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Systemic risks caused by worldwide simultaneous bad and good harvest in agricultural market and trade under future climate change

—stochastic simulation by the computable general equilibrium model—

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Background

- Global simultaneous crop failures or too rich harvest result in synchronized yield fluctuation (SYF) and can be enhanced by future climate change.
- IPCC's special report (2019)
  - Global average food price in 2050 would increase by 23% from current level, due to future climate change in addition to an increase in world population.
- Such agricultural disruption is a risk in the global economy, and hence clarifying the influence of this risk is a important.

Previous studies

- Wright (2010)
  - The causes of past spikes of agricultural price were not speculation as well as rising oil prices.
  - True criminal was imbalances in supply and demand in addition to changes in grain stock levels in the global market.

Previous studies (2)

- CGE model:
  - The CGE model is a powerful analytical tool because it can analyze changes in supply and demand equilibrium and changes in equilibrium prices at the same time.
  - Previous studies used CGE model to assess risks;
    - Earthquake disasters (Kunimitsu, 2017; Tokunaga and Okiyama, 2017),
    - Climate change (Kunimitsu, 2015; Hasegawa et al., 2016; Kahsay et al., 2018; Xie et al., 2019), and
    - Environmental policy (Palatnik and Roson, 2012; Lee, 2009; Calzadilla et al. , 2011, Kunimitsu, 2019)

Previous studies (3)

- Hosoe (2016)
  - examined the impacts of productivity shock and effects of trade liberalization in four major grain markets by Monte Carlo simulation analysis using a global CGE model (Randomly and regionally independent shocks).
  - They conclude that trade liberalization has no worries of which the fluctuation of Japanese market will be expanded in response to fluctuations in overseas productivity.
  - However, their study did not analyze the impacts of correlated shocks among major grains and among countries as well.
- Gaupp et al.(2020)
  - Synchronized yield fluctuations under global warming since 1981 has already resulted in annual combined losses of wheat, maize, and barley.
- Schweizer (2020)
  - Fragility caused by the shocks that correlate among goods and regions is called "systemic risk" in the field of finance.

Purpose and feature

- This study aims to analyze whether future climate change increases systemic risk via synchronized yield fluctuations (SYF).
- If such systemic risk exists, we try to quantify the influence of SYF in the global food market with trade liberalization.
- Features
  - We identify the SYF among countries and among 4 main crops such as rice, wheat, maize and soybeans, under future climate change by using crop model and 5 Global Climate Models (GCM).
  - Then, the fluctuations in agricultural prices are calculated by CGE model, and price volatilities were compared with and without SYF, by applying deterministic or stochastic simulations.

Method

Crop model (Sakurai et al., 2016)

- To predict future crop yields (4 crops) based on prediction of 5 GCM's.

No.	GCMs	Institutions developing the model
1	GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory
2	HadGEM2-ES	Met Office Hadley Centre and Instituto Nacional de Pesquisas Espaciais
3	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
4	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
5	NorESM1-M	Norwegian Climate Centre

Crop model (Sakurai et al., 2016)

- The crop model:
  - a hybrid model which consists of non-linear functions.
  - reproduces the crop growth process by using the observed parameters from the field experiments, and uncertain parameters estimated by the MCMC method with statistical yield data.
  - This model has relatively high accuracy of prediction as compared to pure process model, and can introduce many climate factors as input data.
- Correlation analysis on crop yields
  - Analysis period as;
    - T1 (1961-2014); FAO's crop yield data period

      Detrended
    - T2 (2015-2050); Crop model with GCM data +0.5-1.8 °C (RCP8.5)
    - T3 (2051-2100); Crop model with GCM data +1.8-4.1 °C (RCP8.5)

Global CGE model

- GTAP 9 in GAMS (Lanz and Rutherford, 2016)
  - Nested type production structure
  - Consumption is based on LES
  - 8 kinds of tax and subsidies (production tax, production factors tax, intermediate input tax, consumption tax, public sector purchase tax, investment tax, export subsidy, and import tariff) are considered in order to cover the tax systems of each country in the world.

Data

- GTAP 9 (Purdue university)
- Countries were aggregated into 38 countries/regions

No	Identifier	Country of Region	No	Identifier	Country of Region
1	AUS	Australia	20	URY	Uruguay
2	CHN	China	21	XSM	Rest of South America
3	JPN	Japan	22	XCA	Rest of Central America
4	KOR	Korea Republic of	23	FRA	France
5	IDN	Indonesia	24	DEU	Germany
6	PHL	Philippines	25	GBR	United Kingdom
7	THA	Thailand	26	XEF	Rest of EFTA
8	VNM	Viet Nam	27	ROU	Romania
9	BGD	Bangladesh	28	RUS	Russian Federation
10	IND	India	29	UKR	Ukraine
11	PAK	Pakistan	30	XER	Rest of Europe
12	XAS	Rest of ASIA	31	IRN	Iran Islamic Republic of
13	CAN	Canada	32	TUR	Turkey
14	USA	United States of America	33	XWS	Rest of Western Asia
15	MEX	Mexico	34	EGY	Egypt
16	ARG	Argentina	35	XAC	South Central Africa
17	BOL	Bolivia	36	XEC	Rest of Eastern Africa
18	BRA	Brazil	37	ZAF	South Africa
19	PRY	Paraguay	38	XTW	Rest of the World

Data (cont.)

- Industrial sectors were aggregated into 12 sectors.

No	Identifier	Industrial sectors	No	Identifier	Industrial sectors
1	PDR	Paddy rice	7	MIN	Minnig & forestry nec
2	WHT	Wheat	8	OFD	Food products nec
3	GRO	Cereal grains nec	9	VOL	Vegetable oils and fats
4	OCR	Crops nec	10	PCR	Processed rice
5	OSD	Oil seeds	11	MAN	Manufacturing
6	OAP	Animal products nec	12	SEV	Service

Simulation method

- The shock of yield fluctuations is assumed to converge in one year; therefore, the simulation performs repeatedly static analysis according to the number of disturbance data.

- Yield fluctuation of each crop assumed to change EFP in the production function as follows.

$$YV_{i,r,t} = \left(\gamma_{A_{i,r}} (EFP_{i,r,t} \bullet A_{i,r})^{\sigma} + \gamma_{K_{i,r}} K^{\sigma} + \gamma_{L_{i,r}} L_{i,r}{}^{\sigma} + \gamma_{N_{i,r}} N_{i,r}{}^{\sigma} \right)^{1/\sigma}$$

Simulation cases

- **Case 1 (Random and regionally independent disturbances in EFP);** 1000 random draws, log normal distribution corresponding to actual yield.

- **Case 2 (SYF in EFP during T2);** prediction of crop model (36 years x 5 GCMs)

$$EFP_{i,r,t} = \left(\widehat{YE}_{i,r,t} \Big/ \overline{YE}_{i,r,2007-15} \right)$$

- **Case 3 (SYF in EFP during T3);** prediction of crop model (50 years x 5 GCMs)

Simulation method (cont.)

- **Case 4, Case 5 and Case 6 (Agricultural trade liberalization cases) in Case 1, 2 and 3.**
  - All regions' import tariffs and export subsidies for agriculture and food sectors (PDR, WHT, GRO, OCR, OSD, OAP, OFE, VOL, and PCR) are set as 0.
  - Other settings are the same as each case.

Results

Robustness of SYF structure

- Correlation coefficients among regions (rice, T3)

	AUS	CHN	JPN	KOR	IDN	PHL	THA	VNM	BGD	IND	PAK	USA	MEX	ARG	BOL	BRA
AUS	1.00	0.15	-0.10	-0.06	0.32	0.41	0.36	0.19	0.07	0.27	0.21	-0.04	0.23	0.04	0.29	0.26
CHN	0.15	1.00	0.11	0.35	0.41	0.60	0.42	0.32	0.21	0.43	0.38	0.37	0.45	0.33	0.18	0.57
JPN	-0.10	0.11	1.00	0.68	0.16	0.07	0.04	0.17	0.13	0.02	-0.09	0.06	0.05	0.20	-0.21	-0.05
KOR	-0.06	0.35	0.68	1.00	0.18	0.19	0.12	0.19	0.11	0.19	0.01	0.14	0.20	0.11	-0.07	0.05
IDN	0.32	0.41	0.16	0.18	1.00	0.67	0.61	0.58	0.38	0.51	0.31	0.19	0.40	0.22	0.02	0.33
PHL	0.41	0.60	0.07	0.19	0.67	1.00	0.71	0.50	0.43	0.58	0.51	0.11	0.55	0.29	0.20	0.52
THA	0.36	0.42	0.04	0.12	0.61	0.71	1.00	0.43	0.43	0.54	0.37	0.09	0.45	0.17	0.11	0.40
VNM	0.19	0.32	0.17	0.19	0.58	0.50	0.43	1.00	0.31	0.36	0.26	0.26	0.41	0.18	-0.04	0.28
BGD	0.07	0.21	0.13	0.11	0.38	0.43	0.43	0.31	1.00	0.64	0.26	-0.04	0.27	0.14	-0.10	0.14
IND	0.27	0.43	0.02	0.19	0.51	0.58	0.54	0.36	0.64	1.00	0.38	0.05	0.38	0.14	0.00	0.32
PAK	0.21	0.38	-0.09	0.01	0.31	0.51	0.37	0.26	0.26	0.38	1.00	0.03	0.41	0.13	0.17	0.34
USA	-0.04	0.37	0.06	0.14	0.19	0.11	0.09	0.26	-0.04	0.05	0.03	1.00	0.19	0.31	-0.03	0.34
MEX	0.23	0.45	0.05	0.20	0.40	0.55	0.45	0.41	0.27	0.38	0.41	0.19	1.00	0.24	0.22	0.36
ARG	0.04	0.33	0.20	0.11	0.22	0.29	0.17	0.18	0.14	0.14	0.13	0.31	0.24	1.00	-0.14	0.57
BOL	0.29	0.18	-0.21	-0.07	0.02	0.20	0.11	-0.04	-0.10	0.00	0.17	-0.03	0.22	-0.14	1.00	0.35
BRA	0.26	0.57	-0.05	0.05	0.33	0.52	0.40	0.28	0.14	0.32	0.34	0.34	0.36	0.57	0.35	1.00

Robustness of correlation coefficients among regions

- nt:total number of combinations
- rr_NZ: r is statistically non-zero in both periods
- rr_+: , r is positive in both periods.
- rr_1: r is bigger in latter period than former period

Crops	Periods	nt	rr_NZ	rr_+	rr_1
Rice	T1→T2	528	31.3%	16.5%	3.6%
	T2→T3	595	44.9%	42.9%	29.6%
Wheat	T1→T2	351	16.2%	8.8%	2.6%
	T2→T3	528	26.1%	17.0%	5.1%
Maze	T1→T2	435	26.2%	13.6%	1.1%
	T2→T3	630	22.9%	15.7%	12.5%
Soybeans	T1→T2	325	9.8%	4.9%	1.8%
	T2→T3	630	39.5%	37.9%	32.7%

Robustness of correlation coefficients among crops

periods	rr_NZ	rr_+	rr_1
T1→T2	50.0%	50.0%	50.0%
T2→T3	100.0%	100.0%	0.0%

- In many regions, the sign of the correlation coefficient was the same and significant over the two periods. ・・・・・ SYF structure is robust over time.

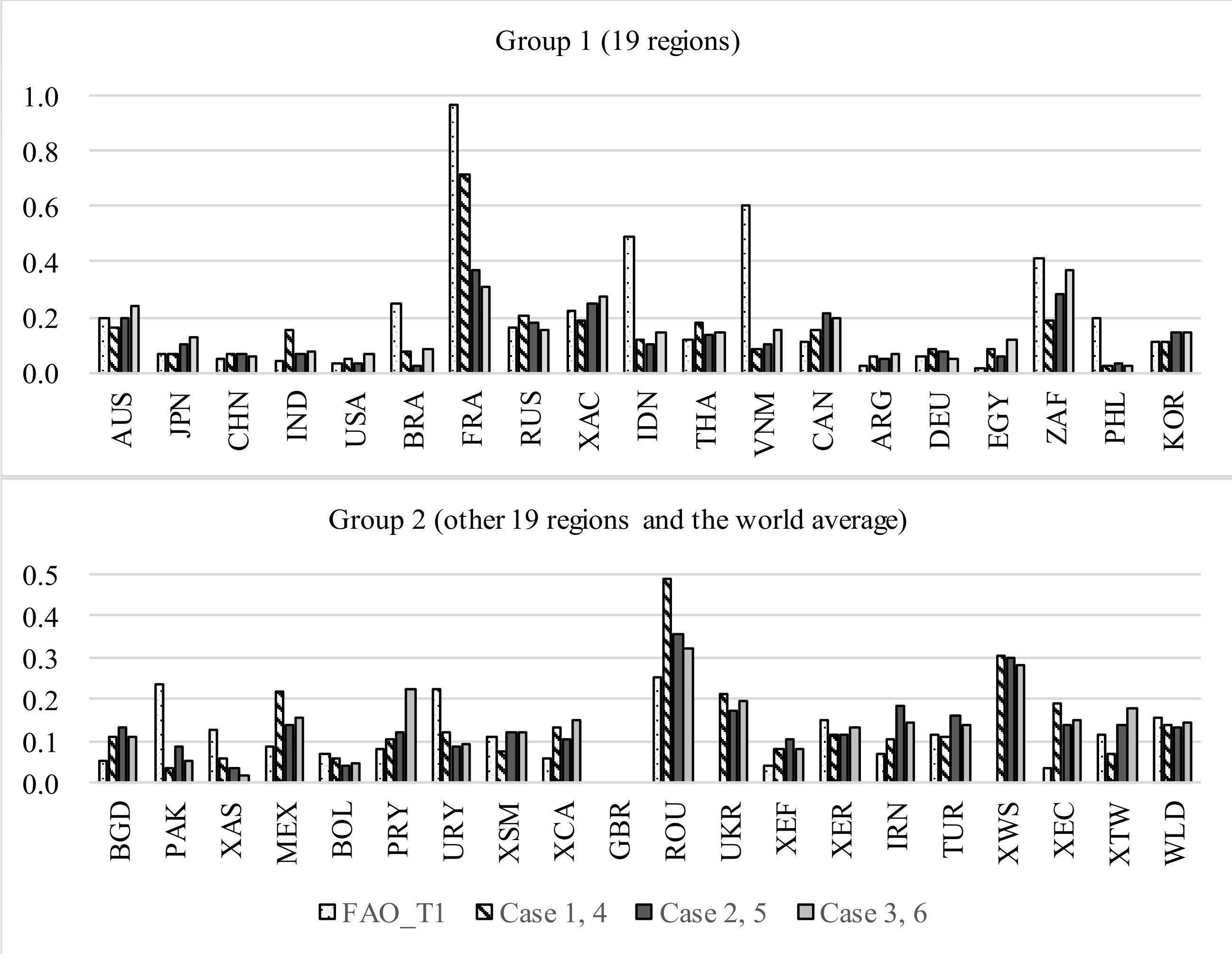
Standard deviation of EFP by region and case (average of 4 crops) as initial shocks

- Fluctuation ranges of EFP shocks were different by regions.
- However, fluctuation ranges were similar among cases.

(Note)

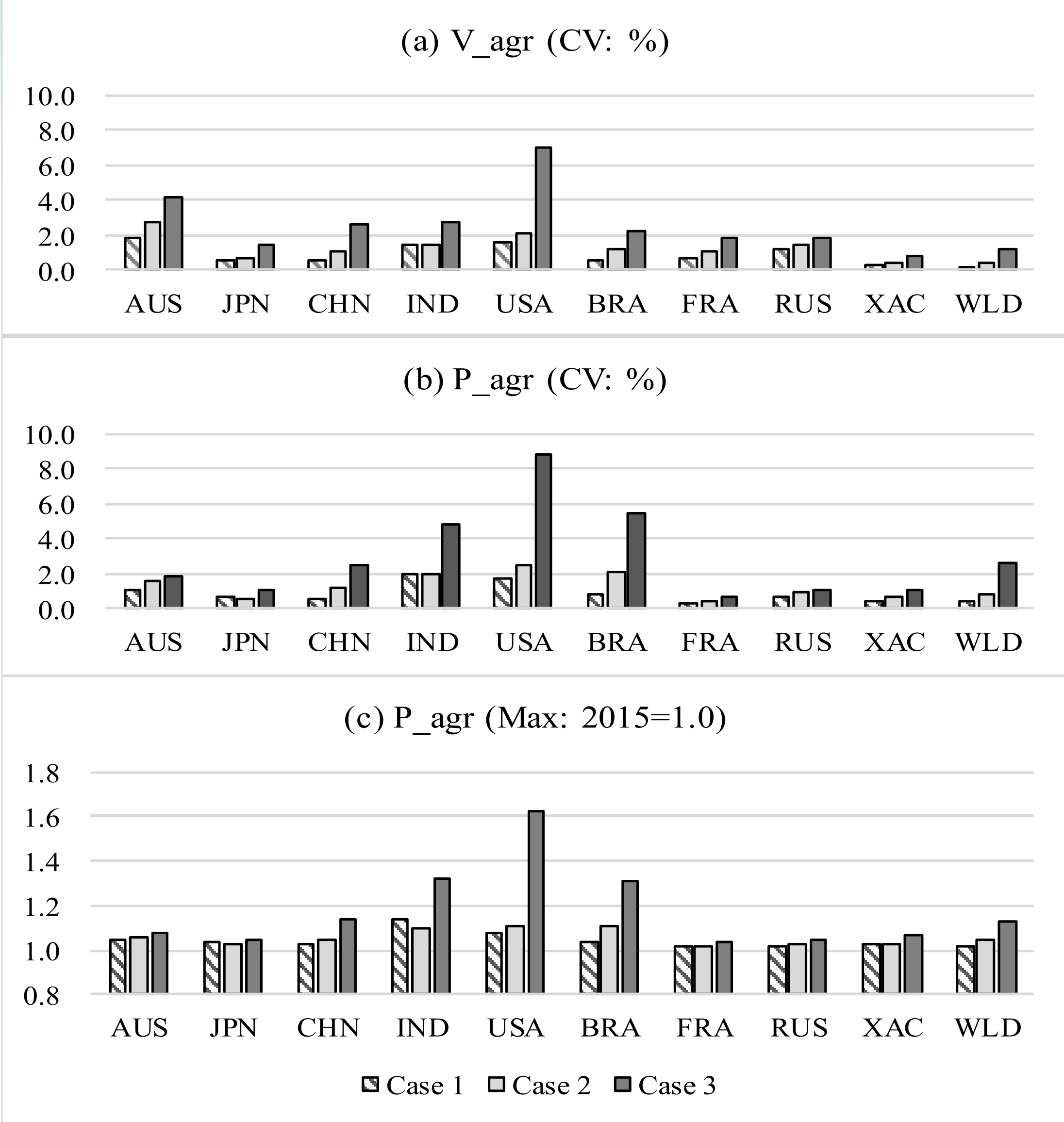
- FAO_T1: actual data of FAO's statistics during T1 period.
- Case 1 and 4: no SYF
- Cases 2, 3, 5, and 6 : with SYF

Average standard deviation of EFP (among four crops)



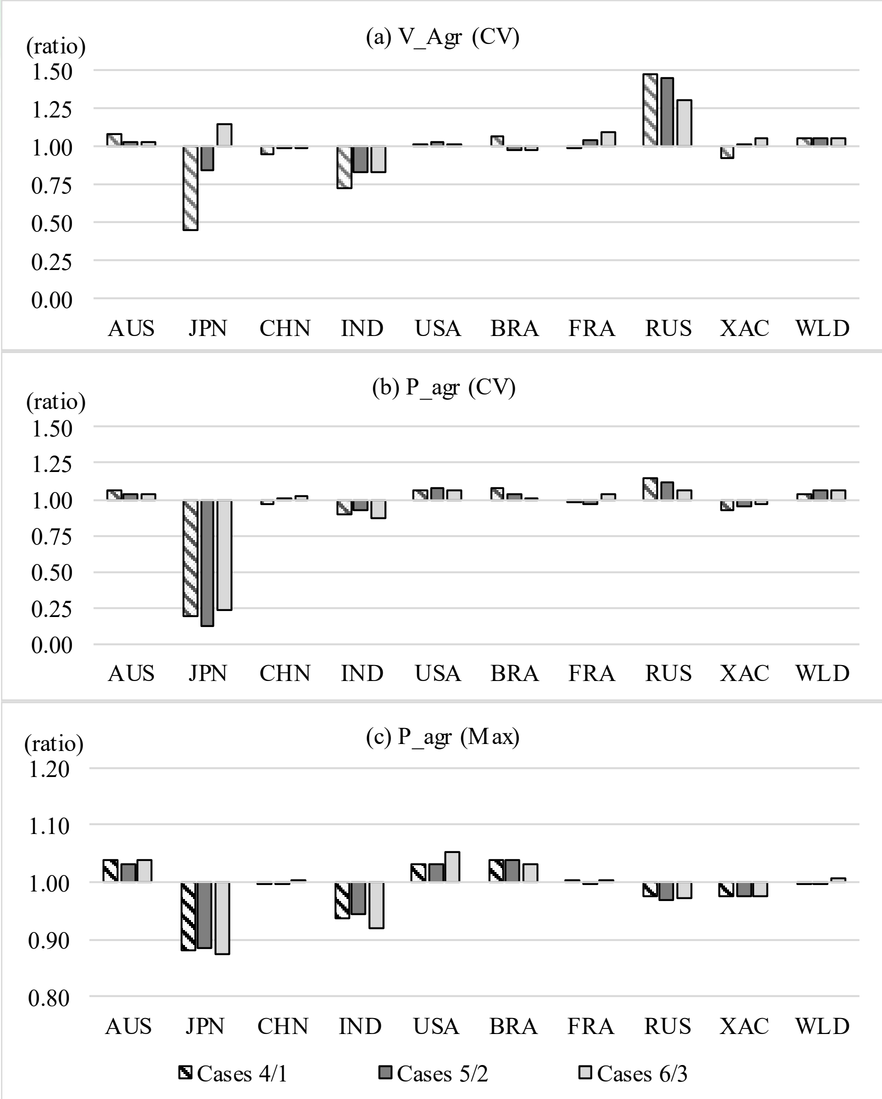
Influence of SYF on agricultural price

- The CV of agricultural value added (V_agr) and agricultural price (P_agr) were larger in Cases 2 and 3 than in Case 1 with non-SYF.
- The average CV in the T3 period increased 2.7 times for Brazil (BRA) and 6.8 times for the United States (USA) as compared to the non-SYF case.
- Regions with large agricultural price volatility, such as the United States, and Brazil, are regions with large domestic agricultural production.



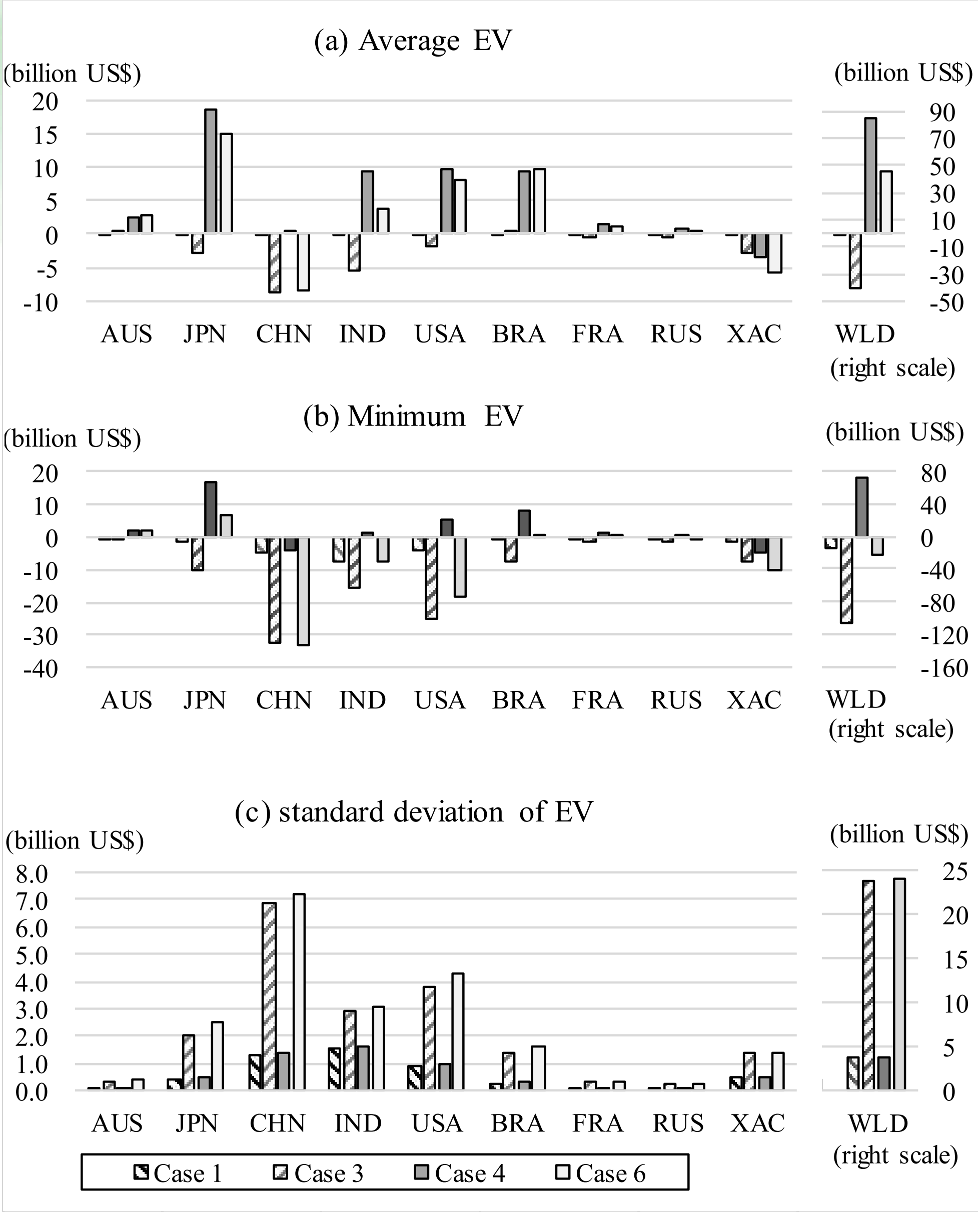
Effects of agricultural trade liberalization on food price volatility

- Cases 4/1: CV in domestic agricultural production decreased in food importing countries, such as Japan and India, but increased some regions like Russia (RUS).
- In Japan and India TL reduced the CV of P_agr. On the other hand, Australia (AUS) and Russia (RUS) increased volatility of V_agr and P_agr due to trade liberalization.
- Comparing Cases 4/1 (non-SYF), Cases 5/2 (T2 period), Cases 6/3 (T3 period) in CV and maximum price, no significant differences between the three ratios were found.
- Effects of trade liberalization, on global average, were similar with or without SYF under climate change.



Influences of SYF on social welfare level

- Case 3 vs. 1 -> the effect of SYF under climate change only
  - SYF decreased social welfare levels in most regions
- Case 4 vs. 1 -> the effect of TL only
  - Trade liberalization increased social welfare levels in many regions
- Case 6 vs. 1 -> the impacts of both SYF and TL
  - The average EV in Case 6 increased in the USA and Brazil, but, at minimum EV, the USA's EV was worse than in Case 1.
- The EV's standard deviation in Cases 3 through 6 were larger than in Case 1.
- In other words, both SFY and TL widened the gap between a good and a bad social welfare year.



Policy implications

- The SYF expands the volatility of food price and EV under future climate change, so SYF can be a cause of systemic risk to the global economy.
- Even food exporting countries (USA) would suffer from rising food prices in an extreme year.
  - A rise in US food price would be led by an increase in agricultural exports motivated by a rise in world food price during simultaneous global crop failure under future climate change. -----> adoption of "embargo policy"
- Enlarging global food stocks and developing high-temperature-tolerance varieties of food are of course needed, but keeping domestic agricultural production in a certain amounts is also important.
- Enhancing the insurance system is needed to compensate for global crop failures.
- The accuracy of climate, crop, and economic models that can predict degree of risk is key. -----> more studies and more statistics

Summary and conclusion

- Synchronicity of annual crop-yield fluctuation is statistically stable among countries as well as among four crops and will be enhanced by future climate change.
- Such SYF is responsible for the agricultural price volatility, and the coefficient of variation increasing 7.1-5.5 times in some regions as compared to the random disturbance (non-SYF) case.
- SYF lowers social welfare levels more than would be expected in non-SYF case, and these negative effects of SYF appear before and after trade liberalization with the same extent.

Summary and conclusion (cont.)

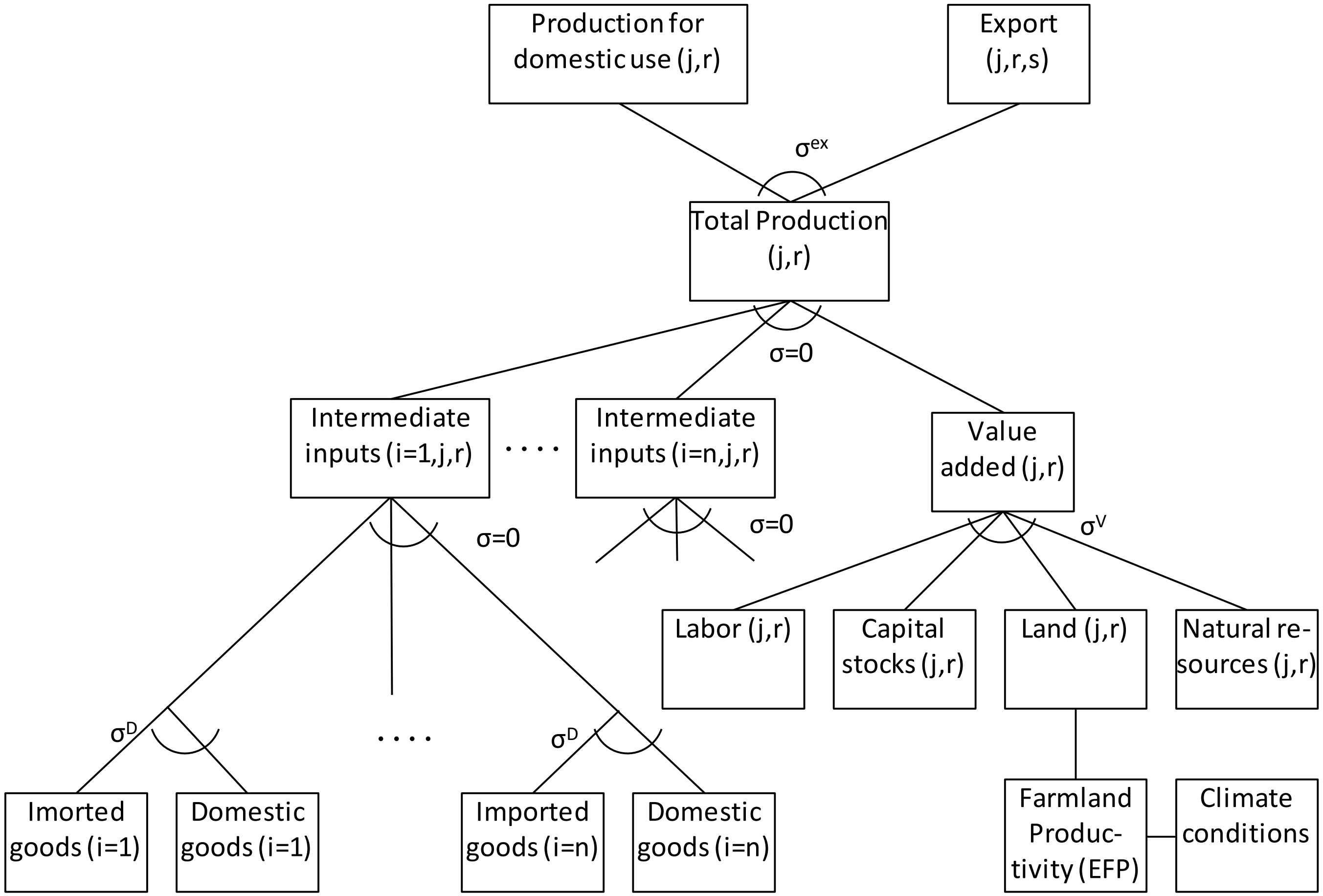
- These outcomes were not due to disturbance ranges of initial shocks, but synchronicity in crop yields matters.
- Thus, SYF is a cause of systemic risk to food security and it must be considered in the design of agricultural policy and insurance systems.

Thank you for listening！

Comments and questions are welcome.

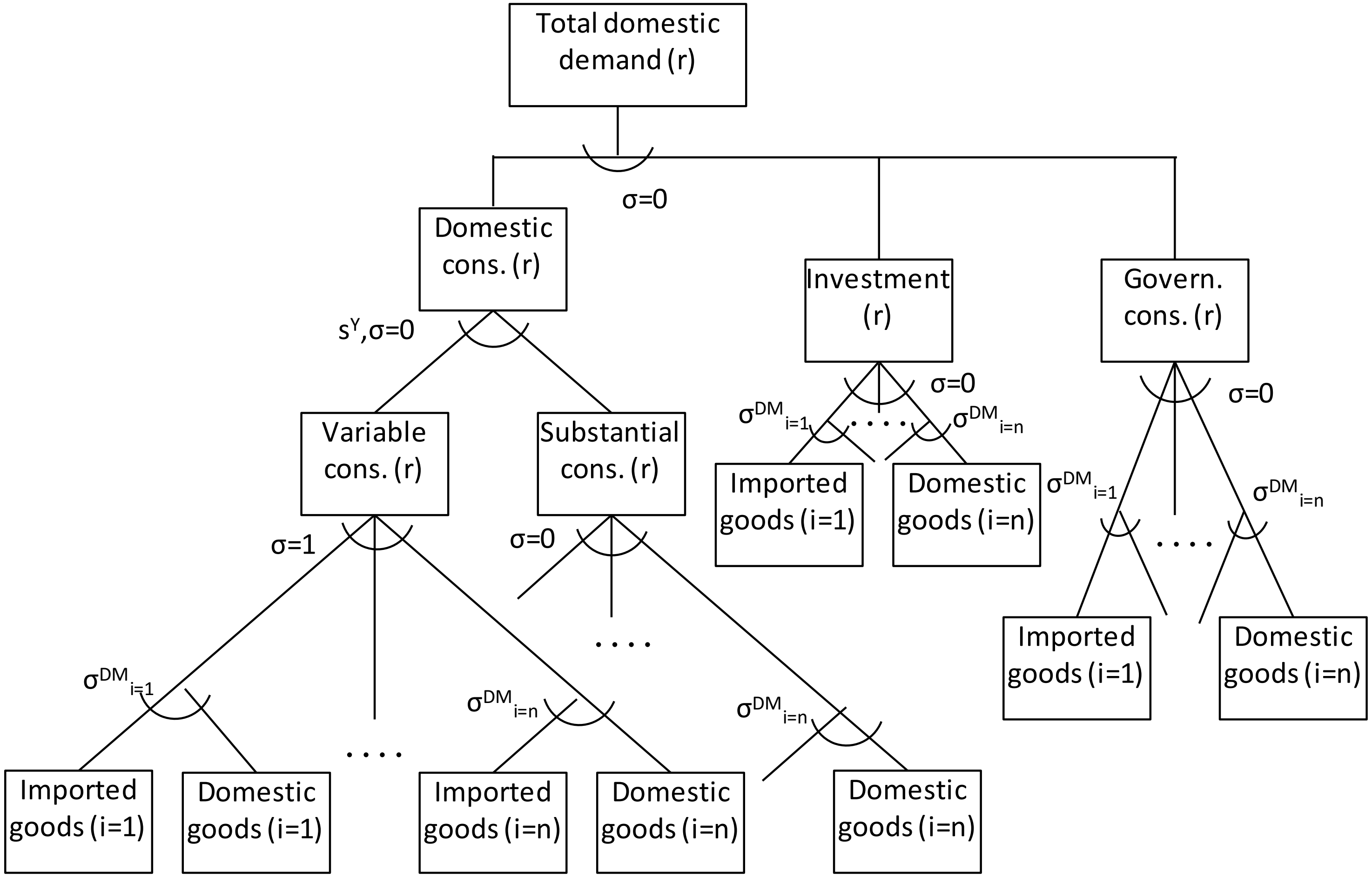
CGE model (Lanz and Rutherford, 2016)

- Nested production function



CGE model (Lanz and Rutherford, 2016) cont.

- Consumption (LES), Investment



CGE model (Lanz and Rutherford, 2016) cont.

- Import and export