters (imports: 1)

	EU	*t statistics（Year for dummy）*	USA	*t statistics（Year for dummy）*	Russia	*t statistics（Year for dummy）*
a28, Domestic Wheat price (t/t-1)	-0.8403	*-3.5474*	-1.2500	*-2.2243*	-1.1069	*-1.3708*
Time trend (t/t-1)	-0.0192	*-1.5397*	0.0288	*3.8076*	-0.1056	*-4.3493*
Constant	9.2279	*25.0941*	7.7408	*43.0037*	10.3374	*15.7495*
Dummy 1	-0.3522	*-2.7290 (2006)*	-0.6948	*-4.2185 (1991)*	-1.4890	*-2.2988 (2009)*
Dummy 2	-0.3440	*-2.5766 (2009)*	-0.4392	*-2.7890 (2003)*	-1.9222	*-2.9481 (2010)*
Dummy 3	-0.4615	*-3.3879 (2013)*	-0.3731	*-2.3625 (2004)*	-	-
Sample	2001-2015		1991-2015		1992-2015	
R-squared	0.8645		0.8151		0.7879	
Adjusted R-squared	0.7628		0.7535		0.7289	
Durbin-Watson stat	2.4207		2.3426		1.4662	

Table A5-2. Estimation of parameters (imports: 2)

	Ukraine	*t statistics（Year for dummy）*	Canada	*t statistics（Year for dummy）*	Australia	*t statistics（Year for dummy）*
a28, Domestic Wheat price (t/t-1)	-0.8916	*-1.6209*	-0.4858	*-3.0643*	-0.2555	*-1.0443*
Time trend (t/t-1)	-0.2492	*-5.3424*	0.0701	*6.9087*	0.0689	*13.4260*
Constant	11.7415	*8.1381*	3.6394	*15.4778*	2.8436	*21.1297*
Dummy 1	-0.9566	*-2.083 (2012)*	0.3507	*2.4872 (2002)*	-0.5176	*-3.8954 (1991)*
Dummy 2	-	-	-	-	-0.3509	*-2.8459 (1993)*
Dummy 3	-	-	-	-	1.3533	*11.8081 (2002)*
Sample	2005-2016		1997-2015		1991-2015	
R-squared	0.8379		0.9259		0.9760	
Adjusted R-squared	0.7299		0.9048		0.9680	
Durbin-Watson stat	2.4045		2.2119		1.7413	

Table A6. Estimation of parameters (exports)

	China	*t statistics（Year for dummy）*	Egypt	*t statistics（Year for dummy）*	India	*t statistics（Year for dummy）*	Indonesia	*t statistics（Year for dummy）*	Pakistan（The rest of the world）	*t statistics（Year for dummy）*
a29, International Wheat price (t/t-1)	0.1815	*2.6479*	0.5092	*1.0524*	0.8186	*3.4879*	0.2864	*1.2347*	1.0536	*3.0826*
Time trend (t/t-1)	-0.0136	*-1.8240*	0.2877	*8.5621*	0.4036	*4.0658*	0.0894	*5.6270*	-0.0448	*-1.8952*
Constant	7.2175	*28.7044*	-4.2554	*-4.3216*	-7.8610	*-2.4230*	-	-	7.9818	*11.3777*
Dummy 1	-0.1484	*-3.0902 (2014)*	-0.1014	*-2.008 (2006)*	5.5029	*3.8763 (2005)*	-0.5184	*-1.9603 (2001)*	-0.9384	*-2.4178 (2000)*
Dummy 2	-0.1139	*-2.4374 (2015)*	-	-	-3.2863	*-2.8031 (2008)*	0.7401	*2.9769 (2004)*	-1.3560	*-3.7687 (2003)*
Dummy 3	-	-	-	-	-	-	-	-	-1.0336	*-3.0366 (2009)*
Sample	2009-2016		2001-2016		2005-2016		2000-2016		2000-2016	
R-squared	0.9403		0.9257		0.8416		0.8930		0.8496	
Adjusted R-squared	0.8607		0.9071		0.7511		0.8574		0.7595	
Durbin-Watson stat	2.2390		1.8388		2.0346		1.3802		1.8367	

Table A7-1. Estimation of parameters (ending stocks: 1)

	EU	*t statistics（Year for dummy）*	China	*t statistics（Year for dummy）*	India	*t statistics（Year for dummy）*	USA	*t statistics（Year for dummy）*
a30, Domestic wheat price (t/t-1)	-0.2213	*-1.8303*	-0.3644	*-2.6186*	-0.6226	*-2.4817*	-0.4334	*-1.6566*
Time trend (t/t-1)	-0.0522	*-3.0770*	-0.0186	*-3.1924*	-0.0652	*-1.4114*	0.0467	*5.7403*
Constant	10.8359	*28.1024*	8.3819	*24.5851*	4.0352	*4.8340*	8.9154	*45.3646*
Dummy 1	0.3783	*2.6869 (1986)*	-0.9125	*-4.1271 (2011)*	0.7543	*1.6988 (2001)*	-0.4731	*-2.8181 (2003)*
Dummy 2	-0.2797	*-1.9598 (1994)*	-1.1142	*-4.8007 (2012)*	-0.9937	*-2.2356 (1997)*	-0.4007	*-2.4524 (2004)*
Dummy 3	-	-	-	-	-0.9187	*-2.0923 (2004)*	-0.5965	*-3.3111 (2007)*
Sample	1980-1996		1989-2015		1991-2008		1991-2015	
R-squared	0.8646		0.7727		0.8236		0.8251	
Adjusted R-squared	0.7834		0.7186		0.7000		0.7531	
Durbin-Watson stat	2.2368		1.3558		1.6161		1.2648	

Table A7-2. Estimation of parameters (ending stocks: 2)

	Russia	*t statistics（Year for dummy）*	Ukraine	*t statistics（Year for dummy）*	Canada	*t statistics（Year for dummy）*	Australia	*t statistics（Year for dummy）*
a30, Domestic wheat price (t/t-1)	-0.5447	*-1.7878*	-0.6924	*-2.0054*	-0.4743	*-2.3833*	-0.6829	*-3.5677*
Time trend (t/t-1)	-0.0473	*-1.6333*	0.0406	*1.2333*	0.0061	*0.6580*	0.0645	*6.7236*
Constant	8.0226	*7.8994*	7.4437	*11.6727*	8.6816	*43.4430*	7.2759	*33.5099*
Dummy 1	0.7721	*1.5426 (1996)*	-0.6979	*-3.3067 (1999)*	-0.4193	*-2.5806 (1994)*	0.7534	*0.7534 (1992)*
Dummy 2	1.4365	*2.8403 (2003)*	0.4240	*1.9679 (2007)*	-0.2528	*-1.7591 (1997)*	-0.5786	*-2.8058 (1998)*
Dummy 3	-	-	-	-	0.2306	*1.3407 (2013)*	-	-
Sample	1987-2008		1994-2008		1991-2014		1991-2015	
R-squared	0.7314		0.8885		0.8069		0.8441	
Adjusted R-squared	0.6240		0.8049		0.7224		0.7922	
Durbin-Watson stat	1.8014		1.5693		2.0506		1.4829	

Table A7-3. Estimation of parameters (ending stocks: 3)

	Argentina	*t statistics*	Indonesia	*t statistics*	Egypt	*t statistics（Year for dummy）*	Pakistan	*t statistics（Year for dummy）*
a30, Domestic wheat price (t/t-1)	-	-	-	-	-0.5450	*-1.7067*	-0.1392	*-1.0657*
Time trend (t/t-1)	0.1003	*5.2195*	-0.0107	*-0.2221*	-0.0979	*-1.5834*	-0.0338	*-1.8153*
Constant	4.4068	*7.3772*	6.2108	*11.4649*	5.0763	*15.8461*	7.6397	*39.1824*
Dummy 1	-	-	-	-	0.7367	*2.2879 (1996)*	-0.6486	*-3.9178 (2002)*
Dummy 2	-	-	-	-	0.7697	*2.5314 (1997)*	-0.5556	*-3.4955 (2003)*
Dummy 3	-	-	-	-	-	-	-0.3237	*-2.0186 (2013)*
Sample	1995-2014		1998-2015		1991-2014		1995-2015	
R-squared	0.7865		0.7433		0.9051		0.8027	
Adjusted R-squared	0.6879		0.6893		0.8716		0.7181	
Durbin-Watson stat	1.0662		1.3219		1.5201		1.8761	

Table A8-1. Estimation of parameters (price tranmission: 1)

	EU	*t statistics（Year for dummy）*	China	*t statistics*	India	*t statistics（Year for dummy）*	USA	*t statistics*	Russia	*t statistics（Year for dummy）*
a31, International wheat price (t/t-1)	0.9662	*9.3967*	0.6310	*7.5389*	0.3449	*5.9326*	0.9309	*20.2469*	0.9909	*7.3505*
Time trend (t/t-1)	-0.0057	*-1.1874*	0.0388	*9.5702*	0.0243	*7.3530*	0.0090	*4.3838*	0.0069	*1.0382*
Constant	4.8969	*83.6228*	4.6764	*104.7225*	4.8082	*139.0873*	4.6807	*192.9311*	4.5578	*53.4204*
Dummy 1	0.3936	*2.8553 (1991)*	-0.3102	*-3.0702*	0.3024	*4.2741 (1991)*	-	-	0.8642	*4.7718 (1992)*
Dummy 2	-0.3355	*-2.5593 (2002)*	-	-	-0.1736	*-2.6409 (2002)*	-	-	-0.4780	*-2.8346 (2002)*
Dummy 3	0.3255	*2.4669 (2010)*	-	-	-0.1230	*-1.8539 (2003)*	-	-	-	-
Sample	1991-2015		1991-2011		1991-2008		1991-2015		1992-2015	
R-squared	0.8915		0.9477		0.9181		0.9759		0.8850	
Adjusted R-squared	0.8629		0.9385		0.8839		0.9738		0.8607	
Durbin-Watson stat	1.8065		1.5415		2.2546		2.0201		2.3919	

Table A8-2. Estimation of parameters (price tranmission: 2)

	Ukraine	*t statistics（Year for dummy）*	Canada	*t statistics（Year for dummy）*	Australia	*t statistics（Year for dummy）*	Argentina	*t statistics（Year for dummy）*	Egypt	*t statistics（Year for dummy）*	Pakistan (The rest of the world)	*t statistics（Year for dummy）*
a31, International wheat price (t/t-1)	0.5342	*4.0981*	0.5807	*5.0375*	0.7067	*8.3293*	0.7465	*8.2500*	0.4068	*3.1281*	0.1937	*1.4990*
Time trend (t/t-1)	0.0235	*3.3704*	0.0348	*6.5393*	0.0151	*3.7569*	-0.0071	*-1.4508*	0.0299	*5.2601*	0.0206	*3.9598*
Constant	4.3372	*52.8961*	4.2694	*66.7674*	4.7845	*105.8621*	4.8893	*85.0569*	4.9358	*77.8535*	4.8971	*87.8836*
Dummy 1	0.4235	*2.5832 (1994)*	-0.2981	*-1.9621 (1994)*	-0.1879	*-1.7576 (2006)*	-0.4013	*-3.3472 (1992)*	-0.4665	*-3.0765 (1992)*	0.3354	*2.5822 (2009)*
Dummy 2	-0.3733	*-2.3219 (1999)*	-0.3052	*-2.0846 (2006)*	-	-	0.6152	*5.2689 (2013)*	-0.3534	*-2.3101 (1996)*	-0.2414	*-1.9195 (2001)*
Dummy 3	-0.4176	*-2.7460 (2002)*	-	-	-	-	-0.2629	*-2.3853 (2006)*	0.3526	*0.3526 (1997)*	-0.3363	*-2.2700 (2008)*
Sample	1994-2015		1991-2015		1991-2014		1992-2014		1980-2003		1991-2010	
R-squared	0.8865		0.9122		0.9144		0.9141		0.8847		0.7907	
Adjusted R-squared	0.8511		0.8946		0.9015		0.8885		0.8526		0.7160	
Durbin-Watson stat	2.2123		1.3617		1.8517		1.3054		1.0075		1.1549	

Table A9-1. Exogenous variables (1)

	Per Capita GDP	Population	
Countries/Region	Changing rate (2017-2022)(%)	2014-2016	2040
EU28	1.8	507,519	509,687
China	7.5	1,396,880	1,417,473
India	9.1	1,309,028	1,605,356
USA	3.8	319,943	374,069
Russia	2.8	143,871	135,837
Ukraine	6.3	44,660	38,658
Canada	1.4	35,948	43,005
Australia	2.8	23,800	30,765
Argentina	6.4	43,416	52,586
Indonesia	8.7	258,136	312,134
Egypt	5.6	93,760	137,066

Table A9-2. Exogenous variables (2)

	Unit	2014-2016	2026	2040
International corn price	USD/ton	164	197	197
International coarse grain price	USD/ton	179	198	198
International rice price	USD/ton	375	416	416
International soybean price	USD/ton	402	446	446
International vegetable oil price	USD/ton	768	902	902
International cotton price	USD/ton	1,583	1,576	1,576
International white sugar price	USD/ton	430	453	453
International beef price	USD/ton	4,298	3,894	3,894
International pork price	USD/ton	2,122	2,396	2,396
International cheese price	USD/ton	3,633	4,276	4,276