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Quantifying the Effects of Agricultural Autarky Policy: Resilience to Yield Volatility and Export Restrictions

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Abstract In the wake of the 2007–2008 global food crisis, various national governmental bodies aimed at increasing their food self-sufficiency to stabilize their domestic markets. Despite the fact that food self-sufficiency is a long-standing policy discussion issue, its effectiveness has not been fully scrutinized with a quantitative modeling approach. Japan's government rigorously protects domestic agricultural producers on the grounds of national food security and, hence, has grappled with enhancing the country's food self-sufficiency, even though economists have strongly argue against this, in terms of the inefficiency of resource allocation. This study developed a stochastic world trade computable general equilibrium model to quantify the benefit/loss of wheat autarky policies for Japan against wheat yield shocks and export bans. It was found that the comprehensive economic burden to materialize full self-sufficiency in wheat is approximately $8700 million, regardless of which of the two methods of market intervention—increasing the import tariff or subsidizing production--is used. Greater self-sufficiency causes higher volatility in the domestic wheat price due to the yield variability in exporting nations being more destabilized than that in exporting countries. Also, the autarky strategies almost halve the welfare deterioration induced by export restrictions, although it does not pay for the implementation cost.

Keywords: *food self-sufficiency, food policy, agricultural yield, export restrictions*

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1. Introduction

Climate change has been identified as having an impact on agricultural and food markets through the increasing frequency of floods and droughts, according to the Fifth Intergovernmental Panel on Climate Change assessment report. Australia, for instance, experienced severe drought in 2006 and 2007, consecutively. More frequent crop failures occurred in Russia and Ukraine due to dry weather in 2010 and 2012, because of which these nations imposed export restrictions to protect their domestic markets, leading to international food market chaos. The price volatility in the global markets was transmitted to regional markets in both developed and developing markets, where societal and political unrest, such as food riots, was provoked [1]. Under such circumstances in these food markets, various countries adopted protectionist regimes by erecting trade barriers, such as import/export taxes or quotas, and renewed attention was drawn to food self-sufficiency after a long period of inactivity since the early 2000s when agricultural prices were low due to the globalization movement. Various governments have aimed to build food autarky systems, including Japan, the UK, Senegal, India, the Philippines, Qatar, Bolivia, and Russia [2].

The government of Japan has an avid interest in food self-sufficiency, using it as an excuse to protect domestic farmers and related-organizations [3]. The self-sufficiency rate of Japan used to be approximately 80% (on a calorie basis) in 1960, but has fallen to only 40% in recent years, which is the lowest number among the Organisation for Economic Co-operation and Development member countries. This downturn resulted from a comparative advantage for Japan in which the secondary and tertiary sectors were rapidly developed at the cost of the growth of the agricultural sector. A questionnaire given out by the government showed that more than 70% of the citizens felt that a 40% food self-sufficiency was low, and more than 80% expressed concern over the food supply, indicating that a great many Japanese residents wanted an increase in food self-sufficiency to ensure food access and steady markets. Contrarily, economists who espouse modern economic theories have strongly argued against this popular notion because increasing self-sufficiency will involve an intolerable economic burden, impairing the efficiency of resource allocation.

The staple diet of Japanese people is rice. The country's self-sufficiency reaches almost 94%, with a prohibitively high import tariff of 800%. Pressure from international political communities to open the border to rice imports have been refused by Japan on the grounds of its concerns about a steady food supply. Tanaka and Hosoe [4] examined the validity of the justification made by the government, concluding that abolishing rice trade barriers would be desirable for the Japanese people because the gain from freely-traded rice would exceed the loss from yield variations in foreign countries by far. In other words, Japan could improve the livelihoods of the Japanese people by accepting a lower self-sufficiency in rice.

Wheat has become an increasingly more important food commodity since the end of the Second World War, with the General Headquarters of the US reforming Japanese society, a part of which has involved donated food stuffs, such as bread for school lunches, and an introduction of the Western culture; these have been willingly accepted by the indigenous people. These events diversified the pattern of food consumption, expediting wheat consumption through the eating of bread and pasta. Although the people heavily rely on traditional Japanese meals, they also consume international foods on a daily basis today. While self-sufficiency in rice is at more than 90%, wheat amounts to only 12%, with 20%, 21%, and 58% being imported from Australia, Canada, and the US in 2011, respectively (FAOSTAT). The tariff rates on durum wheat and wheat flour are set at 65 JPY/kg and 106 JPY/kg, respectively (Trade Statistics of Japan). In spite of an abundance of studies in the existing literature on the effect of self-sufficiency in food, most of them are dedicated to a descriptive or qualitative method, while quantitative studies are scarce [3].

This study analyzed the impacts of wheat self-sufficiency policy in Japan, using a world trade stochastic computable general equilibrium (CGE) model with the Monte Carlo method, assuming that wheat autarky can be achieved by increasing its import tariff or production subsidy. We conducted three types of simulations. First, full self-sufficiency in wheat was simulated by hiking either the import tariff or production subsidy for wheat (deterministic simulations). Second, we scrutinized the resilience of households or local markets against wheat yield shocks with/without a food autarky policy (stochastic simulations). Finally, the durability of Japan's economy against export bans by major exporting countries was investigated (deterministic simulations).

This analysis contributes to the literature in several ways. We discovered the implementation costs of achieving 100% self-sufficiency in wheat through import tariff or farming subsidy. Second, the benefit/loss of the policy measure against probabilistic productivity shocks was revealed. Finally, we quantified the effects of the wheat autarky system, in relation to export restrictions by Australia, Canada, and the US, on household welfare in Japan. The quantification of self-sufficiency strategies is of vital importance in judging whether those measures deserve to be enforced, although the literature has largely ignored quantitative analyses on this issue.

2. Data and Method

We constructed a multi-regional CGE model using the Monte Carlo method, following Tanaka and Hosoe [4], which extends the single-country model developed by Devarajan et al. [5]. The major modification to the model of Tanaka and Hosoe [4] was the incorporation of regional correlations in randomly-generated productivity shocks in the model. In particular, the previous model underestimated the extreme positive and negative shocks that simultaneously occurred in different regions. Our model, on the other hand, considered the correlated relationships between countries when generating weather-induced productivity shocks, following the method of Erhan et al. [6].

For the estimation of yield variations, the data for production and area harvested from the FAOSTAT were used. The data source of the CGE model was GTAP version 9, from which a multi-regional social accounting matrix was composed of 13 regions, 10 sectors, and 5 production factors (Table 1).

Table 1. Aggregations in the model

Region	Sector	Factor
Australia	Paddy rice	Skilled labor
Canada	Wheat	Unskilled labor
France	Other cereals	Capital
Germany	Other crops	Farmland
Japan	Livestock and meat	Natural resources
Kazakhstan	Food	
Russia	Extraction	
Ukraine	Manufacturing	
USA	Service	
Rest of the World	Transport	

2.1. Yield Volatility

We measured yield variability for each region using the autoregressive integrated moving average (ARIMA) method to remove time trends, which is fit to time-series yearly data on wheat yield. The residuals generated from the regressions were used to estimate productivity volatilities. The ARIMA models are presented as follows:

$$Y_{t,r} = \sum_{i=t-p}^{t-1} \delta_{i,r} Y_{i,r} + \sum_{j=t-q}^{t} \theta_{j,r} \mu_{j,r} \quad (1)$$

where δ_i and θ_j signify the parameters to be estimated, and Y_i and μ_j are wheat yield and the forecast error in a given period of time, respectively [7]. The subscripts p, q, and r describe the number of autoregressive terms, the number of moving average terms, and the region, respectively. The Akaike information criterion was used to select the models. The results of the coefficients and standard deviations (SDs) of yield volatility are presented in Table 2.

Based on the SDs, 1000 non-correlated randomized yield shocks were generated, following $N(1, \sigma_r)$. Non-correlated iterations were converted into regionally correlated iterations by a Cholesky decomposition of the covariance matrix [6]. The Pearson correlation values between regions are illustrated in Table 3.

Table 2. Results of the ARIMA models

	Autoregressive factor			Moving average factor		
						SD
Japan	0.73		-1.24	-0.49	0.74	0.107
Australia	0.06	0.13	-1.00			0.196
Canada	-0.42		0.00			0.079
France	-0.34		-0.99			0.083
Germany	0.19	-0.34	-1.00			0.066
Kazakhstan	-0.28		-1.00			0.159
Russia	0.87	-0.38	-1.98	0.99		0.098
Ukraine	-0.34					0.159
USA	0.18	-0.39	-1.00			0.061
Rest of the World (ROW)	0.03		0.99			0.044

Table 3. Pearson correlations between regions

	Japan	Australia	Canada	France	Germany	Kazakhstan	Russia	Ukraine	USA	ROW
Japan	1.00									
Australia	-0.19	1.00								
Canada	-0.27	0.11	1.00							
France	0.22	0.33	0.12	1.00						
Germany	-0.08	0.22	0.12	0.35	1.00					
Kazakhstan	0.33	-0.06	-0.39	-0.28	-0.32	1.00				
Russia	0.03	0.00	-0.11	-0.38	0.03	0.56	1.00			
Ukraine	0.08	-0.03	-0.11	-0.17	0.31	0.22	0.59	1.00		
USA	-0.40	-0.18	0.37	-0.25	-0.10	-0.02	-0.19	-0.08	1.00	
ROW	0.07	0.19	0.05	0.03	0.29	0.00	0.42	0.54	-0.21	1.00

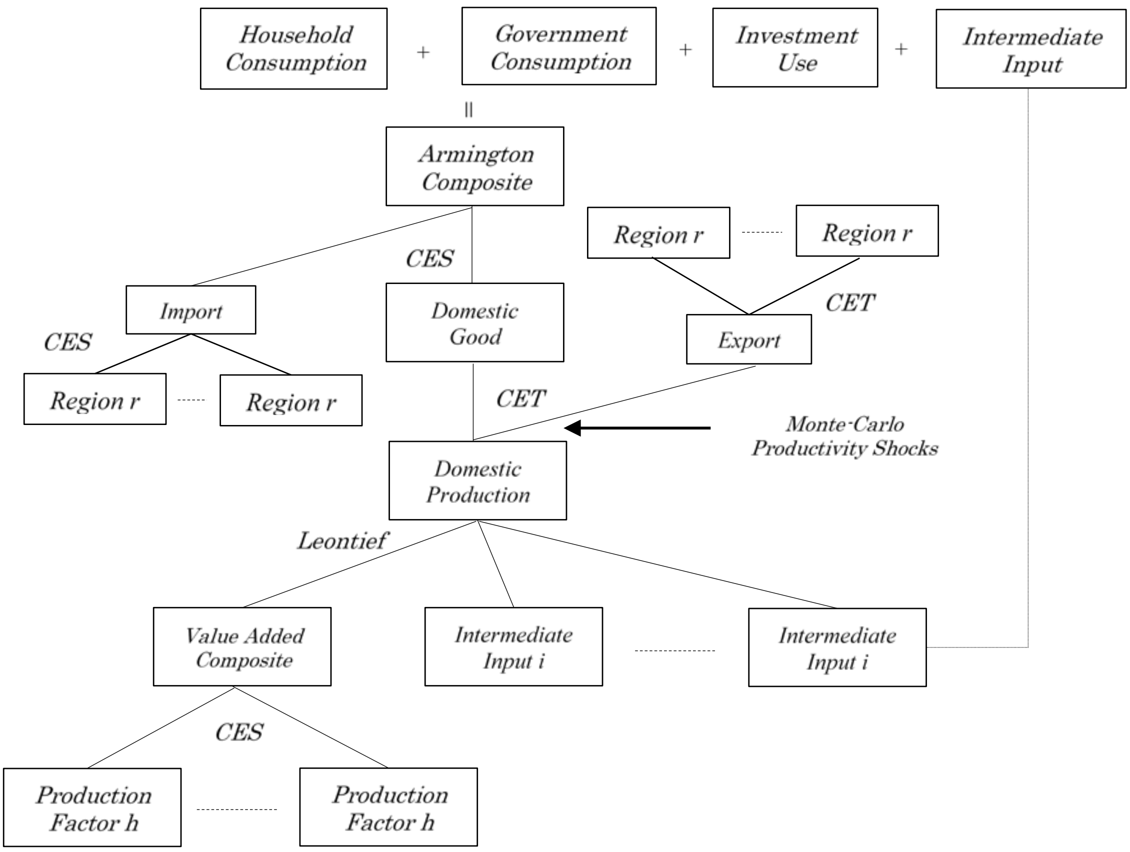

Figure 1. Overview of the model

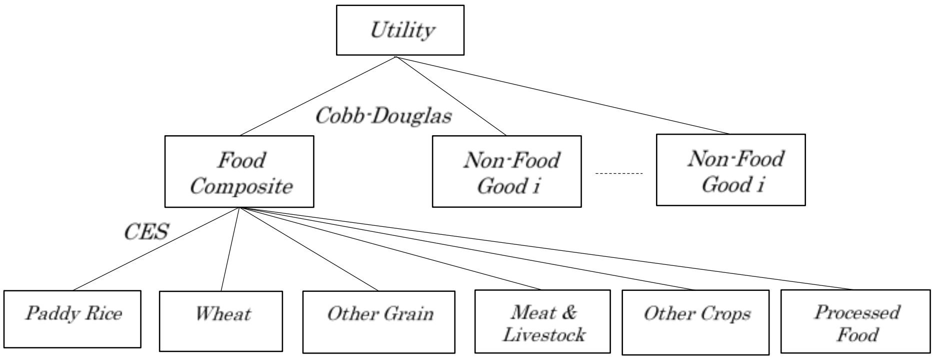

Figure 2. Structure of household consumption

2.2. Model Structure

Each region encompassed 10 sectoral industries and five factors of production (Table 1). Each representative industry behaved as a perfectly competitive, profit-maximizing producer, following the Leontief formula (Figure 1). Value-added production factors were aggregated to produce a value-added composite good, using a constant elasticity of substitution (CES) production function (Figure 2). We assumed an elasticity of substitution of 0.26 for the cereal industries (paddy rice, wheat, and other grains), quoting the GTAP Database version 9[1]. Factor mobility was assumed in two ways for different scenarios: 1) all the factors were assumed to be mobile across industries, but not across international boundaries, under full market adjustment; and 2) only unskilled labor was assumed to be able to move between sectors, while the other factors were fixed for a short-term setting. All factors were assumed to be fully employed.

Sectoral outputs produced by representative firms were distributed between foreign and domestic markets, using the constant elasticity of transformation technology. The domestic goods and composite imports were integrated to make composite goods with a CES function [9]. The import composite goods comprised imported goods from various regions, and the composite exports were disaggregated into exports from individual regions.

Composite goods synthesized by domestic goods and composite imports were consumed by households, government, investment agents, and other sectors as intermediate inputs. Food-related products aggregated for a food composite, using a CES function, directly contributed to the utility of the representative household, with non-food products using the Cobb-Douglas formula (Figure 2). Following estimates from past studies, the elasticity for a household's food consumption was assumed to be 0.1[2].

2.3. Scenario Design

We established 14 scenarios to analyze the economic solidarity of Japan against productivity shocks and export bans. The scenarios shown in Table 4 are categorized into three parts. First, the 'Reference' scenario has no shock. In Scenarios T and S, the nation achieves 100% self-sufficiency in wheat through hiking import tax or production subsidy, respectively. These scenarios were assumed to measure the long-term effects under the full market adjustment, in which all five factors were mobile across sectors, but did not go beyond the national boundaries.

The second set of experiments was designed for gauging the probabilistic effects of yield shocks. In Scenarios A, J, and R, productivity varied in all the regions, only in Japan, and only in the rest of the world, respectively. Scenarios A-T, J-T, and R-T added an import tax shock to Scenarios A, J, and R. Scenarios A-S, J-S, and R-S alike were established to evaluate the robustness of the economy against yield variations in all the regions, Japan, and the rest of the world, respectively, under wheat autarky controlled by an additional production subsidy to wheat farmers. These scenarios pondered the short-term effects, using a partial factor mobility assumption, under which only labor was movable across industries, but not internationally, and the other four factors were immobile.

The third group of scenarios (Ex, Ex-T, and Ex-S) simulated wheat export restrictions to Japan by its major trading partners, such as Australia, Canada, and the US, under different assumptions—no self-sufficiency policy, full self-sufficiency attained by elevating import tariffs, and farming subsidy. In these scenarios, simulations were also run to assess the short-term impacts, using the identical factor mobility assumption employed in the second category of scenarios.

Table 4. Scenarios

	Import	Production	Yield Shock		
	Tariff	Subsidy	Japan	ROW	Export Ban
Reference					
T	×				
S		×			
A			×	×	
J			×		
R	×			×	
A-T	×		×	×	
J-T	×		×		
R-T				×	
A-S		×	×	×	
J-S		×	×		
R-S		×		×	
Ex-T	×				×
Ex-S		×			×

[1] See Table A2 for the elasticities of other sectors.
[2] The price elasticity of demand for wheat and maize was -0.12 and -0.24, respectively [8].

3. Results

This section reports the simulation results based on the three types of experiments. First, we explain the deterministic outcomes, assuming that full self-sufficiency was materialized by increasing the import tariff on wheat or the production subsidy to wheat farmers. Second, we present stochastic results in which 1000 productivity shocks were given to each region, with or without the wheat autarky policies. Finally, we assumed that major exporters of wheat to Japan, namely Australia, Canada and the US, imposed export bans on wheat to Japan using a deterministic approach.

3.1. Realization of Wheat Autarky Attained by Import Tariff or Production Subsidy

The level of import tariff calculated from the GTAP Database was about 70%, which would need to be at 386% for Japan to be self-sufficient in wheat (Scenario T). Subsidy to the wheat sector was around 54% in 2011, and would need to be set at 82.8% to make the country self-sufficient (Scenario S). In spite of the identical policy goal between the scenarios, they differ in several ways. Scenarios T and S created heterogeneous impacts on household welfare; however, systemic impacts, including Equivalent Variation (EV) and tax revenue changes, were estimated at around $8700 million. Subsidy lowered the domestic wheat price and, accordingly, expedited its consumption, while the import tariff pushed up local prices and decreased the consumption of wheat. Therefore, the EV is lowered by the latter policy. By contrast, household welfare was ameliorated by subsidization. Some nations experienced welfare degradation with the policy measures taken by Japan, mainly because major exporters to Japan, such as Australia, Canada, and the US, missed opportunities to sell their products to Japan, and Russia—a large exporting nation—suffered a loss due to the lower international price caused by decreased demand on the global market, in spite of the fact that it did not export much wheat to Japan.

3.2. Analysis Using Weather-induced Yield Shocks

With no self-sufficiency policy measure being implemented (Scenarios A, J, and R), foreign yield variabilities more significantly affected variables such as domestic price, household consumption, household welfare, and producer price (Table 6). Before carrying out the policy, the productivity shocks originating in Japan had limited impacts on both welfare and local price (the SDs in Scenario J), most of which were attributable to foreign yield variations (the SDs in Scenario R). This is because the self-sufficiency rate arrived at only 12% and, therefore, 88% needed to be wheat imported from overseas. The average welfare level amounted to about −$2800 million when the complete self-sufficiency was actualized with import tax (Scenarios A-T, J-T, and R-T), which, interestingly, increased the volatilities of EV compared with the counterparts of the no policy scenarios on the grounds that farming operators pushed up wheat production, with the domestic price being increased by hindering the import of inexpensive overseas wheat. Also, the yield volatility in Japan was generally greater than that in the primary exporting countries, such as the US and Canada, although Australia's yield was slightly more volatile than that of Japan (Scenarios A, J, and R). As stated, the subsidy scenarios boosted the mean of EV by approximately $1600 million (Scenarios A-S, J-S, and R-S); however, livelihood was destabilized in comparison with those in Scenarios A, J, and R, although the volatilities were marginally alleviated compared to those in the import tariff scenarios. The SDs in the subsidy scenarios were smaller than those in the no policy scenarios because the price became relatively elastic when supply was extremely scarce. Accordingly, subsidization expedited wheat farming activity and increased the supply, leading to a small elasticity and small volatilities of price.

3.3. Export Ban by Major Exporting Countries

The EV displayed in Table 7 was measured from the point after the implementation of the self-sufficiency policy (the welfare changes accompanying the import tariff or subsidization policies are excluded). Japan suffered a $4960 million loss with export restrictions by Australia, Canada, and the US (Scenario EX), but the damage was approximately halved by the self-sufficiency policy measures through either raising the import tariff or the farming subsidy (Scenarios EX-T and EX-S) (Table 7). These policy benefits were estimated at $2004 million and $2366 million under full self-sufficiency that was actualized by increasing the import tax or production subsidy, respectively; however, considering the fact that the overall cost, including the policy implementation welfare benefit/cost and a change in tax revenue, reached $8746 million and $8766 million by the two means, respectively (Scenarios T and S), and the economic burden to achieve 100% self-sufficiency exceeded 4.4 and 3.7 times the expected benefit, in the case of the export bans, which implies that a wheat autarky system in Japan would not likely pay for such a politically uncertain event, even if they occurred every year. Moreover, such extreme export quotas on wheat to Japan have never been imposed historically. Several nations, such as the USA, Canada, Australia, Russia, and Ukraine, receive benefits from the export restrictions imposed by the primary trade partners of Japan because large exporters of wheat enjoy opportunities to sell their wheat products at a higher price in response to shortages in the international market.

3.4. Robustness Tests

This subsection presents the results of the sensitivity analysis against the Armington elasticity that governs international trade flows, which is one of the most influential parameters in the simulation results. We conducted the identical simulations, changing the parameters by ±30% for each scenario, to check whether our main conclusions were maintained. In all the sensitivity simulations, the level of import tariff or production subsidy was readjusted to achieve full self-sufficiency using the Armington elasticity mended.

Table 5. Welfare impacts of self-sufficiency policy implementation

	EV [mil. USD]		Change in Tax Revenue [mil. USD]		Total [mil. USD]	
	T	S	T	S	T	S
	(1)	(2)	(3)	(4)	(1)+(3)	(2)+(4)
Japan	-2812.8	1660.9	-5952.8	-10426.9	-8765.6	-8766.0
Australia	-8.1	-14.6	-11.5	-11.6	-19.6	-26.3
Canada	-28.1	-24.0	-10.5	-9.6	-38.6	-33.6
France	1.8	1.7	-0.6	0.0	1.2	1.6
Germany	0.8	0.2	-0.7	-0.3	0.1	-0.1
Kazakhstan	-1.7	-1.3	-0.6	-0.4	-2.3	-1.7
Russia	-9.2	-9.0	-16.8	-12.5	-26.0	-21.5
Ukraine	0.3	0.3	0.5	0.4	0.8	0.7
USA	-109.7	-106.1	63.6	55.8	-46.1	-50.3
RoW	68.1	15.1	-61.2	-48.8	6.9	-33.7

Unit: Million USD.

Table 6. Summary of the stochastic simulation results

	EV (Welfare) [mil. USD]				Change in Domestic Price [%]			
	Mean	SD	Min	Max	Mean	SD	Min	Max
A	-27.4	225.6	-1050.7	499.6	1.3	9.4	-21.5	43.1
J	3.5	13.1	-11.1	55.5	0.0	0.8	-2.2	3.3
R	-30.8	223.1	-966.1	504.7	1.3	9.4	-20.6	40.6
A-T	-2798.8	362.2	-4419.3	-1788.8	75.5	22.2	22.6	182.1
J-T	-2774.4	201.9	-3073.2	-1984.9	73.8	17.7	24.9	133.7
R-T	-2833.3	287.0	-3866.0	-2036.5	75.6	12.1	47.0	127.0
A-S	1658.1	327.2	199.8	2551.8	-35.6	7.5	-53.5	1.8
J-S	1679.5	109.8	1526.5	2063.9	-36.3	5.4	-50.3	-16.8
R-S	1639.7	295.6	601.0	2471.0	-35.7	4.8	-46.8	-14.8

Table 7. Effects of export bans by main trading partners

	EV [mil. USD]			Benefit [mil. USD]	
	Ex	Ex-T	Ex-S	Ex-T	Ex-S
	(1)	(2)	(3)	(2)-(1)	(3)-(1)
Japan	-4959.7	-2955.7	-2594.0	2004.0	2365.8
Australia	208.1	2.7	7.9	-205.3	-200.2
Canada	221.3	16.6	28.0	-204.6	-193.3
France	-2.2	4.3	2.3	6.4	4.5
Germany	18.1	0.9	1.3	-17.2	-16.8
Kazakhstan	13.4	-10.6	-6.1	-24.0	-19.5
Russia	168.2	-55.2	-32.2	-223.4	-200.4
Ukraine	108.3	-2.3	4.5	-110.6	-103.8
USA	404.2	136.4	112.8	-267.8	-291.4
RoW	87.4	114.5	-16.6	27.1	-104.0

Table 8. Sensitivity results for changes in the Armington elasticity by +30%: wheat autarky actualized by import tariff or production subsidy

	EV [mil. USD]		Change in Tax Revenue [mil. USD]		Total [mil. USD]	
	T	S	T	S	T	S
	(1)	(2)	(3)	(4)	(1)+(3)	(2)+(4)
Japan	-2030.3	1587.5	-6650.6	-10217.1	-8680.9	-8629.6
Australia	-8.8	-14.1	-11.9	-12.1	-20.7	-26.2
Canada	-30.8	-27.2	-11.0	-10.2	-41.8	-37.4
France	1.6	1.4	-0.3	0.2	1.3	1.7
Germany	0.6	0.1	-0.5	-0.1	0.1	0.0
Kazakhstan	-1.7	-1.2	-0.5	-0.4	-2.2	-1.6
Russia	-9.0	-8.0	-16.4	-12.5	-25.4	-20.5
Ukraine	0.1	-0.3	0.4	0.1	0.6	-0.2
USA	-108.7	-103.9	70.8	63.7	-37.9	-40.2
ROW	71.0	39.2	-59.0	-46.8	12.0	-7.6

Table 9. Sensitivity results for changes in the Armington elasticity by –30%: wheat autarky actualized by import tariff or production subsidy

	EV [mil. USD]		Change in Tax Revenue [mil. USD]		Total [mil. USD]	
	T	S	T	S	T	S
	(1)	(2)	(3)	(4)	(1)+(3)	(2)+(4)
Japan	-2030.3	1587.5	-6650.6	-10217.1	-8680.9	-8629.6
Australia	-8.8	-14.1	-11.9	-12.1	-20.7	-26.2
Canada	-30.8	-27.2	-11.0	-10.2	-41.8	-37.4
France	1.6	1.4	-0.3	0.2	1.3	1.7
Germany	0.6	0.1	-0.5	-0.1	0.1	0.0
Kazakhstan	-1.7	-1.2	-0.5	-0.4	-2.2	-1.6
Russia	-9.0	-8.0	-16.4	-12.5	-25.4	-20.5
Ukraine	0.1	-0.3	0.4	0.1	0.6	-0.2
USA	-108.7	-103.9	70.8	63.7	-37.9	-40.2
ROW	71.0	39.2	-59.0	-46.8	12.0	-7.6

Table 10. Sensitivity of stochastic results to changes in the Armington elasticity

	Standard Deviation			
	+30%	-30%	+30%	-30%
	EV [mil. USD]		Domestic Price [%]	
A	221.8	234.5	9.1	10.0
J	10.1	21.0	0.7	1.1
R	219.2	232.0	9.1	9.9
A-T	409.4	372.1	22.5	25.0
J-T	306.8	131.5	19.4	17.5
R-T	248.8	341.0	9.6	17.2
A-S	316.6	353.7	7.9	7.0
J-S	124.7	84.5	5.8	4.6
R-S	273.5	336.6	4.8	5.1

Table 11. Sensitivity results with changes in the Armington elasticity by +30%: impacts of export bans

	EV [mil. USD]			Benefit [mil. USD]	
	Ex	Ex-T	Ex-S	Ex-T	Ex-S
	(1)	(2)	(3)	(2)-(1)	(3)-(1)
Japan	-3263.9	-1584.9	-1475.1	1679.0	1788.8
Australia	125.0	-6.6	0.1	-131.7	-124.9
Canada	122.0	0.8	10.1	-121.2	-112.0
France	-1.9	2.1	1.3	3.9	3.1
Germany	11.8	0.0	0.5	-11.9	-11.4
Kazakhstan	9.0	-5.5	-3.5	-14.5	-12.4
Russia	109.1	-32.7	-20.1	-141.9	-129.2
Ukraine	70.9	-4.1	1.0	-74.9	-69.9
USA	225.2	52.5	51.8	-172.7	-173.4
ROW	52.0	53.0	-18.3	1.0	-70.3

Table 12. Sensitivity results with changes in the Armington elasticity by –30%: impacts of export bans

	EV [mil. USD]			Benefit [mil. USD]	
	Ex	Ex-T	Ex-S	Ex-T	Ex-S
	(1)	(2)	(3)	(2)-(1)	(3)-(1)
Japan	-10325.0	-6380.9	-5225.8	3944.2	5099.2
Australia	488.9	63.5	68.1	-425.4	-420.8
Canada	577.9	92.8	124.0	-485.1	-453.9
France	-1.8	9.9	4.5	11.7	6.3
Germany	37.6	5.1	5.6	-32.5	-32.1
Kazakhstan	27.5	-22.7	-9.7	-50.2	-37.3
Russia	354.5	-91.3	-31.4	-445.9	-386.0
Ukraine	222.7	12.0	27.1	-210.7	-195.6
USA	1048.2	418.3	342.1	-629.9	-706.1
ROW	357.5	360.3	-21.0	2.7	-378.5

The welfare changes of the self-sufficiency policy enforcement amount to around –$2030 million and $1587 million for Scenarios T and S, respectively, which is qualitatively robust, and the whole economic loss arrived at around $8600 million, which resembles the original outcomes (Table 8 and Table 9). Regarding the resilience of the economy, the SDs for welfare and domestic price seem to range narrowly, indicating that the volatility is attributable to external regions with no self-sufficiency measure, but is due more to domestic productivity variability using the autarky policy strategies in the robustness tests as well (Table 10). Although the extent of the welfare shocks against export restrictions by the trading partners is widely extended in the absolute term, the suffering under no policy implementation is halved by the autarky strategies in the sensitivity exercises (Table 11 and Table 12).

4. Conclusions

We analyzed the effectiveness of self-sufficiency in wheat in Japan against yield variability and export quotas, using a stochastic world trade CGE model. Our main findings are as follows. (1) The wheat autarky scheme achieved by boosting the import tariff or subsidizing wheat farming could affect Japan's economy in similar ways, by approximately $8700 million, while the two interventions negatively and positively varied household welfare, respectively. (2) Household welfare becomes more volatile with, rather than without, the policy measures because the wheat supply to households in Japan relies more on internal sources than external markets after the policy enforcement, and wheat productivity in Japan is more unstable than its major trade partners. (3) Once the wheat autarky system was established, household welfare degradation is significantly alleviated; however, the economic burden to make the country self-sufficient is greater than the benefit.

Tanaka [3] examined the effect of self-sufficiency in wheat for Egypt, concluding that its autarky system alleviated welfare and price volatility using a revenue-neutral approach. By contrast, we argue that self-sufficiency policies could increase the volatilities of welfare and domestic price of wheat in Japan. We found that the extended volatilities were attributable to the greater yield volatility in Japan, rather than those in foreign countries, despite that it is generally believed among people that self-sufficiency functions as a market stabilizer. One of the important findings is that agricultural market steadiness, when increasing self-sufficiency, crucially depends on the relative yield stability to exporting countries.

This paper focused only on the wheat sector in Japan, although a large proportion of the Japanese people are concerned about the supply of general food commodities. At the least, we found it economically irrational for the national government to intervene in the market to make the country self-sufficient in wheat, in the context of its national food security. Nonetheless, the value of agricultural farming ranges widely beyond securing the food supply, including, for example, maintaining the scenery in the countryside, the biodiversity, ecosystem, and farming communities. Such types of value seem to be difficult to estimate precisely, but they are an essential procedure for discussion and policy enactment. This topic is still open to future work.

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Appendix: Algebraic Model Summary

The full description of our world trade computable general equilibrium model is shown in Section A.1.

A.1 Model Structure

-Symbol

Sets

i, j : commodities/sectors (other than the food composite)

fd : food commodities/sectors

nfd : non-food commodities/sectors

ifd : non-food commodities plus the food composite

r, s, r' : regions

h : factors (capital, skilled labor, unskilled labor, farmland, natural resources)

Endogenous variables

$X^p_{i,r}$: household consumption

XFD_r : food composite

$X^g_{i,r}$: government consumption

$X^v_{i,r}$: investment uses

$X_{i,j,r}$: intermediate uses of the i-th good by the j-th sector

$F_{h,j,r}$: factor uses

$Y_{j,r}$: value added

$Z_{j,r}$: gross output

$Q_{i,r}$: Armington composite good

$M_{i,r}$: composite imports

$D_{i,r}$: domestic goods

$E_{i,r}$: composite exports

$T_{i,r,s}$: inter-regional transportation from the r-th region to the s-th region

TT_r : exports of inter-regional shipping service by the r-th region

Q^s : composite inter-regional shipping service

S^p_r : household savings

S^g_r : government savings

T^d_r : direct taxes

$T^z_{j,r}$: production taxes

$T^m_{j,s,r}$: import tariffs

$T^e_{j,r,s}$: export taxes

$T^f_{h,j,r}$: factor input taxes

p^{XFD}_r : price of food composite

$p^q_{i,r}$: price of Armington composite goods

$p^f_{h,j,r}$: price of factors

$p^y_{j,r}$: price of value added

$p^z_{i,r}$: price of gross output

$p^m_{i,r}$: price of composite imports

$p^d_{i,r}$: price of domestic goods

$p^e_{i,r}$: price of composite exports

$p^t_{i,r,s}$: price of goods shipped from the r-th region to the s-th region

p^s : inter-regional shipping service price in US dollars

$\varepsilon_{r,s}$: exchange rates to convert the r-th region's currency into the s-th region's currency

Exogenous variables and parameters

S^f_r : current account deficits in US dollars

$FF_{h,j,r}$: factor endowment initially employed in the j-th sector

$TFP_{j,r}$: productivity; $TFP_{wheat,r} \sim N\left(1,\sigma_r^2\right)$ or $N(1,0)$

σ_r : standard deviation of productivity in wheat sector

$Z^0_{j,r}$: initial amount of gross output

τ^d_r : direct tax rates

$\tau^z_{i,r}$: production tax rates

$\tau^m_{i,s,r}$: import tariff rates on inbound shipping from the s-th region

$\tau^e_{i,r,s}$: export tax rates on outbound shipping to the s-th region

$\tau^s_{i,r,s}$: inter-regional shipping service requirement per unit transportation of the i-th good from the r-th region to the s-th region

$\tau^f_{h,j,r}$: factor input tax rates.

-Household

$$Utility\ function: UU_r = XFD_r^{\alpha_r^{XFD}} \prod_{nfd} X^{p\ \ \alpha_{nfd,r}}_{nfd,r} \quad \forall r \quad (A.1)$$

Demand functions for consumption

$$X^p_{nfd,r} = \frac{\alpha_{nfd,r}}{p^q_{nfd,r}}\left(\sum_{h,j} p^f_{h,j,r}F_{h,j,r} - T^d_r - S^p_r\right) \quad \forall nfd,r \quad (A.2)$$

$$XFD_r = \frac{\alpha^{XFD}_r}{p^{XFD}_r}\left(\sum_{h,j} p^f_{h,j,r}F_{h,j,r} - T^d_r - S^p_r\right) \quad \forall r \quad (A.3)$$

Food composite aggregation function

$$XFD_r = \Theta_r\left(\sum_{fd}\Delta_{fd,r} X^{p\ \Psi}_{fd,r}\right)^{1/\Psi} \quad \forall r \quad (A.4)$$

(Note that $\Psi = (\varepsilon^f - 1)/\varepsilon^f$)

$$X^p_{fd,r} = \left(\frac{\Theta_r^{\ \Psi}\Delta_{fd,r}\, p^{XFD}_r}{p^q_{fd,r}}\right)^{\frac{1}{1-\Psi}} XFD_r \quad \forall fd,r \quad (A.5)$$

Savings function

$$S^p_r = s^p_r \sum_{h,j} p^f_{h,j,r}F_{h,j,r} \quad \forall r \quad (A.6)$$

-Value added producing firm
Factor demand function

$$F_{h,j,r} = \left(\frac{b_{j,r}^{\ \eta^{va}_j}\ \beta_{h,j,r}\, p^y_{j,r}}{\left(1+\tau^f_{h,j,r}\right)\ p^f_{h,j,r}}\right)^{\frac{1}{1-\eta^{va}_j}} Y_{j,r} \quad \forall h,j,r \quad (A.7)$$

(Note that $\eta_i^{va} = (\varepsilon^{va} - 1)/\varepsilon^{va}$).

Value added production function

$$Y_{j,r} = b_{j,r} \left(\sum_h \beta_{h,j,r} F_{h,j,r}{}^{\eta_j^{va}} \right)^{1/\eta_j^{va}} \quad \forall j,r \qquad (A.8)$$

-Gross output producing firm

(Production function:

$$Z_{j,r} = TFP_{j,r} \min\left(\left\{ \frac{X_{i,j,r}}{ax_{i,j,r}} \right\}_i, \frac{Y_{j,r}}{ay_{j,r}} \right) \quad \forall j,r) \qquad (A.9)$$

Demand function for intermediates

$$X_{i,j,r} = \frac{\alpha x_{i,j,r} Z_{j,r}}{TFP_{j,r}} \quad \forall i,j,r \qquad (A.10)$$

Demand function for value added

$$Y_{j,r} = \frac{ay_{j,r} Z_{j,r}}{TFP_{j,r}} \quad \forall j,r \qquad (A.11)$$

Unit price function

$$p_{j,r}^z = \frac{1}{TFP_{j,r}} \left(\sum_i ax_{i,j,r} p_{i,r}^q + ay_{j,r} p_{j,r}^y \right) \quad \forall j,r \qquad (A.12)$$

-Government

Demand function for government consumption

$$X_{i,r}^g = \frac{\iota_{i,r}}{p_{i,r}^q} \begin{pmatrix} T_r^d + \sum_{h,j} T_{h,j,r}^f + \sum_j T_{j,r}^z \\ + \sum_{j,s} T_{j,s,r}^m + \sum_{j,s} T_{j,r,s}^e - S_r^g \end{pmatrix} \quad \forall i,r \qquad (A.13)$$

Direct tax revenue

$$T_r^d = \tau_r^d \sum_{h,j} p_{h,j,r}^f F_{h,j,r} \quad \forall r \qquad (A.14)$$

Production tax revenue

$$T_{j,r}^z = \tau_{j,r}^z p_{j,r}^z Z_{j,r} \quad \forall j,r \qquad (A.15)$$

Import tariff revenue

$$T_{j,s,r}^m = \tau_{j,s,r}^m \begin{bmatrix} \left(1+\tau_{j,s,r}^e\right) \varepsilon_{s,r} p_{j,s,r}^t \\ +\tau_{j,s,r}^s \varepsilon_{USA,r} p^s \end{bmatrix} T_{j,s,r} \quad \forall j,s,r \qquad (A.16)$$

Export tax revenue

$$T_{j,r,s}^e = \tau_{j,r,s}^e p_{j,r,s}^t T_{j,r,s} \quad \forall j,r,s \qquad (A.17)$$

Factor input tax revenue

$$T_{h,j,r}^f = \tau_{h,j,r}^f p_{h,j,r}^f F_{h,j,r} \quad \forall h,j,r \qquad (A.18)$$

Government savings function

$$S_r^g = s_r^g \begin{pmatrix} T_r^d + \sum_{h,j} T_{h,j,r}^f + \sum_j T_{j,r}^z \\ + \sum_{j,s} T_{j,s,r}^m + \sum_{j,s} T_{j,r,s}^e \end{pmatrix} \quad \forall r \qquad (A.19)$$

-Investment

Demand function for commodities for investment uses

$$X_{i,r}^v = \frac{\lambda_{i,r}}{p_{i,r}^q} \left(S_r^p + S_r^g + \varepsilon_{USA,r} S_r^f \right) \quad \forall i,r \qquad (A.20)$$

-Armington composite good producing firm

Composite good production function

$$Q_{i,r} = \gamma_{i,r} \left(\delta_{i,r}^m M_{i,r}{}^{\eta_i} + \delta_{i,r}^d D_{i,r}{}^{\eta_i} \right)^{1/\eta_i} \quad \forall i,r \qquad (A.21)$$

(Note that $\eta_i = (\varepsilon - 1)/\varepsilon$)

Composite import demand function

$$M_{i,r} = \left(\frac{\gamma_{i,r}{}^{\eta_i} \delta_{i,r}^m p_{i,r}^q}{p_{i,r}^m} \right)^{\frac{1}{1-\eta_i}} Q_{i,r} \quad \forall i,r \qquad (A.22)$$

Domestic good demand function

$$D_{i,r} = \left(\frac{\gamma_{i,r}{}^{\eta_i} \delta_{i,r}^d p_{i,r}^q}{p_{i,r}^d} \right)^{\frac{1}{1-\eta_i}} Q_{i,r} \quad \forall i,r \qquad (A.23)$$

-Import variety aggregation firm

Composite import production function

$$M_{i,r} = \omega_{i,r} \left(\sum_s \kappa_{i,s,r} T_{i,s,r}{}^{\varpi_i} \right)^{1/\varpi_i} \quad \forall i,r \qquad (A.24)$$

Import demand function

$$T_{i,s,r} = \left(\frac{\omega_{i,r}{}^{\varpi_i} \kappa_{i,s,r} p_{i,r}^m}{\left(1+\tau_{i,s,r}^m\right) \begin{bmatrix} \left(1+\tau_{i,s,r}^e\right) \varepsilon_{s,r} p_{i,s,r}^t \\ +\tau_{i,s,r}^s \varepsilon_{USA,r} p^s \end{bmatrix}} \right)^{\frac{1}{1-\varpi_i}} M_{i,r} \quad \forall i,s,r \qquad (A.25)$$

-Gross output transforming firm

CET transformation function

$$Z_{i,r} = \theta_{i,r} \left(\xi_{i,r}^e E_{i,r}{}^{\varphi_i} + \xi_{i,r}^d D_{i,r}{}^{\varphi_i} \right)^{1/\varphi_i} \quad \forall i,r \qquad (A.26)$$

(Note that $\varphi_i = (\varepsilon_i + 1)/\varepsilon_i$)

Composite export supply function

$$E_{i,r} = \left(\frac{\theta_{i,r}{}^{\varphi_i} \xi_{i,r}^e \left(1+\tau_{i,r}^z\right) p_{i,r}^z}{p_{i,r}^e} \right)^{\frac{1}{1-\varphi_i}} Z_{i,r} \quad \forall i,r \qquad (A.27)$$

Domestic good supply function

$$D_{i,r} = \left(\frac{\theta_{i,r}{}^{\varphi_i} \xi_{i,r}^d \left(1+\tau_{i,r}^z\right) p_{i,r}^z}{p_{i,r}^d} \right)^{\frac{1}{1-\varphi_i}} Z_{i,r} \quad \forall i,r \qquad (A.28)$$

-Export variety producing firm

Composite export transformation function

$$E_{i,r} = \varsigma_{i,r}\left(\sum_{s}\rho_{i,r,s}{T_{i,r,s}}^{\phi_i}\right)^{1/\phi_i} \quad \forall i,r \qquad (A.29)$$

Export supply function

$$T_{i,r,s} = \left(\frac{{\varsigma_{i,r}}^{\phi_i}\rho_{i,r,s}p_{i,r}^{e}}{p_{i,r,s}^{t}}\right)^{\frac{1}{1-\phi_i}} E_{i,r} \quad \forall i,r,s \qquad (A.30)$$

Balance of payments

$$\sum_{i,s}\begin{bmatrix}(1+\tau_{i,r,s}^{e})\varepsilon_{r,USA}p_{i,r,s}^{t}T_{i,r,s} + S_r^f \\ +\varepsilon_{r,USA}(1+\tau_{TRS,r}^{z})p_{TRS,r}^{z}TT_r\end{bmatrix} = \sum_{i,s}\begin{bmatrix}\tau_{i,s,r}^{s}p^{s}\varepsilon_{USA,USA} \\ +(1+\tau_{i,s,r}^{e})p_{i,s,r}^{t}\varepsilon_{s,USA}\end{bmatrix}T_{i,s,r} \quad \forall r \qquad (A.31)$$

-Inter-regional shipping sector [10]
Inter-regional shipping service production function

$$Q^s = c\prod_{r}{TT_r}^{\chi_r} \qquad (A.32)$$

Input demand function for international shipping service provided by the r-th country

$$TT_r = \frac{\chi_r}{\left(1+\tau_{TRS,r}^{z}\right)\ \varepsilon_{r,USA}p_{TRS,r}^{z}}p^sQ^s \quad \forall r \qquad (A.33)$$

-Market-clearing conditions
Commodity market

$$Q_{i,r} = X_{i,r}^{p} + X_{i,r}^{g} + X_{i,r}^{v} + \sum_{j}X_{i,j,r} \quad \forall i,r \qquad (A.34)$$

Capital markets

$$FF_{CAP,j,r} = F_{CAP,j,r} \quad \forall j,r \qquad (A.35)$$

Labor market

$$\sum_{j}FF_{LAB,j,r} = \sum_{j}F_{LAB,j,r} \quad \forall r \qquad (A.36)$$

$$p_{LAB,j,r}^{f} = p_{LAB,i,r}^{f} \quad \forall i,j,r \qquad (A.37)$$

Foreign exchange rate arbitrage condition

$$\varepsilon_{r,r'}\cdot\varepsilon_{r',s} = \varepsilon_{r,s} \quad \forall r,r',s \qquad (A.38)$$

Inter-regional shipping service market

$$Q^s = \sum_{i,r,s}\tau_{i,r,s}^{s}T_{i,r,s}. \qquad (A.39)$$