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How to Improve World Food Supply Stability under Future Uncertainty: Potential Role of WTO Regulation on Export Restrictions in Rice

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Abstract In recent years, international grain markets have been exposed to considerable price volatility which was partly caused by supply shocks driven by extreme climate events affecting major grain exporters. In addition, a number of exporting countries resorted to distortive trade measures in the form of export restrictions which have led to additional shortages, undermining the reliability of the world trading system. Recent climate studies suggest that climate change-induced extreme events are likely to increase yield fluctuations. As trade volumes are also projected to increase, export restrictions constitute a systemic threat to the security of the global food supply. However, WTO rules and regulations on export restrictions are lenient, offering ample 'policy space' to member countries. In this context, this paper explores the potential welfare implications of productivity shocks and consequent export restrictions imposed on rice. We use a world trade stochastic computable general equilibrium (CGE) model with the Monte Carlo method, taking into account risk factors in the form of a wide range of productivity shocks to world rice supplies. Our findings suggest that welfare losses that are likely to be caused by increased yield variability, due to climate change or other factors, are expected to grow substantially if countries react to productivity shocks by imposing export restrictions. Losses incurred by rice importing countries in Asia and Africa are expected to be particularly high. The paper links these results to potential WTO reform initiatives aiming at improving world food supply stability under future uncertainty.

Keywords: *export restriction, rice, computable general equilibrium*

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1. Introduction

International grain markets have been exposed to considerable price volatility in recent years. The underlying cyclical and structural causes and the effectiveness of policy measures that aim to stabilize prices have been at the top of the research and policy agenda [1-14]. Continued price fluctuations were partly caused by supply volatility driven by extreme climate events which have affected major grain exporters such as Ukraine, Australia, Russia, Thailand and the United States (US) [15]. In addition, a number of exporting countries resorted to distortive trade measures in the form of export restrictions which have led to additional shortages, while also undermining the reliability of the world trading system [16,17,18,19,20].

By imposing export restrictions, countries intend to insulate their markets from external price fluctuations, but doing so often proves to be counterproductive [9,19,21]. As has been observed in recent years, while exporting countries followed each other's lead in reacting to price hikes by imposing restrictive measures, importing countries simultaneously reduced their applied tariffs [19]. As a result, the insulating effect of export restrictions was offset by increased international prices and higher volatility [20]. Hence there seems to be a collective action problem resulting in substantial distortion of commodity markets.

However, international trade rules and regulations, defined by the World Trade Organization (WTO), where such collective action problems could be prevented, are lenient about export restrictions [11,16,18,19,22,23]. WTO law offers ample 'policy space' for its members to institute export quotas if applied 'temporarily' to prevent or relieve a 'critical shortage' of 'essential' commodities like foodstuffs. However, it does not define the trigger mechanisms (i.e. what constitutes reaching the stage of 'critical shortage') or the legal boundaries of the legitimate scope and duration of such measures [18]. Moreover, WTO law is also almost silent on export duties, leaving this area, which is a growing source of trade distortion, unregulated or under-regulated. It allows Members to impose export duties on any commodity at any time [18,22,23].[1]

This is particularly problematic in light of the potential impacts of climate change, which are likely to aggravate price hikes and volatility. Recent model simulations suggest that by 2050, climate change might result in additional price increases ranging from 30–37% for rice and 52–55% for maize, to 94-111% for wheat [24,25,26]. The frequency and intensity of extreme events, which will damage the world's food supply chains, are expected to increase too [25,27]. Migration of production to areas of the world which suffer higher yield variability might also lead to a surge in productivity volatility [28,29,30,31,32]. In turn, countries may react to productivity shocks by instituting export restrictions [33].

At the same time, as a result of climate change, developing regions are predicted to increase their imports of grains substantially. For example, based on the CSIRO climate model (see footnote 3), South Asia, which exported around 15 million metric tons (mt) of cereals in 2000, is projected to import up to 54 million mt by 2050; the Middle East, North Africa and sub-Saharan Africa, which are already net importers of cereals, are expected to increase the volumes of cereals they import by around 30% [24]. As countries rely more on trade under the impact of climate change, export restrictions constitute a major systemic threat to the reliability of the world trading system [34,35,36,37,38].

In this context, this article explores the potential welfare implications of productivity shocks and consequent export restrictions imposed on rice.[2] We use a computable general equilibrium (CGE) model with a Monte Carlo simulation. Our method provides a comprehensive framework to analyse international rice markets under uncertainty. We take into account risk factors in the form of a wide range of productivity shocks to world rice supplies.

We simulate export restrictions on rice imposed by rice exporters in reaction to domestic productivity shocks. We explore how these shocks and consequent policy measures might affect domestic and international prices and trade flows in the rice sector. We also explore the implications of various alternatives for potential WTO reform aiming at maintaining sufficient domestic policy autonomy for most Members of the WTO while limiting the global welfare losses caused by export restrictions. Seeking such 'optimality', we explore the implications of (i) clearly defined trigger mechanisms and (ii) targeted differentiation of regulatory disciplines for export restrictions, whereby major exporters (defined by market share) react to the same productivity shocks by imposing lower levels of restrictions than minor exporters. By using a CGE model, we can depict the welfare elasticity of various disciplines that are differentiated at the supplier level.

This article is structured as follows. We first explain our world trade CGE model and simulation scenarios. Then, we present simulation results. In the last section we draw conclusions and discuss how our findings could inform the policy debate on the role of the WTO in improving global food security.

[1] However, there are exceptions. Some newly acceded members of the WTO, namely Mongolia, Ukraine, China, and the Russian Federation have specific accession commitments (known as "WTO-plus" commitments) to phase out export duties or to limit them to a designated number of tariff lines with a bound rate. See Karapinar [16].

[2] Rice has been selected since it is the most important staple food crop for the world's population (FAO) and it allows for the examination of export restrictions – as rice markets have recently been exposed to substantial price fluctuations, and distortive trade policy interventions.

2. Structure of the Stochastic CGE Model

The world-scale stochastic computable general equilibrium (CGE) model by Tanaka and Hosoe [39] (also [13,37], which is constructed based on the single-country CGE model by Devarajan et al. [40] is employed in the present research with the 2007 global social accounting matrices (SAM) composed of the Global Trade Analysis Project (GTAP) database version 8. The regional aggregation is made for rice producing, exporting, and importing countries. Each region has 12 sectors, and five factors of production (Table 1).

Table 1. List of regions, sectors, and factors in the model

Region	Sector	Factor
China	Paddy rice[b]	Capital
Egypt	Wheat[b]	Skilled labor
India[a]	Other grains[b]	Unskilled labor
Italy	Other agriculture[b]	Natural resources
Pakistan[a]	Processed rice[b]	Farmland
Philippines	Other food[b]	
Thailand[a]	Crude oil	
Uruguay	Coal	
USA[a]	Gas	
Vietnam[a]	Petroleum	
Rest of Asia	Transport	
Rest of Europe	Others	
Rest of Africa		
Rest of the World		

Notes: a and b indicate large exporters and food sectors in the model, respectively. Paddy and processed rice are husked and unhusked rice.

Each sector is represented by a perfectly competitive profit-maximizing firm with a Leontief production function for gross output and with a constant elasticity of substitution (CES) production function for value-added components (Figure 1). We quoted the elasticity of substitution for factors of production from the GTAP database, assuming 0.25 for agricultural sectors (paddy rice, wheat, other grains and other agriculture).[3] Assuming relatively short-term and uncertain situations under which farming sectors cannot fully respond to unexpected positive or negative productivity shocks, only unskilled labor is mobile across sectors, but not internationally. Other factors (skilled labor, capital, farmland, and natural resources) are immobile between sectors and between regions. The primary factors are fully employed.

[3] See Appendix for more information.

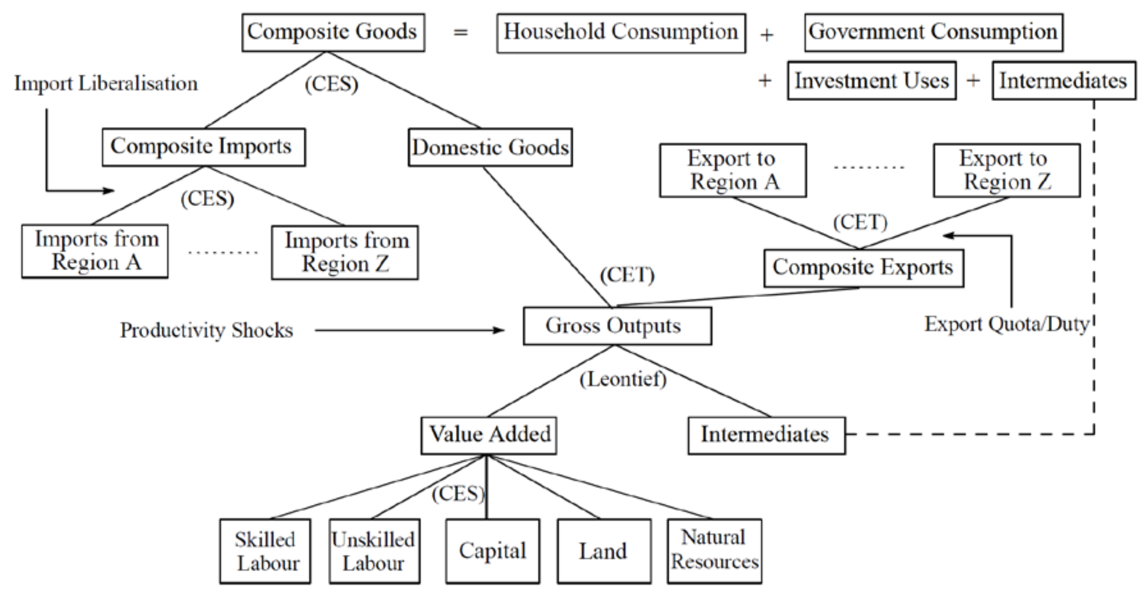

Figure 1. Model structure: Overview

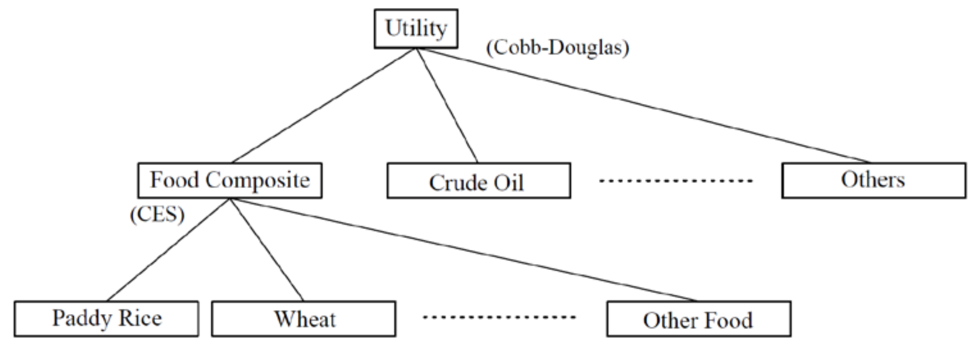

Figure 2. Model structure: Household consumption

Sectoral gross outputs are split into domestic outputs and composite exports using a constant elasticity of transformation (CET) function. The domestic goods and composite imports are aggregated into composite goods using a CES function as assumed by Armington [41]. The composite imports consist of imports from various regions, and the composite exports are decomposed into exports to various regions. For these CES/CET functions we use the elasticity of substitution as suggested in the GTAP database. Only in the rice stock scenarios are rice reserves released in the domestic markets.

The elasticity of substitution represents the similarity of goods differentiated by the origin and destination of trade. For example, the elasticity of substitution between the domestic goods and the composite imports is assumed to be 5.05 for paddy rice and 2.60 for processed rice. [4] Although we do not explicitly control for the different types of rice grains in the model, the nested CES structure approximately reflects the preferences of countries. Share parameters in the CES functions are calibrated to reproduce the actual trade flows of rice. Exchange rates are flexibly adjusted so that the current account balance remains constant in US dollar terms in all regions. The saving-driven investment is adopted as a model closure.

Composite goods are used for consumption by the representative household, as well as for government, investment, and intermediate input. Food commodities are aggregated to make food composite, which contributes to utility with non-food items (Figure 2). This structure describes substitution among foods in household consumption with a CES function, which gives flexibility to our assumptions about the price elasticity of demand of food. Following Tanaka and Hosoe [39], we assume that its elasticity of substitution is 0.1. If the commodity is non-food, it directly influences utility.

3. Simulation Scenarios

We conduct comparative static analyses considering the following scenario factors: (i) fluctuations of productivity in the paddy rice sector; (ii) non-differentiated export duties and quotas imposed by rice exporting countries; (iii) differentiated export duties and quotas imposed by rice exporting countries; (iv) partial abolition of trade barriers by rice importing countries.

[4] As is often assumed, these elasticities are doubled and used for the elasticity of substitution/transformation in the composite imports/exports aggregation functions. Sensitivity analysis is conducted with 50% larger and smaller elasticity values for paddy and processed rice sectors. The results indicate that our findings are qualitatively robust, as shown in the appendix.

Table 2. Simulation scenarios

		Export Quota		Export Tax		Import Tax	New Reference	2 x SD	Price Trigger	
No.	Scenario	Diff.	Non-diff.	Diff.	Non-diff.	Liberalization	Equilibrium		25%	15%
1	P									
2	P_2xSD							x		
3	P_N_2xSD						x	x		
4	DQ25-50_2xSD_25%	x				x		x	x	
5	DQ50-95_2xSD_25%	x				x		x	x	
6	NQ50_2xSD_25%		x			x		x	x	
7	NQ95_2xSD_25%		x			x		x	x	
8	Dduty25-50_2xSD_25%			x		x		x	x	
9	Dduty50-100_2xSD_25%			x		x		x	x	
10	Nduty50_2xSD_25%				x	x		x	x	
11	Nduty100_2xSD_25%				x	x		x	x	
12	DQ25-50_N_2xSD_25%	x				x	x	x	x	
13	DQ50-95_N_2xSD_25%	x				x	x	x	x	
14	NQ50_N_2xSD_25%		x			x	x	x	x	
15	NQ95_N_2xSD_25%		x			x	x	x	x	
16	Dduty25-50_N_2xSD_25%			x		x	x	x	x	
17	Dduty50-100_N_2xSD_25%			x		x	x	x	x	
18	Nduty50_N_2xSD_25%				x	x	x	x	x	
19	Nduty100_N_2xSD_25%				x	x	x	x	x	
20	DQ25-50_15%	x				x				x
21	DQ50-95_15%	x				x				x
22	NQ50_15%		x			x				x
23	NQ95_15%		x			x				x
24	Dduty25-50_15%			x		x				x
25	Dduty50-100_15%			x		x				x
26	Nduty50_15%				x	x				x
27	Nduty100_15%				x	x				x
30	DQ25-50_2xSD_15%	x				x		x		x
31	DQ50-95_2xSD_15%	x				x		x		x
32	NQ50_2xSD_15%		x			x		x		x
33	NQ95_2xSD_15%		x			x		x		x
34	Dduty25-50_2xSD_15%			x		x		x		x
35	Dduty50-100_2xSD_15%			x		x		x		x
36	Nduty50_2xSD_15%				x	x		x		x
37	Nduty100_2xSD_15%				x	x		x		x
38	DQ25-50_N_2xSD_15%	x				x	x	x		x
39	DQ50-95_N_2xSD_15%	x				x	x	x		x
40	NQ50_N_2xSD_15%		x			x	x	x		x
41	NQ95_N_2xSD_15%		x			x	x	x		x
42	Dduty25-50_N_2xSD_15%			x		x	x	x		x
43	Dduty50-100_N_2xSD_15%			x		x	x	x		x
44	Nduty50_N_2xSD_15%				x	x	x	x		x
45	Nduty100_N_2xSD_15%				x	x	x	x		x

Notes: Diff.=Differentiated, Non-diff=Non-differentiated, SD = standard deviation, DQ = Differentiated quantitative restrictions, NQ = Non-differentiated quantitative restrictions, Dduty = Differentiated duty, Nduty = Non-differentiated duty, _15% = Price trigger of 15%, _25% = Price trigger of 25%, _N: New reference equilibrium, 2xSD = standard deviation twice as observed.
Example: DQ25-50_15% = Differentiated quantitative restrictions applied at 25% for major exporter, 50% by minor exporters, both responding to the price trigger of 15%.

We set up 45 scenarios to determine the extent to which global welfare is affected by those scenario factors identified in Table 2.

Scenario factor 1: Productivity shocks

We assume that productivity shocks occur randomly to the total factor productivity parameter of the gross output production function in paddy rice sector, following the independent identically distributed normal distribution $N(1, \sigma_r^2)$ for region r.[5] We measure the productivity of paddy rice sector as production per acre of harvested area, and estimate the standard deviations σ_r of the productivity of these 14 regions with time series data for 21 years (1990–2010) provided by the FAOSTAT, removing effect of time trend on productivity of each region by simple OLS regression (Figure 3). We simulate 1000 Monte Carlo draws for each scenario. Among our 1000 draws, Uruguay shows the largest standard deviation of productivity, followed by Pakistan and the Philippines.

We then conduct simulations with the standard deviations for paddy rice productivity shocks that are twice as large as the observed productivity standard deviations, in order to account for future uncertainty, which might lead to increased productivity fluctuations due to climate change and other factors. The literature on the potential impacts of climate change on future rice productivity projects significant impacts that may cause substantial productivity volatility due to temperature and water stress and extreme climate events such as droughts and flooding [25]. In this context, we consider scenarios based on a larger standard deviation than recently observed in order to take into account the potential implications of future uncertainty in general.

[5] See Annex for detail on the assumptions of Monte Carlo draws.

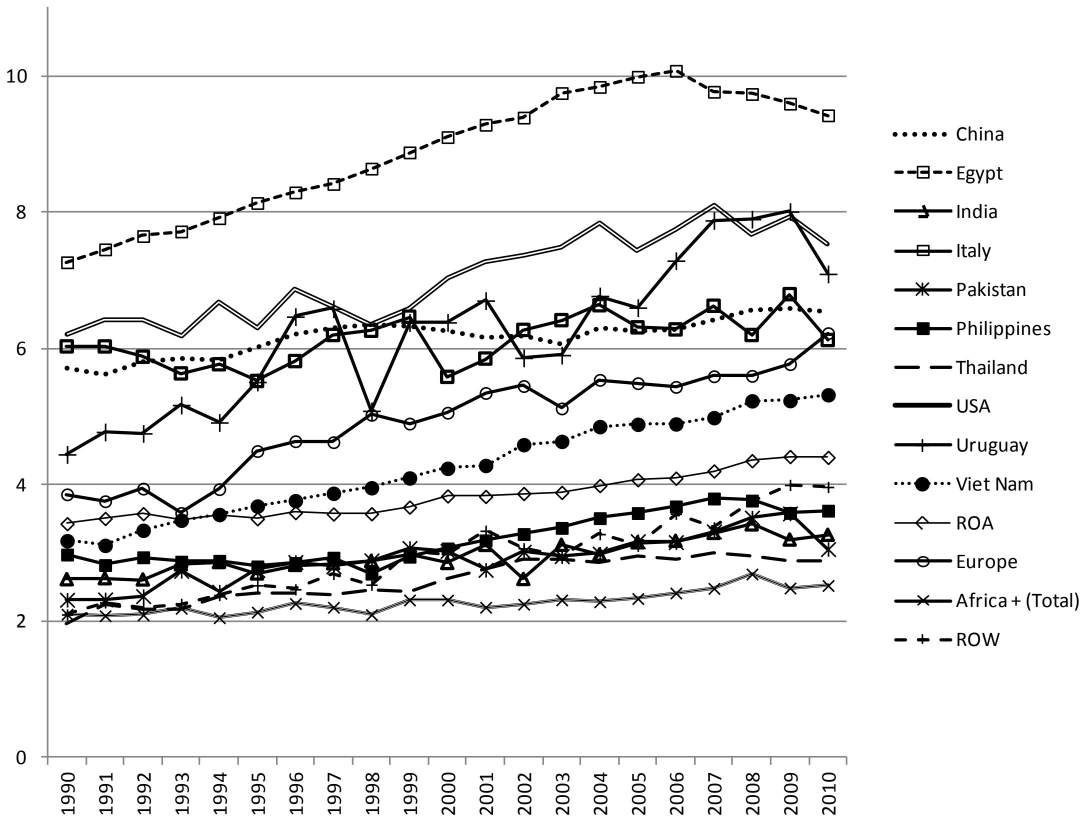

Figure 3. Paddy rice productivity [Unit: tonnes/hectare] (Data source: FAOSTAT)

Scenario factor 2: Non-differentiated export quotas and duties

We explore the implications of two price triggers combined with various levels of export quotas and duties. As it would be arbitrary to test for a particular trigger or a restriction level, our objective is to illustrate the potential direction and the extent of the welfare implications of alternative triggers and a range of export restrictions. We use two price triggers, namely the Trigger 15% and the Trigger 25%, which would allow a country to institute export restrictions when the domestic price of processed rice exceeds the reference price by 15% and 25%, respectively.

Then we test for the implications of export quotas and export duties applied at identical levels (e.g. non-differentiated) by all exporting countries where the price of rice has reached the trigger percentage. Accordingly, we consider two types of restrictions with two application levels each, namely quantitative restrictions applied at 50% and 95%, and export duties applied at 50% and 100%, respectively. [6]

Scenario factor 3: Differentiated export duties and quotas

We also analyse the implications of 'differentiated' restrictions, where major exporters (defined by market share) react to the same price triggers by imposing lower levels of restrictions than minor exporters (or importers).[7] In order to identify the difference between differentiated and non-differentiated restrictions, we first test for quantitative restrictions imposed at 25% by major exporters and at 50% for minor exporters, and secondly at 50% for major exporters and at 95% for minor exporters, respectively. As for export duties, we first take the scenario whereby export duties are imposed at 25% by major exporters and at 50% by minor exporters and, secondly, at 50% by major exporters and at 100% by minor exporters, respectively. In total, four export quota and four export duty scenarios are tested (Table 3).

Scenario factor 4: New reference equilibrium with lower trade barriers

In designing scenarios for the analysis of export restrictions, we also reconsidered the reference equilibrium, which describes the status quo. If we simulate export restrictions based simply on the reference equilibrium that is characterized by relatively 'thin' rice markets, [8] it is obvious that the impact of export restrictions will be relatively small. In reality, the damage from export restrictions is serious when importing countries lower their tariff barriers (as they have done in recent years) and start substituting imported rice for domestic rice under a freer rice-trade regime. This new situation may imply a reduction in the domestic production capacity of the importing countries as a result of the reallocation of factors (particularly capital) away from the rice sector in the medium and long run. We simulated this situation by assuming a partial (50%) rice trade liberalization with inter-sectoral mobility of all the factors and defining a new reference equilibrium.

[6] Because 100% of quantitative restrictions can cause solution problems, it is approximately set at 95%.

[7] In this study, large exporters are defined by the top five exporting countries (FAOSTAT).

[8] As rice in many countries is mainly produced and consumed domestically, its international trade is thin. Only a small fraction of production is exported and imported internationally [35].

Table 3. Export quota and duty scenarios

		Quotas (%)		Duties (%)	
		Major exporters	Non-major exporters	Major exporters	Non-major exporters
Level 1	Non-differentiated	50	50	50	50
	Differentiated	25	50	25	50
Level 2	Non-differentiated (leve2)	95	95	100	100
	Differentiated	50	95	50	100

Table 4. Summary statistics of simulation results

	World EV				Change in World Ave. Price of Processed Rice			
	Mean [mil. USD]	SD	Max [mil. USD]	Min [mil. USD]	Mean [%]	SD	Max [%]	Min [%]
P	-195	1468	4287	-5238	0.4	2.2	8.9	-5.8
P_2xSD	-751	3042	7754	-11808	1.9	5.0	26.2	-10.0
P_N_2xSD	-1271	2959	6954	-11901	0.9	4.9	25.2	-10.6
DQ25-50_2xSD_25%	-727	2979	7754	-10653	1.8	4.9	25.7	-10.0
DQ50-95_2xSD_25%	-762	3017	7754	-10992	1.8	4.9	25.7	-10.0
NQ50_2xSD_25%	-740	2997	7754	-10710	1.8	4.9	25.7	-10.0
NQ95_2xSD_25%	-864	3175	7754	-15069	1.9	5.0	25.9	-10.0
Dduty25-50_2xSD_25%	-737	2988	7754	-10819	1.8	4.9	25.4	-10.0
Dduty50-100_2xSD_25%	-752	3005	7754	-10990	1.8	4.9	25.2	-10.0
Nduty50_2xSD_25%	-746	2999	7754	-10920	1.8	4.9	25.2	-10.0
Nduty100_2xSD_25%	-773	3031	7754	-11190	1.8	4.9	25.1	-10.0
DQ25-50_N_2xSD_25%	-1282	2973	6954	-12050	0.9	4.9	24.7	-10.6
DQ50-95_N_2xSD_25%	-1326	3019	6954	-12526	1.0	4.9	24.7	-10.6
NQ50_N_2xSD_25%	-1306	3002	6954	-12105	1.0	4.9	24.7	-10.6
NQ95_N_2xSD_25%	-1469	3224	6954	-14925	1.1	5.1	25.0	-10.6
Dduty25-50_N_2xSD_25%	-1285	2973	6954	-11972	0.9	4.8	24.4	-10.6
Dduty50-100_N_2xSD_25%	-1303	2991	6954	-12113	0.9	4.9	24.3	-10.6
Nduty50_N_2xSD_25%	-1297	2985	6954	-12113	0.9	4.8	24.3	-10.6
Nduty100_N_2xSD_25%	-1330	3020	6954	-12421	1.0	4.9	24.4	-10.6
DQ25-50_15%	-196	1469	4287	-5238	0.4	2.2	8.4	-5.8
DQ50-95_15%	-201	1475	4287	-5238	0.4	2.2	8.7	-5.8
NQ50_15%	-198	1471	4287	-5238	0.4	2.2	8.4	-5.8
NQ95_15%	-214	1494	4287	-5238	0.5	2.2	8.7	-5.8
Dduty25-50_15%	-197	1471	4287	-5238	0.4	2.2	8.5	-5.8
Dduty50-100_15%	-200	1473	4287	-5238	0.4	2.2	8.6	-5.8
Nduty50_15%	-199	1472	4287	-5238	0.4	2.2	8.5	-5.8
Nduty100_15%	-202	1477	4287	-5238	0.4	2.2	8.6	-5.8
DQ25-50_2xSD_15%	-680	2919	7754	-11053	1.6	4.8	26.2	-10.0
DQ50-95_2xSD_15%	-833	3056	7754	-13132	1.8	4.9	26.8	-10.0
NQ50_2xSD_15%	-733	2948	7754	-11156	1.6	4.8	25.5	-10.0
NQ95_2xSD_15%	-1214	3508	7754	-19127	2.1	5.4	32.4	-10.0
Dduty25-50_2xSD_15%	-699	2922	7754	-10947	1.6	4.7	25.7	-10.0
Dduty50-100_2xSD_15%	-757	2968	7754	-11385	1.6	4.8	25.8	-10.0
Nduty50_2xSD_15%	-733	2948	7754	-11156	1.6	4.8	25.5	-10.0
Nduty100_2xSD_15%	-821	3020	7754	-9685	1.6	4.7	18.8	-10.0
DQ25-50_N_2xSD_15%	-1341	3016	6954	-13200	1.0	4.9	25.2	-10.6
DQ50-95_N_2xSD_15%	-1553	3200	6954	-14862	1.3	5.2	26.6	-10.6
NQ50_N_2xSD_15%	-1473	3130	6954	-14459	1.2	5.1	26.4	-10.6
NQ95_N_2xSD_15%	-2160	3866	6954	-20453	1.9	5.9	32.0	-10.6
Dduty25-50_N_2xSD_15%	-1319	2976	6954	-12331	0.9	4.8	24.7	-10.6
Dduty50-100_N_2xSD_15%	-1390	3030	6954	-12795	1.0	4.9	24.7	-10.6
Nduty50_N_2xSD_15%	-1365	3008	6954	-12615	1.0	4.8	24.5	-10.6
Nduty100_N_2xSD_15%	-1498	3112	6954	-13513	1.1	4.9	24.8	-10.6

4. Simulation Results

We simulate random productivity shocks and various policies and quantify the welfare implications of various forms of export restrictions and exporters' stocks. The simulation results are summarized in Table 4.

4.1. Productivity Shocks

We assume that productivity shocks are generated randomly to the total factor productivity parameter of the gross output production function in paddy rice sector, following the independent identically distributed normal distribution. Testing for the original (observed) standard deviation of productivity, we find that productivity shocks lead to a decrease in the mean global welfare by around US$ 195 million (min −5238, max 4287). Importing countries in Asia (including, China, India, the Philippines and rest of Asia) account for significant losses, amounting to US$ 131 million. However, for other major regions, the amount of productivity-shock-induced losses is not substantial. This implies that world rice supplies are likely to be relatively stable under the impact of supply shocks (other things being equal), given the level of productivity variability observed over the past 20 years.

However if the world's yield variability increases in the future due to climate change or other factors such as the migration of production to areas of the world which suffer higher yield variability, importing countries are likely to incur substantial welfare losses. When we test for a scenario of standard deviation of productivity being twice as big as that observed, mean global welfare losses triple to approximately US$ 751 million (min -11808, max 7754). Asian importers sustain the biggest losses, amounting to US$ 542 million. Mean welfare losses in China and India approach US$ 166 million and US$ 144 million, respectively. The results show that potential increases in yield variability could result in substantial reductions in global and regional welfare.

4.2. Impacts on Prices

We explore the implications of productivity shocks on both world and domestic prices of rice. This exercise is important to identify the implications of using price triggers for imposing export restrictions (see below). Testing for the original (observed) standard deviation of productivity, we find that productivity shocks lead to only a marginal increase in world prices, 0.4% on average, with a likely maximum of 8.9%. In the case of the scenario of standard deviation of productivity being twice as big as that observed, a productivity shock would lead world prices to go up by 1.9% on average, with a maximum potential increase of 26.2%.[9]

Certain countries are likely to be exposed to higher domestic price volatility and hikes. For example, India, Pakistan and the US are likely to face higher price increases and volatility above world averages. In India, productivity shocks lead domestic prices to go up by 9.42 % on average, with a maximum potential increase of 268.27% (based on the scenario of double standard deviation). In Pakistan, the same scenario produces average price increase of 9.23 %, with a maximum likely spike of 150.43%. In the US, average price increase as a result of increased product shocks is 6.35%, with a maximum of 89.41%.

Therefore, we find that productive shocks alone (with the observed and doubled standard deviations) do not lead to substantial price hikes on the world market on average. However, some major consumer and producer countries are exposed to higher productivity-shock-induced price hikes and volatility than other countries.

4.3. Impact of Export Duties and Quotas

We turn now to the scenario combining price shocks and export restrictions and we test for the impacts of export duties and quotas. For this analysis, we identify two price triggers, namely 15%, and 25%. These triggers would allow for a country to institute export restrictions when the domestic price of rice exceeds the corresponding trigger price. We first test for the implications of export quotas and export duties applied at identical levels (e.g. non-differentiated) by all exporting countries which have reached the price trigger. Accordingly, we consider quantitative restrictions of 50% and 95%, and export duties of 50% and 100%, respectively.

4.4. Price Trigger 15%

Testing for the original (observed) standard deviation of productivity, we observe, as expected from the analysis of price impacts, only a few cases where the triggers are reached. Even the lowest price trigger, namely 15%, is reached fewer than 10 times out of 1000 Monte Carlo draws. Since the price impact based on observed variation of productivity is low, the scenario whereby countries would resort to export restrictions if domestic prices were to go up by 15% does not produce significant results. This implies that if patterns of productivity variability remain similar to what has been observed in the past two decades, *productivity shocks alone* are *unlikely* to produce domestic price increases which would trigger export restrictions out of concerns about scarcity of domestic supplies.[10]

However, when we account for future uncertainty through the scenario of double standard deviation of productivity, price impacts are large enough for some countries to trigger export restrictions; this allows us to explore their welfare implications. For the price trigger 15%, on average in 60 cases out of 1000 draws, prices reach the trigger (cross country average). Among the major exporting countries, India, Pakistan and Thailand experience the highest number of cases where the price trigger is reached by 136, 94, and 83 times (out of 1000 draws) respectively.

Then we test for the implications of export duties and quotas. As expected, while importing countries largely

[9] World average domestic prices are calculated with weights of consumption quantity of regions.

[10] The price trigger of 25% is reached only in two cases (out of 1000) in India. No other country or region reached the 25% price trigger in any of the 1000 draws. Since the marginal welfare implications of these scenarios are insignificant, we do not consider the analysis of price triggers for 25% and beyond.

lose out, exporting countries benefit from export restrictions. Applied at 50% (Level 1) export duties lead to additional decreases in the mean welfare of importing countries (including India) from US$ −813.7 million (mean value of productivity shocks) to US$ −952.43 million, implying a 17% welfare loss in addition to the losses resulting from productivity shocks. Applied at 100% (Level 2) export duties will further decrease the mean welfare to US$ −1074.42 million, resulting in an additional welfare loss of 13%. Africa's additional losses are particularly high compared to importing country averages. In cases where exporters trigger 50% and 100% duties, Africa suffers additional losses of welfare of 78% and 141% respectively.

Export quotas have stronger impacts on global and domestic welfare. Applied at 50%, export quotas (triggered by a 15% price rise) increase the additional welfare losses (in importing countries and India) from US$ −813.7 million (mean value of productivity shocks) to US$ −958.33 million. An export quota at 95%, which is approaching an export ban, causes substantial welfare damage to importing countries which would incur average additional welfare losses 62% higher than they would incur under productivity shocks alone. Similarly, Africa's additional losses are particularly high compared to importing country averages. In the cases of exporters triggering 50% and 95% quotas, the continent would suffer additional losses of welfare of 91% and 251% respectively.

Exporters' gains from instituting export restrictions vary depending on the level and type of the measure. Cumulatively exporting countries – including Thailand, the US, Pakistan, Italy, Uruguay and Vietnam – gain around US$ 219.91 million out of export duties imposed at 50%. Their gain increases to US$ 253.61 million if the duty is increased to 100%. This means that welfare losses incurred by importing countries are much higher than the potential gains that exporters could realize. [11] As such export duties result in higher gains for exporting countries, but these gains lead to disproportionately high welfare losses in importing countries. In fact, for every additional US$ 1 million that exporting countries gain out of export duties, importing countries lose more than US$ 4 million.

If quotas are used instead of duties, exporting countries' gains are lower while importing countries' losses are higher. While quotas applied at 50% generate around US$ 208.4 million for exporting countries (which is lower than gains under 50% duty), further increases in quotas reduce gains significantly, to US$ 196.62 million. Africa and rest of Asia (rest of Asia) are the two main regions that would suffer from the severe effects of quantitative export restrictions. In the extreme case of a quantitative restriction of 95% (based on a 15% price trigger) the mean welfare of the two regions drops by around US$ -286.82 million and US$ -419.72 million, respectively. This would have significant implications for food security, as poverty and malnutrition rates are particularly high in these two regions.

4.5. Price Trigger 25%

Using the price trigger 25%, we observe only 18 cases (out of 1000 draws) on average (cross country average) where prices reach the trigger. Among exporting countries, India, Uruguay and Pakistan experience the highest number of triggered cases: 57, 31, and 30, respectively. As expected, when the trigger is higher, the number of cases above the trigger is smaller, thereby reducing the welfare impacts of export restrictions. Applied at 50%, export duties lead to additional decreases in the mean welfare of importing countries (including India) from US$−813.7 million (mean value of productivity shock) to US$−855.66 million. Applied at 100%, export duties will further reduce the mean welfare to US$ −889.42 million, implying a 9% welfare loss in addition to productivity shocks. Similar to the scenario of the trigger 15%, Africa's additional losses are particularly high in comparison to importing country averages. In the cases of exporters triggering 100% duties, the continent would suffer additional losses of welfare of 36%, which is much lower than 141% in the case of the price trigger of 15%, yet still significant.

At this trigger level, export quotas, even when applied at prohibitive rates, do not cause substantial welfare losses. Applied at 95%, importing countries incur average additional welfare losses that are 20% higher than these countries would incur under productivity shocks alone. As such the amount of welfare losses associated with export restriction is highly sensitive to price triggers. The welfare losses that the restrictions cause diminish significantly with marginal increases in the trigger (Table 4).

4.6. Impact of Differentiated Export Quotas

We also test for the implications of 'differentiated' restrictions, where major exporters (defined by market share) react to the same price triggers by imposing lower levels of restrictions than minor exporters. As a significant number of cases is being reached, we use the 15% trigger to illustrate the implications of differentiated application of export restrictions.

As indicated above, if all countries apply the same duty rate of 50%, reaching the price trigger would lead to additional welfare losses for importing countries of US$ - 138.73 million. By reducing the export duties imposed by major exporters, five countries in total, to 25% while keeping them at 50% for the rest of the world, the additional welfare losses could be reduced by 38%. Similarly, for the higher rate scenario, by reducing export duties imposed by major exporters to 50% while keeping them at 100% for the rest of the world, the additional welfare losses could be reduced by 35%. In both scenarios, Africa's additional welfare losses are reduced by around 32-40%.

As for export quotas, by reducing export quotas imposed by major exporters to 25% while keeping them at 50% for the rest of the world, the additional welfare losses could be eliminated by 68%. For the higher rate scenario, reducing export quotas imposed by major exporters to 50% while keeping them at 95% for the rest of the world could reduce the additional welfare losses by 59%. As such, application of differentiated export restrictions offers significant welfare gains (or reduced welfare losses) (as compared to non-differentiated export restrictions).

[11] Exporting countries' gains are lower if quotas are used instead of duties. While quotas applied at 50% generate around US$ 258.96 million (which is lower than gains under 50% duty), further increases in quotas reduce gains significantly.

5. Regulatory Efficiency and Optimal Reform of WTO Rules

There have been reform efforts at the WTO to bring in some form of regulation of export restrictions imposed on food commodities. [12] Net importing countries such as Jordan, Japan and Switzerland have submitted various reform proposals, involving 'tariffication' of export quotas and binding of export duties. Reform proposals also included provisions prohibiting, among others, export restrictions imposed on food aid supplied by the World Food Programme (WFP) to cover its emergency food relief operations. However, all reform efforts have so far failed to make it to formal negotiations. They have faced strong opposition mainly from developing countries[13] that wish to maintain their autonomy, known as 'policy space,' to impose export restrictions to respond to domestic and external supply shocks.

There is, however, an emerging consensus, at least in the scholarly literature, that this area of 'regulatory deficiency' should be brought under discipline through future negotiations at the WTO [9,12,18,22,23]. In light of the results of this study, we propose an alternative which would aim at maintaining plenty of domestic policy autonomy for most WTO Members while limiting the global welfare losses caused by export restrictions. Such 'optimality' could be based on the following features [22].

Objective criteria on triggers: Similar to the negotiations on the Special Safeguard Mechanism (SSM), objective criteria concerning triggers and scope of export restrictions need to be incorporated into the new disciplines that could be negotiated at the WTO [43,44]. [14] In particular, price-based triggers could be used for this purpose. When the domestic price of a food commodity exceeds a certain level, the member country could have the option to restrict the exports of that particular commodity. This would constitute a justified basis for a country to institute a trade-distortive measure. It would also improve the predictability of the policy. As indicated above, price triggers above 25% are not highly sensitive to productivity (only) shocks. As price triggers go below 25%, the likelihood that they are reached increases in light of the observed trends of productivity volatility.

Tariffication of all quotas: Our results suggest that export duties are less distortive than quotas, a finding which is supported by the literature [16,21]. Higher quota levels damage even the exporting countries. In particular, the welfare losses that importing countries, especially those in Africa, face increase dramatically if export quotas applied above the 50% level. Hence our results support the most recent WTO reform efforts of Japan and Switzerland proposing tariffication of all export quotas. This will also bring potential benefits in relation to the negotiation, monitoring and enforcement of future regulation.

Differentiated bound rates for export duties: The maximum level of duties should be negotiated and be based on objective criteria. Market share offers an effective objective criterion for determining the maximum amount of duty that a Member is allowed to charge. Major exporters with significant market share in world export markets would be subject to a lower ceiling than non-major exporters or importers. As our study shows, such a differentiated approach would limit the adverse welfare implications of export restrictions imposed by larger exporters while allowing small exporters (and non-exporters) more policy space in this field – as the impact of their export restrictions on global welfare is smaller than that of those with higher market shares. Similarly, it would also reduce price volatility in commodity groups that are traded at a low intensity and hence are more exposed to the impacts of export restrictions imposed by major suppliers.

Such new disciplines could help avoid the collective action problem mentioned above while maintaining substantial policy flexibility for the vast majority of WTO Members. The latter would also improve the political feasibility of reform efforts through multilateral negotiations.

6. Conclusions

Under future uncertainty, productivity shocks in agriculture might increase due to climate change and other factors, which may prompt countries to impose export restrictions. We have used a world trade stochastic computable general equilibrium (CGE) model with the Monte Carlo method in order to explore the potential welfare implications of productivity shocks and consequent export restrictions imposed on rice. Our results show that, under the impact of productivity shocks alone, world rice supplies are expected to stay relatively stable based on the level of volatility (of productivity) observed in the past 20 years. However, when the volatility of productivity is doubled in our scenario to account for future uncertainty, mean global welfare losses triple. This implies that potential increases in yield volatility in the future, due possibly to climate change and other factors such as migration of production to areas of high volatility, will lead to substantial welfare losses.

We then tested for the implications of export duties and quotas that countries impose in reaction to productivity shocks. While export duties result in net welfare gains for exporting countries, they lead to disproportionately high welfare losses in importing countries. In fact, for every additional US$ 1 million that exporting countries gain,

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[12] For proposals on export restrictions, see WTO Secretariat [42], 'Export Restrictions and Taxes', <www.wto.org/english/tratop_e/agric_e/negs_bkgrnd09_taxes_e.htm>, 5 Jan 2013. [42]

[13] See WTO Secretariat (2008), 'Unofficial Guide to the 10 July 2008 ''Revised Draft Modalities''', 18 Jul. 2008, <www.wto.org/english/tratop_E/agric_e/ag_modals_july08_e.htm>, 5 Jan 2013. [43]

[14] The Special Safeguard Mechanism (SSM) allows countries to go beyond their bound tariffs to apply additional duties to remedy the sudden influx of imports. Based on WTO negotiations on the subject, it could have a price-based trigger which uses a reference price (i.e. three-year moving average of import prices) and when the import price of a particular food commodity that is subject to the SSM falls below 85% of the reference price, an SSM qualifying member country is allowed to impose an additional import tariff to remove the 85% of the shortfall [43,44]. Similarly, the volume-based trigger could be used when the volume of imports in a year exceeds a reference volume (i.e. three-year moving average of import volumes). Depending on how far the reference volumes are exceeded, additional import duties of up to 50% of the binding could be (gradually) imposed [33,44].

importing countries lose more than US$ 4 million. If quotas are used instead of duties, exporting countries' gains are lower while importing countries' losses are even higher than those that result from duties. In all scenarios, the losses in importing countries in Asia and Africa are higher than importing country averages, an important finding which underlines that regions where poverty and malnutrition are prevalent are highly exposed to market distortions caused by export restrictions.

We have also tested for the implications of 'differentiated' export restrictions, where major exporters react to the same productivity shocks by imposing lower levels of restrictions than minor exporters. Our results suggest that halving the export duties imposed by the major exporters, five countries in total, while maintaining them for the rest of the world, could reduce the related welfare losses by up to 60%. This is a case for differentiated regulation through the WTO, which could be based on tariffication of all export restrictions, followed by the negotiation of ceilings on duties. We argue that major exporters (defined by market share) should be subject to a lower ceiling than non-major exporters or importers. Such a differentiated approach offers a substantial degree of regulatory efficiency in achieving significant welfare gains (or mitigating losses) by bringing in additional regulation only in a small number of countries while leaving a large policy space for the vast majority of member countries.

Implementing the ideas on stricter regulation of export restrictions and of exporter stocks is not politically feasible in the current phase of WTO negotiations. However, one might envisage a more rationalized regulation of export restrictions and emergency stocks through clearly defined triggers, legal boundaries and enforcement mechanisms. A future trading system where importing countries' obligations to reduce import barriers are balanced with major exporting countries' obligations to provide reliable supplies is essential for global food supply security under the impact of future uncertainty exacerbated by climate change.

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Appendix: Sensitivity Analyses

Robustness examinations are conducted in this section with changes in the Armington elasticity, and the elasticity of factor substitution (Tables A.2-A.5). The alternative assumptions of the parameters are indicated in Table A.1.

Table A.1. Elasticity values

	Armington composite	Value added
Paddy rice	5.05	0.25
Wheat	4.45	0.25
Other grains	1.30	0.25
Other agriculture	2.19	0.25
Processed rice	2.60	1.12
Food	2.47	1.12
Crude oil	5.20	0.20
Coal	3.05	0.20
Gas	17.20	0.20
Petroleum	2.10	1.26
Transport	1.90	1.68
Others	2.47	1.32
In sensitivity analyses	±50% for rice sectors	±50% for agricultural sectors

Source: the GTAP Database version 8.

Sensitivity analysis: Armington elasticity

Elasticity of substitution for the Armington aggregation $1/(1-\eta_i)$ and elasticity of transformation for gross output $1/(\varphi_i-1)$ are obtained from the GTAP database (Table A.1). These elasticities are doubled for the elasticities for import variety aggregation $1/(1-\omega_i)$ and for export variety production $1/(\phi_i - 1)$. We carried out sensitivity analyses of our simulation results with respect to the Armington elasticity of substitution for the paddy and processed rice sectors. We alternatively assumed 50% larger and smaller for both of the sectors.

Export quota scenarios give relatively larger welfare losses than export tax scenarios, and the scenarios with non-differentiated 95% quota show the lowest economic welfare among the other export restriction scenarios in cases of larger and smaller Armington elasticities. When the standard deviations of productivity shocks are doubled, welfare losses become about triple although in some cases where restrictions are stricter such as NQ95, welfare variations responded more sensitively. Also, the relative relationship of welfare effects in each set of the eight restriction scenarios is well maintained with the changes in the elasticities.

Table A.2 Sensitivity analyses: Armington elasticity +50%

	World EV				Change in World Ave. Price of Processed Rice			
	Mean [mil. USD]	SD	Max [mil. USD]	Min [mil. USD]	Mean [%]	SD	Max [%]	Min [%]
P	-174	1438	4182	-5076 #	0.4	2.2	8.7	-5.7
P_2xSD	-655	2962	7642	-11308 #	1.6	4.8	24.7	-9.9
P_N_2xSD	-1852	2839	6231	-11869 #	0.2	4.6	22.9	-10.9
DQ25-50_2xSD_25%	-637	2923	7642	-11268 #	1.5	4.7	22.7	-9.9
DQ50-95_2xSD_25%	-647	2936	7642	-11402 #	1.5	4.7	22.8	-9.9
NQ50_2xSD_25%	-639	2928	7642	-11402 #	1.5	4.7	22.6	-9.9
NQ95_2xSD_25%	-680	2989	7642	-12900 #	1.6	4.7	22.9	-9.9
Dduty25-50_2xSD_25%	-643	2931	7642	-11361 #	1.5	4.7	22.6	-9.9
Dduty50-100_2xSD_25%	-652	2941	7642	-11510 #	1.5	4.7	22.6	-9.9
Nduty50_2xSD_25%	-649	2939	7642	-11510 #	1.5	4.7	22.5	-9.9
Nduty100_2xSD_25%	-662	2957	7642	-11829 #	1.5	4.7	22.7	-9.9
DQ25-50_N_2xSD_25%	-1852	2839	6231	-11869 #	0.2	4.6	22.9	-10.9
DQ50-95_N_2xSD_25%	-1856	2846	6231	-11906 #	0.2	4.5	21.8	-10.9
NQ50_N_2xSD_25%	-1869	2866	6231	-12187 #	0.2	4.6	21.9	-10.9
NQ95_N_2xSD_25%	-1864	2859	6231	-11997 #	0.2	4.5	21.8	-10.9
Dduty25-50_N_2xSD_25%	-1917	2949	6231	-13485 #	0.2	4.6	21.9	-10.9
Dduty50-100_N_2xSD_25%	-1859	2849	6231	-11995 #	0.2	4.5	21.6	-10.9
Nduty50_N_2xSD_25%	-1868	2861	6231	-12172 #	0.2	4.5	21.6	-10.9
Nduty100_N_2xSD_25%	-1866	2858	6231	-12090 #	0.2	4.5	21.6	-10.9
DQ25-50_15%	-1882	2882	6231	-12360 #	0.2	4.5	21.7	-10.9
DQ50-95_15%	-174	1438	4182	-5076 #	0.4	2.2	8.0	-5.7
NQ50_15%	-176	1441	4182	-5076 #	0.4	2.2	8.2	-5.7
NQ95_15%	-174	1439	4182	-5076 #	0.4	2.2	8.0	-5.7
Dduty25-50_15%	-185	1456	4182	-5076 #	0.4	2.2	8.0	-5.7
Dduty50-100_15%	-175	1440	4182	-5076 #	0.4	2.2	8.1	-5.7
Nduty50_15%	-176	1442	4182	-5076 #	0.4	2.2	8.1	-5.7
Nduty100_15%	-176	1441	4182	-5076 #	0.4	2.2	8.1	-5.7
DQ25-50_2xSD_15%	-178	1444	4182	-5076 #	0.4	2.2	8.1	-5.7
DQ50-95_2xSD_15%	-572	2844	7642	-10648 #	1.4	4.5	22.9	-9.9
NQ50_2xSD_15%	-639	2922	7642	-11962 #	1.4	4.6	24.0	-9.9
NQ95_2xSD_15%	-598	2882	7642	-11649 #	1.4	4.6	24.0	-9.9
Dduty25-50_2xSD_15%	-798	3152	7642	-16054 #	1.6	4.8	28.0	-9.9
Dduty50-100_2xSD_15%	-571	2821	7642	-9162 #	1.3	4.4	17.1	-9.9
Nduty50_2xSD_15%	-632	2900	7642	-11029 #	1.4	4.5	23.0	-9.9
Nduty100_2xSD_15%	-617	2885	7642	-10909 #	1.4	4.5	22.9	-9.9
DQ25-50_N_2xSD_15%	-678	2954	7642	-11875 #	1.4	4.6	23.1	-9.9
DQ50-95_N_2xSD_15%	-1898	2902	6231	-13100 #	0.2	4.6	22.1	-10.9
NQ50_N_2xSD_15%	-1999	3014	6231	-14668 #	0.3	4.7	22.8	-10.9
NQ95_N_2xSD_15%	-1964	2977	6231	-14279 #	0.3	4.7	22.8	-10.9
Dduty25-50_N_2xSD_15%	-2281	3374	6231	-19007 #	0.6	5.1	25.9	-10.9
Dduty50-100_N_2xSD_15%	-1895	2882	6231	-12379 #	0.2	4.5	21.9	-10.9
Nduty50_N_2xSD_15%	-1944	2928	6231	-12868 #	0.2	4.5	22.0	-10.9
Nduty100_N_2xSD_15%	-1929	2911	6231	-12670 #	0.2	4.5	21.9	-10.9

Table A.3. Sensitivity analyses: Armington elasticity -50%

	World EV					Change in World Ave. Price of Processed Rice			
	Mean [mil. USD]	SD	Max [mil. USD]	Min [mil. USD]		Mean [%]	SD	Max [%]	Min [%]
P	-227	1514	4436	-5469	#	0.5	2.3	9.2	-5.9
P_2xSD	-894	3165	7913	-12765	#	2.2	5.3	28.6	-10.0
P_N_2xSD	-1027	3127	7647	-12709	#	1.9	5.3	28.2	-10.4
DQ25-50_2xSD_25%	-894	3132	7913	-11464	#	2.2	5.2	28.6	-10.0
DQ50-95_2xSD_25%	-1063	3257	7913	-12785	#	2.4	5.4	29.1	-10.0
NQ50_2xSD_25%	-979	3196	7913	-12089	#	2.3	5.3	28.4	-10.0
NQ95_2xSD_25%	-1592	3931	7913	-23227	#	3.0	6.3	40.8	-10.0
Dduty25-50_2xSD_25%	-893	3125	7913	-11154	#	2.2	5.2	28.3	-10.0
Dduty50-100_2xSD_25%	-922	3145	7913	-11316	#	2.2	5.2	28.1	-10.0
Nduty50_2xSD_25%	-911	3137	7913	-11154	#	2.2	5.2	28.1	-10.0
Nduty100_2xSD_25%	-964	3175	7913	-11480	#	2.2	5.3	28.1	-10.0
DQ25-50_N_2xSD_25%	-1027	3127	7647	-12709	#	1.9	5.3	28.2	-10.4
DQ50-95_N_2xSD_25%	-1063	3173	7647	-12530	#	1.9	5.1	22.6	-10.4
NQ50_N_2xSD_25%	-1257	3283	7647	-13615	#	2.2	5.5	29.2	-10.4
NQ95_N_2xSD_25%	-1173	3222	7647	-13073	#	2.1	5.4	28.1	-10.4
Dduty25-50_N_2xSD_25%	-1929	4136	7647	-30429	#	3.0	6.7	55.3	-10.4
Dduty50-100_N_2xSD_25%	-1061	3142	7647	-12530	#	1.9	5.3	28.2	-10.4
Nduty50_N_2xSD_25%	-1074	3143	7647	-12671	#	1.9	5.2	27.7	-10.4
Nduty100_N_2xSD_25%	-1063	3136	7647	-12671	#	1.9	5.2	27.7	-10.4
DQ25-50_15%	-1122	3174	7647	-12949	#	2.0	5.3	27.8	-10.4
DQ50-95_15%	-235	1515	4436	-5593	#	0.5	2.3	9.2	-5.9
NQ50_15%	-292	1575	4436	-6617	#	0.6	2.4	12.7	-5.9
NQ95_15%	-267	1555	4436	-6617	#	0.6	2.4	12.7	-5.9
Dduty25-50_15%	-456	1979	4436	-18118	#	0.8	3.0	28.8	-5.9
Dduty50-100_15%	-229	1509	4436	-5523	#	0.5	2.3	9.0	-5.9
Nduty50_15%	-239	1517	4436	-5599	#	0.5	2.3	9.1	-5.9
Nduty100_15%	-267	1555	4436	-6617	#	0.6	2.4	12.7	-5.9
DQ25-50_2xSD_15%	-252	1531	4436	-5629	#	0.6	2.3	9.9	-5.9
DQ50-95_2xSD_15%	-899	3109	7913	-11657	#	2.1	5.3	29.1	-10.0
NQ50_2xSD_15%	-1376	3439	7913	-15611	#	2.7	5.7	32.7	-10.0
NQ95_2xSD_15%	-1129	3269	7913	-13927	#	2.5	5.5	31.8	-10.0
Dduty25-50_2xSD_15%	-2708	5011	7913	-35307	#	4.4	8.0	62.8	-10.0
Dduty50-100_2xSD_15%	-857	3063	7913	-11141	#	2.0	5.1	28.5	-10.0
Nduty50_2xSD_15%	-933	3106	7913	-11350	#	2.1	5.2	28.6	-10.0
Nduty100_2xSD_15%	-900	3086	7913	-11180	#	2.1	5.2	28.4	-10.0
DQ25-50_N_2xSD_15%	-1030	3161	7913	-11932	#	2.3	5.3	28.5	-10.0
DQ50-95_N_2xSD_15%	-1167	3200	7647	-13396	#	2.1	5.4	28.8	-10.4
NQ50_N_2xSD_15%	-1720	3565	7647	-16984	#	2.9	5.9	32.8	-10.4
NQ95_N_2xSD_15%	-1490	3413	7647	-15655	#	2.7	5.8	31.9	-10.4
Dduty25-50_N_2xSD_15%	-3521	5468	7647	-31592	#	5.3	8.7	55.2	-10.4
Dduty50-100_N_2xSD_15%	-1068	3119	7647	-12063	#	1.9	5.2	28.1	-10.4
Nduty50_N_2xSD_15%	-1150	3161	7647	-12370	#	2.0	5.3	28.2	-10.4
Nduty100_N_2xSD_15%	-1119	3143	7647	-12214	#	2.0	5.2	28.0	-10.4

Sensitivity analysis: value added aggregation

While the elasticities of substitution among primary factors are assumed to be 0.25 for agricultural sectors in the analysis, we alternatively assume ±50% of the original values in the robustness tests. The outcomes demonstrate that larger volatility of productivity expand EV losses about as three times big in spite of the fact that 95% export quotas are likely to affect them a little more negatively. In the same as the tests for Armington aggregation, export quota is more distortive than export tax, and 95% export quota marks the lowest value in welfare compared with those in other restriction scenarios of each setting. Moreover, the order of welfare impacts between the scenarios concerning export restrictions is supported.

Table A.4. Sensitivity analysis: elasticity of factor substitution in agricultural sectors +50%

	World EV				Change in World Ave. Price of Processed Rice			
	Mean [mil. USD]	SD	Max [mil. USD]	Min [mil. USD]	Mean [%]	SD	Max [%]	Min [%]
P	-176	1477	4402	-5206	0.3	1.7	6.3	-4.8
P_2xSD	-662	3023	8017	-11482	1.1	3.7	16.6	-8.5
P_N_2xSD	-1152	2945	7203	-11600	0.4	3.6	15.7	-9.1
DQ25-50_2xSD_25%	-659	3015	8017	-11530	1.1	3.7	16.4	-8.5
DQ50-95_2xSD_25%	-674	3032	8017	-11817	1.1	3.7	16.4	-8.5
NQ50_2xSD_25%	-665	3024	8017	-11617	1.1	3.7	16.4	-8.5
NQ95_2xSD_25%	-722	3104	8017	-14583	1.2	3.8	19.3	-8.5
Dduty25-50_2xSD_25%	-664	3020	8017	-11562	1.1	3.7	16.2	-8.5
Dduty50-100_2xSD_25%	-671	3028	8017	-11650	1.1	3.7	16.1	-8.5
Nduty50_2xSD_25%	-671	3028	8017	-11650	1.1	3.7	16.1	-8.5
Nduty100_2xSD_25%	-681	3040	8017	-11688	1.1	3.7	16.1	-8.5
DQ25-50_N_2xSD_25%	-1152	2945	7203	-11600	0.4	3.6	15.7	-9.1
DQ50-95_N_2xSD_25%	-1156	2951	7203	-11666	0.4	3.6	15.6	-9.1
NQ50_N_2xSD_25%	-1178	2970	7203	-11940	0.4	3.6	15.8	-9.1
NQ95_N_2xSD_25%	-1169	2963	7203	-11666	0.4	3.6	15.6	-9.1
Dduty25-50_N_2xSD_25%	-1250	3062	7203	-13468	0.5	3.7	16.7	-9.1
Dduty50-100_N_2xSD_25%	-1160	2952	7203	-11667	0.4	3.6	15.5	-9.1
Nduty50_N_2xSD_25%	-1169	2960	7203	-11756	0.4	3.6	15.6	-9.1
Nduty100_N_2xSD_25%	-1166	2958	7203	-11667	0.4	3.6	15.5	-9.1
DQ25-50_15%	-1183	2974	7203	-11756	0.4	3.6	15.6	-9.1
DQ50-95_15%	-176	1477	4402	-5206	0.3	1.7	6.3	-4.8
NQ50_15%	-178	1478	4402	-5206	0.3	1.7	6.3	-4.8
NQ95_15%	-177	1477	4402	-5206	0.3	1.7	6.3	-4.8
Dduty25-50_15%	-182	1484	4402	-5206	0.3	1.7	6.3	-4.8
Dduty50-100_15%	-176	1477	4402	-5206	0.3	1.7	6.3	-4.8
Nduty50_15%	-177	1478	4402	-5206	0.3	1.7	6.3	-4.8
Nduty100_15%	-177	1477	4402	-5206	0.3	1.7	6.3	-4.8
DQ25-50_2xSD_15%	-178	1479	4402	-5206	0.3	1.7	6.3	-4.8
DQ50-95_2xSD_15%	-623	2942	8017	-9895	1.0	3.6	16.4	-8.5
NQ50_2xSD_15%	-711	3009	8017	-10750	1.1	3.7	16.4	-8.5
NQ95_2xSD_15%	-668	2979	8017	-10516	1.1	3.6	16.4	-8.5
Dduty25-50_2xSD_15%	-955	3285	8017	-17423	1.3	3.9	23.2	-8.5
Dduty50-100_2xSD_15%	-643	2952	8017	-9979	1.0	3.6	16.2	-8.5
Nduty50_2xSD_15%	-680	2980	8017	-10160	1.1	3.6	16.1	-8.5
Nduty100_2xSD_15%	-668	2971	8017	-10152	1.0	3.6	16.1	-8.5
DQ25-50_N_2xSD_15%	-731	3024	8017	-10699	1.1	3.7	16.1	-8.5
DQ50-95_N_2xSD_15%	-1191	2973	7203	-12467	0.4	3.6	15.6	-9.1
NQ50_N_2xSD_15%	-1320	3067	7203	-13744	0.6	3.7	15.8	-9.1
NQ95_N_2xSD_15%	-1279	3037	7203	-13263	0.5	3.7	15.6	-9.1
Dduty25-50_N_2xSD_15%	-1728	3481	7203	-17237	0.9	4.1	21.9	-9.1
Dduty50-100_N_2xSD_15%	-1187	2960	7203	-11845	0.4	3.6	15.5	-9.1
Nduty50_N_2xSD_15%	-1237	2994	7203	-12206	0.5	3.6	15.6	-9.1
Nduty100_N_2xSD_15%	-1224	2984	7203	-12066	0.4	3.6	15.5	-9.1

Table A.5. Sensitivity analysis: elasticity of factor substitution in agricultural sectors -50%

	World EV				Change in World Ave. Price of Processed Rice			
	Mean [mil. USD]	SD	Max [mil. USD	Min [mil. USD]	Mean [%]	SD	Max [%]	Min [%]
P	-240	1459	4065	-5351	1.0	3.6	17.8	-8.0
P_2xSD	-960	3143	7267	-13712	4.3	9.3	69.9	-12.9
P_N_2xSD	-1524	3047	6515	-14274	2.9	8.9	66.6	-13.6
DQ25-50_2xSD_25%	-916	3070	7267	-16133	3.9	9.0	88.9	-12.9
DQ50-95_2xSD_25%	-1035	3236	7267	-18360	4.1	9.3	96.5	-12.9
NQ50_2xSD_25%	-957	3146	7267	-17576	3.9	9.2	94.6	-12.9
NQ95_2xSD_25%	-1308	3732	7267	-24169	4.4	10.3	114.0	-12.9
Dduty25-50_2xSD_25%	-924	3050	7267	-14040	3.8	8.5	65.2	-12.9
Dduty50-100_2xSD_25%	-963	3093	7267	-14403	3.8	8.6	66.3	-12.9
Nduty50_2xSD_25%	-942	3070	7267	-14232	3.8	8.5	65.9	-12.9
Nduty100_2xSD_25%	-1006	3144	7267	-14892	3.8	8.6	68.5	-12.9
DQ25-50_N_2xSD_25%	-1524	3047	6515	-14274	2.9	8.9	66.6	-13.6
DQ50-95_N_2xSD_25%	-1572	3128	6515	-16752	2.9	9.5	87.6	-13.6
NQ50_N_2xSD_25%	-1712	3333	6515	-18927	3.2	9.9	94.4	-13.6
NQ95_N_2xSD_25%	-1639	3244	6515	-18123	3.1	9.8	92.7	-13.6
Dduty25-50_N_2xSD_25%	-2061	3959	6515	-24845	3.7	11.2	110.5	-13.6
Dduty50-100_N_2xSD_25%	-1549	3055	6515	-14580	2.7	8.5	64.1	-13.6
Nduty50_N_2xSD_25%	-1590	3101	6515	-14925	2.7	8.6	65.1	-13.6
Nduty100_N_2xSD_25%	-1569	3077	6515	-14748	2.7	8.6	64.8	-13.6
DQ25-50_15%	-1640	3160	6515	-15362	2.8	8.7	67.0	-13.6
DQ50-95_15%	-223	1423	4065	-4993	0.9	3.4	16.3	-8.0
NQ50_15%	-258	1470	4065	-6280	0.9	3.5	16.6	-8.0
NQ95_15%	-235	1446	4065	-6017	0.9	3.5	16.3	-8.0
Dduty25-50_15%	-335	1643	4065	-11080	1.0	3.7	24.4	-8.0
Dduty50-100_15%	-227	1426	4065	-5010	0.9	3.4	16.2	-8.0
Nduty50_15%	-240	1442	4065	-5279	0.9	3.4	16.3	-8.0
Nduty100_15%	-234	1435	4065	-5155	0.9	3.4	16.2	-8.0
DQ25-50_2xSD_15%	-255	1464	4065	-5630	0.9	3.4	16.6	-8.0
DQ50-95_2xSD_15%	-790	3032	7267	-16959	3.5	9.5	93.6	-12.9
NQ50_2xSD_15%	-1154	3492	7267	-21199	4.1	10.4	106.5	-12.9
NQ95_2xSD_15%	-943	3237	7267	-18932	3.8	10.0	100.9	-12.9
Dduty25-50_2xSD_15%	-1944	4761	7267	-37236	5.5	13.1	131.8	-12.9
Dduty50-100_2xSD_15%	-753	2905	7267	-14243	3.2	8.3	67.1	-12.9
Nduty50_2xSD_15%	-854	2990	7267	-14822	3.3	8.4	69.2	-12.9
Nduty100_2xSD_15%	-798	2939	7267	-14444	3.2	8.4	67.9	-12.9
DQ25-50_N_2xSD_15%	-964	3081	7267	-15358	3.4	8.6	71.4	-12.9
DQ50-95_N_2xSD_15%	-1694	3259	6515	-18190	3.2	10.0	95.8	-13.6
NQ50_N_2xSD_15%	-2120	3741	6515	-23019	3.9	11.0	109.8	-13.6
NQ95_N_2xSD_15%	-1939	3530	6515	-20642	3.7	10.6	104.6	-13.6
Dduty25-50_N_2xSD_15%	-3205	5139	6515	-34395	5.9	13.9	141.6	-13.6
Dduty50-100_N_2xSD_15%	-1588	3066	6515	-14841	2.6	8.5	65.8	-13.6
Nduty50_N_2xSD_15%	-1695	3154	6515	-15467	2.7	8.6	67.8	-13.6
Nduty100_N_2xSD_15%	-1643	3105	6515	-15081	2.6	8.6	66.6	-13.6

Annex: Detailed specification of the model and Monte Carlo simulations

The full description of our world trade computable general equilibrium model is shown in Section B.1. This section is followed by Section B.2, where we examine distributions of productivity and the Monte Carlo draws.

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
$X_{i,r}^{p}$: household consumption
XFD_r : food composite
$X_{i,r}^{g}$: government consumption
$X_{i,r}^{v}$: 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_r^p : household savings
S_r^g : government savings
T_r^d : direct taxes
$T_{j,r}^z$: production taxes
$T_{j,s,r}^m$: import tariffs
$T_{j,r,s}^e$: export taxes
$T_{h,j,r}^f$: factor input taxes
p_r^{XFD} : price of food composite
$p_{i,r}^q$: price of Armington composite goods
$p_{h,j,r}^f$: price of factors
$p_{j,r}^y$: price of value added
$p_{i,r}^z$: price of gross output
$p_{i,r}^m$: price of composite imports
$p_{i,r}^d$: 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

EMS_r : release of emergency rice stocks

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

σ_r : standard deviation of productivity in the paddy rice sector

$\overline{EMS}_r$: capacity of emergency rice stocks

$Z^0_{j,r}$: 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: $UU_r = XFD_r^{\alpha_r^{XFD}} \prod_{nfd} {X^p_{nfd,r}}^{\alpha_{nfd,r}} \qquad \forall r$)

Demand functions for consumption

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

$$XFD_r = \frac{\alpha_r^{XFD}}{p_r^{XFD}} \left(\sum_{h,j} p^f_{h,j,r} F_{h,j,r} - T^d_r - S^p_r \right) \qquad \forall r$$

Food composite aggregation function

$$XFD_r = \Theta_r \left(\sum_{fd} \Delta_{fd,r} {X^p_{fd,r}}^{\Psi} \right)^{1/\Psi} \qquad \forall r$$

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

$$X^p_{fd,r} = \left(\frac{{\Theta_r}^{\Psi} \Delta_{fd,r}\, p_r^{XFD}}{p^q_{fd,r}} \right)^{\frac{1}{1-\Psi}} XFD_r \qquad \forall fd, r$$

Savings function

$$S^p_r = s^p_r \sum_{h,j} p^f_{h,j,r} F_{h,j,r} \qquad \forall r$$

-Value added producing firm

Factor demand function

$$F_{h,j,r} = \left(\frac{b_{j,r}^{\eta_j^{va}} \beta_{h,j,r} p_{j,r}^{y}}{\left(1+\tau_{h,j,r}^{f}\right) p_{h,j,r}^{f}} \right)^{\frac{1}{1-\eta_j^{va}}} Y_{j,r} \qquad \forall h, j, r$$

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

Value added production function

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

-Gross output producing firm

(Production function: $Z_{j,r} = TFP_{j,r} \min \left(\left\{ \frac{X_{i,j,r}}{ax_{i,j,r}} \right\}_i , \frac{Y_{j,r}}{ay_{j,r}} \right) \qquad \forall j, r$)

Demand function for intermediates

$$X_{i,j,r} = \frac{\alpha x_{i,j,r} Z_{j,r}}{TFP_{j,r}} \qquad \forall i, j, r$$

Demand function for value added

$$Y_{j,r} = \frac{ay_{j,r} Z_{j,r}}{TFP_{j,r}} \qquad \forall j, r$$

Unit price function

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

-Government

Demand function for government consumption

$$X_{i,r}^{g} = \frac{\iota_{i,r}}{p_{i,r}^{q}} \left(T_r^{d} + \sum_{h,j} T_{h,j,r}^{f} + \sum_{j} T_{j,r}^{z} + \sum_{j,s} T_{j,s,r}^{m} + \sum_{j,s} T_{j,r,s}^{e} - S_r^{g} \right) \qquad \forall i, r$$

Direct tax revenue

$$T_r^{d} = \tau_r^{d} \sum_{h,j} p_{h,j,r}^{f} F_{h,j,r} \qquad \forall r$$

Production tax revenue

$$T_{j,r}^{z} = \tau_{j,r}^{z} p_{j,r}^{z} Z_{j,r} \qquad \forall j, r$$

Import tariff revenue

$$T_{j,s,r}^{m} = \tau_{j,s,r}^{m} \left[\left(1+\tau_{j,s,r}^{e}\right) \varepsilon_{s,r} p_{j,s,r}^{t} + \tau_{j,s,r}^{s} \varepsilon_{USA,r} p^{s} \right] T_{j,s,r} \qquad \forall j, s, r$$

Export tax revenue

$$T_{j,r,s}^{e} = \tau_{j,r,s}^{e} p_{j,r,s}^{t} T_{j,r,s} \qquad \forall j, r, s$$

Factor input tax revenue

$$T_{h,j,r}^{f} = \tau_{h,j,r}^{f} p_{h,j,r}^{f} F_{h,j,r} \qquad \forall h, j, r$$

Government savings function

$$S_r^g = s_r^g \left(T_r^d + \sum_{h,j} T_{h,j,r}^f + \sum_j T_{j,r}^z + \sum_{j,s} T_{j,s,r}^m + \sum_{j,s} T_{j,r,s}^e \right) \qquad \forall r$$

-Investment
Demand function for commodities for investment uses

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

-Armington composite good producing firm
Composite good production function

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

(Note that $\eta_i = (\varepsilon - 1)/\varepsilon$)
Composite import demand function

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

Domestic good demand function

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

-Import variety aggregation firm
Composite import production function

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

Import demand function

$$T_{i,s,r} = \left(\frac{\omega_{i,r}{}^{\varpi_i} \kappa_{i,s,r} p_{i,r}^m}{\left(1+\tau_{i,s,r}^m\right)\left[\left(1+\tau_{i,s,r}^e\right)\varepsilon_{s,r} p_{i,s,r}^t + \tau_{i,s,r}^s \varepsilon_{USA,r} p^s\right]} \right)^{\frac{1}{1-\varpi_i}} M_{i,r} \qquad \forall i,s,r$$

-Gross output transforming firm
i) For $i = PDR$ (paddy rice):
CET transformation function

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

(Note that $\varphi_i = (\varepsilon_i + 1)/\varepsilon_i$).
Composite export supply function

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

Domestic good supply function

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

For simulation with Scenario S: Release of emergency stocks

$$EMS_r = \min\left\{\overline{EMS}_r, \max\left[(1-TFP_{i,r})Z_{i,r}^{0}, 0\right]\right\}.$$

ii) For $i = TRS$ (transportation):

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

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

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

iii) For $i \neq PDR, TRS$:

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

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

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

-Export variety producing firm
Composite export transformation function

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

Export supply function

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

-Inter-regional shipping sector[15]
Inter-regional shipping service production function

$$Q^{s} = c \prod_{r} TT_r{}^{\chi_r}$$

[15] About the inter-regional shipping sector, see Hertel [45].

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

$$TT_r = \frac{\chi_r}{\left(1+\tau^z_{TRS,r}\right)\ \varepsilon_{r,USA}\, p^z_{TRS,r}} p^s Q^s \qquad \forall r$$

-Market-clearing conditions
Commodity market

$$Q_{i,r} = X^p_{i,r} + X^g_{i,r} + X^v_{i,r} + \sum_j X_{i,j,r} \qquad \forall i,r$$

Capital markets

$$FF_{CAP,j,r} = F_{CAP,j,r} \qquad \forall j,r$$

Labor market

$$\sum_j FF_{LAB,j,r} = \sum_j F_{LAB,j,r} \qquad \forall r$$

$$p^f_{LAB,j,r} = p^f_{LAB,i,r} \qquad \forall i,j,r$$

Foreign exchange rate arbitrage condition

$$\varepsilon_{r,r'} \cdot \varepsilon_{r',s} = \varepsilon_{r,s} \qquad \forall r,r',s$$

Inter-regional shipping service market

$$Q^s = \sum_{i,r,s} \tau^s_{i,r,s} T_{i,r,s}$$

Monte Carlo draws and productivity distribution

We assume independent and identically distributed normal distribution in our Monte Carlo simulations to generate random productivity shocks of paddy rice sector. Questions about the assumptions would be the normality of the distributions and the correlation between regions. Figures B.1 and B.2 show the distributions of the residuals of OLS regressions of rice productivity in the world and India over the period 1961-2011, which seem to follow the normal distribution.

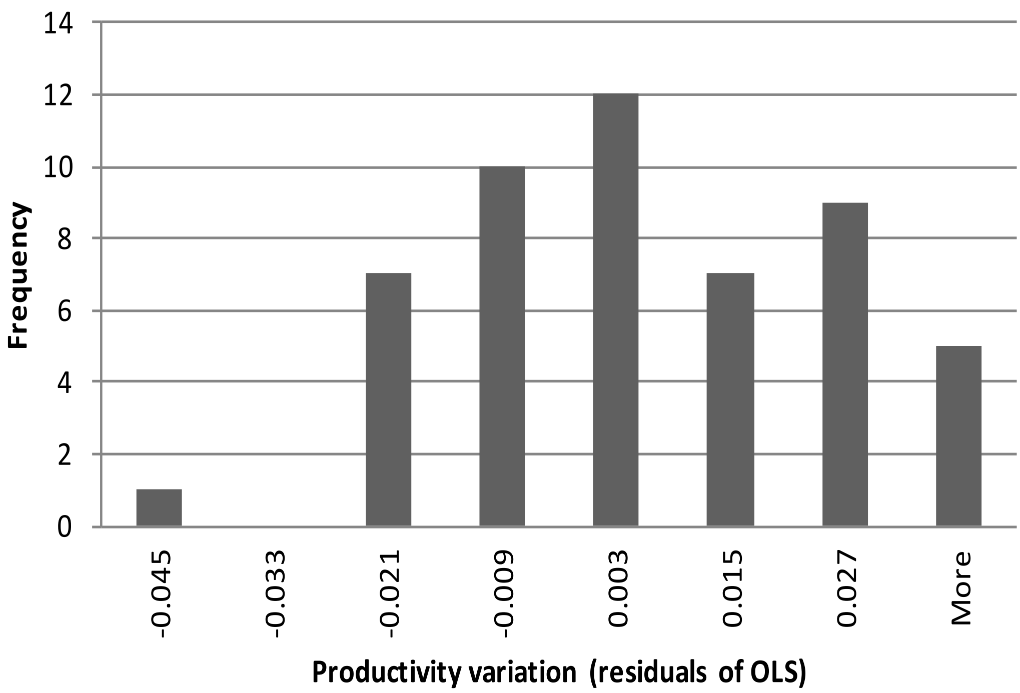

Figure B.1. Distribution of paddy rice productivity of the world (1961-2011) (Source: Authors' calculation from the FAOSTAT)

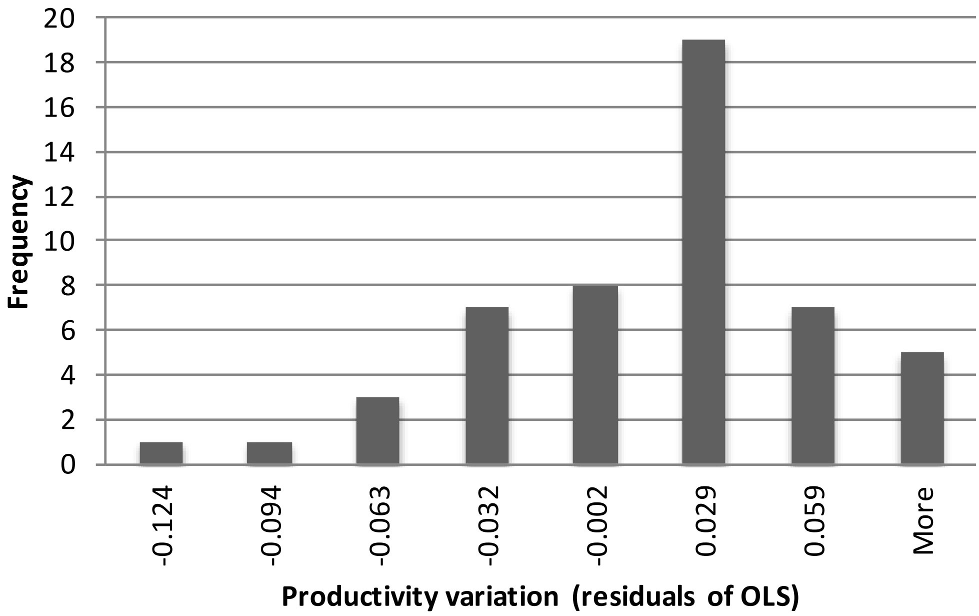

Figure B.2. Distribution of paddy rice productivity (1961-2011) (Source: Authors' calculation from the FAOSTAT)

In our analyses, we do not consider spatial correlations of rice productivity shocks between regions. Table B.1 indicates the correlations of the OLS residuals of paddy rice productivity over 1990-2010, which are generally quite low, meaning that no systematic spatial correlation is found in terms of the distance or the adjacency among regions.

Table B.1. Correlation of the OLS residuals of productivity changes between regions

	China	Egypt	India	Italy	Pakistan	Philippines	Thailand	USA	Uruguay	Vietnam	ROAS	ROE	ROAF	ROW
China														
Egypt	-0.17													
India	-0.01	-0.12												
Italy	-0.05	0.04	-0.03											
Pakistan	0.57	0.06	0.06	-0.28										
Philippines	-0.66	0.04	0.16	0.04	-0.25									
Thailand	-0.45	0.72	-0.22	0.10	-0.14	0.14								
USA	-0.52	0.32	-0.09	-0.10	-0.24	0.62	0.52							
Uruguay	0.44	-0.08	0.31	-0.26	0.50	0.07	-0.18	0.21						
Vietnam	-0.19	0.36	-0.32	0.10	0.10	0.35	0.25	0.22	-0.25					
ROAS	-0.38	-0.60	0.12	-0.19	-0.17	0.59	-0.32	0.27	0.08	-0.05				
ROE	0.40	0.22	-0.50	0.25	-0.18	-0.47	0.14	-0.17	-0.14	-0.02	-0.46			
ROAF	0.15	-0.39	0.37	0.01	0.45	0.33	-0.41	-0.08	0.51	0.02	0.48	-0.44		
ROW	0.08	-0.38	0.03	-0.22	-0.07	-0.05	-0.39	-0.07	0.36	-0.33	0.36	0.04	0.22	

Source: Authors' calculation from the FAOSTAT.
Notes: ROAS, ROE, ROAF, and ROW stand for Rest of Asia, Rest of Europe, Rest of Africa, and Rest of the World, respectively.