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Economic and environmental impacts of agricultural non-tariff measures: evidence based on *ad valorem* equivalent estimates

RESEARCH ARTICLE

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Abstract

Non-tariff measures as hidden barriers to agricultural trade would not only result in production and welfare distortions due to the international relocation of activities along the agricultural value chain, but also yield subsequent consequences to both the scale and distribution of carbon emissions from the agri-food system. This paper estimates *ad valorem* equivalents of non-tariff measures using a gravity model in combination with detailed bilateral trade data of 2001-2019, and incorporates the estimations in the Global Trade Analysis Project model and a multi-regional input-output table of Eora26 to quantify economic and environmental impacts of non-tariff measures. We show that while tariff equivalents are on average positive for all types of non-tariff measures, there are substantial heterogeneities across countries and products. The extra trade barriers imposed by these measures would increase the scale of domestic agriculture-related sectors for most agriculture importing countries, and vice versa for major exporters. Meanwhile, they would reduce the global welfare at amount of 16 millions US dollars on average and in particular, the welfare of key imposers and targeting markets of non-tariff measures. Carbon emissions from the agri-food system tend to increase about 1% around the world, especially due to the larger food processing industry in developed countries. Our paper confirms that non-tariff measures lead to both welfare distortions and carbon emissions in the agri-food system. It thus calls for urgent needs to promote further reforms of the agricultural trade regime and the policy coordination across countries to facilitate agri-food system transformation with more integration and sustainability.

Keywords: non-tariff measures, *ad valorem* equivalents, welfare distortions, carbon emissions
JEL code: Q13, Q15, Q17, Q18, Q56

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1. Introduction

Non-tariff measures (NTMs) are nowadays replacing tariffs as the most essential barriers to agricultural trade. Through trade liberalization and bilateral or multilateral free trade negotiations, the global average tariff rates on agricultural trade have been substantially reduced over the past decades. In major developed economies such as the US, EU and Japan, tariffs have declined from 40% in the mid-20th century to less than 3% by 2020. Since joining the World Trade Organization (WTO) in 2001, China's average tariff rate has also been more than halved from the initial level of 15%. By contrast, non-tariff measures, which include both classical price and quantity controls and more generally, technical measures that set out basic rules for food safety requirements and product standards, are increasingly used around the world, especially during the period after the Global Financial Crisis. As the two primary categories of agricultural non-tariff measures, the number of Technical Barriers to Trade and Sanitary and Phytosanitary Measures has respectively increased from 1,005 and 530 in 2007 to 1,998 and 1,053 in 2019. Both experienced an average rate of annual growth exceeding 6.5%.

Through both the scale and distribution of trade flows, agricultural NTMs might result in fundamental impacts on the output, structure, and inter-sectoral linkages of the agri-food system, which would consequently lead to changes and redistributions of carbon emissions across countries. Agriculture is one of the largest sources of the global carbon emissions. Over the past three decades, the greenhouse gas emissions from the agri-food system around the world has grown by 17%. In 2019, around 31% of anthropogenic emissions stemmed from the agri-food system, with an amount of 17 billion tonnes of carbon dioxide equivalent (FAO, 2021). The driver of emission increases differs across countries: while changes in farming and land use were the main cause of agri-food carbon emissions in developing countries, pre- and post-production processes accounted for more than half of emissions by developed countries. By relocating agriculture and related production activities away from those with comparative advantages, non-tariff measures would increase the overall scale of the world's agri-food system and therefore pose additional environmental challenges to these sectors for a given intensity of carbon emissions.

In this paper, we assess both economic and environmental impacts of non-tariff measures in the agri-food system based on *ad valorem* equivalent (AVE) estimates to quantify trade barriers. We first extend the gravity model approach of Kee (2006) to derive tariff equivalents of NTMs at the detailed product level and aggregate these estimates by sector and country based on trade flow structures to demonstrate both sectoral and geographic distributions of additional trade barriers. Estimation reveals that in general, agricultural NTMs entail positive AVEs which imply additional import tariffs. These tariffs are especially notable in major NTM imposing economies like the EU, US, and China as well as in the sector of food products.

We then introduce estimated AVEs as additional tariff rates into the The Global Trade Analysis Project (GTAP) model to examine subsequent economic and environmental impacts. Although GTAP is one of workhorse simulation models across various trade environments, past applications typically treat non-tariff measures as a counted variable that is directly translated as transport costs. They are thus not only confounded with other determinants of trade costs such as institutions and technologies, but also suffer from aggregation biases as increasing distortions with more NTMs are overlooked. Besides, the GTAP model also lacks a necessary module to capture emissions along the agri-food value chain, which impedes an overall identification of environmental consequences. We bring both AVE estimates and the input-output (IO) table of the Eora26 database[1] to GTAP to address these challenges. Simulation results indicate that non-tariff measures usually expand the domestic agri-food sector in agricultural importing countries and shrink it in most exporters, which further lead to noticeable welfare distortions both at the aggregate level and across countries. In terms of environmental effects, non-tariff measures are found to increase total carbon emissions from the agri-food system, particularly from NTM imposing economies and the food processing sector.

[1] https://worldmrio.com/eora26

Our paper demonstrates that agricultural NTMs lead to both welfare distortions and carbon emission challenges to the agri-food system. It thus highlights necessary priorities to be given to promote further reforms of the agricultural trade regime and the policy coordination across countries to facilitate agri-food system transformation towards a greater integration and sustainability. The rest of the paper is organized as follows. Section 2 provides a literature review of quantification methods of non-tariff measures and studies on their trade, welfare, as well as environmental consequences. Section 3 presents our empirical methods and data, while estimation and simulation results are demonstrated and discussed in Section 4. Finally, Section 5 concludes the paper.

2. Literature review

2.1 Methods to quantify non-tariff measures

The earliest quantification of non-tariff measures relies on indices for measures of concern at stock. While Swann (1996) and Schlueter (2009) simply aggregate all non-tariff measures, their index cannot distinguish regulations that target different products and based on different food safety standards. To overcome these limitations and consider the level of trade restrictions directly, Wilson and Otsuki (2004) adopt a measure constructed from the maximum residual level allowed in each product (e.g. aflatoxin content in peanuts and grains). The stringency of non-tariff measures is also reflected by the frequency and coverage in application. Stephenson (2002) and Disdier *et al*. (2008) calculate the scope of product coverage of non-tariff measures by country and sector at the macro level. Seeing that non-tariff measures tend to increase trade costs and distort market prices, Deardorff and Stern (1997) propose a price-wedge method by computing the differentials between global and domestic product prices to quantify non-tariff measures. Recently, Kee *et al.* (2006) invented an *ad valorem* approach based on the gravity model to systematically estimate tariff equivalents of non-tariff measures. The approach first introduces non-tariff trade measures to a standard gravity model of international trade. It then estimates tariff equivalents by regressing bilateral trade flows on the incidence of various non-tariff measures as well as conventional gravity determinants.

2.2 Impacts of non-tariff measures on agricultural trade

Non-tariff measures can be both trade restricting and facilitating. Using a gravity model, Tran *et al.* (2012) find that food safety regulations of aquatic products restrict exports from low- and middle-income countries. Zhou *et al.* (2019) further show that the response of China's agricultural exports to border controls of the United States is concentrated in the short run and various substantially across sectors. Beestermöller *et al.* (2018) identify negative spillovers of non-tariff measures across firms, which indicate possible deterrence to firms which are not directly affected by the measures. Recently, Sun *et al.* (2021) use data on Chinese import rejections to add to the picture of the impeding effect of non-tariff measures on agricultural trade from the perspective of food safety regulations. In contrast, Jaud *et al.* (2013) argue that exporters could mitigate negative impacts of non-tariff measures by diversifying product sources. Anders and Caswell (2009) even reveal trade expansions with non-tariff measures due to catalytic effects, which state that these measures can reduce the information asymmetry between consumers and exporters. Due to the complex relationship between non-tariff measures and trade (Sheldon, 2012), to determine the optimal level of non-tariff measures is thus often challenging in practice (Swinnen, 2017; Swinnen and Vandemoortele, 2011). In addition, Ghodsi (2022) proposed a theoretical framework and empirically investigated the impact of regulatory NTMs on the quality of agricultural imports for both sanitary and phytosanitary measures (SPS) and technical barriers to trade (TBT) types of regulatory NTMs and found that they were effective in improving the quality of imported agricultural products.

2.3 Welfare consequences of agricultural non-tariff measures

The welfare consequence of non-tariff measures tends to depend on the market structure. Ikeda and Toshimitsu (2010) confirm a positive effect with monopolistic competition but a negative one with Bertrand oligopoly. Van Tongeren (2009) builds an analytical model of consumers, producers, and foreign suppliers to show that product labeling could improve consumer welfare by mitigating negative externalities and information asymmetry. However, findings from empirical studies based on equilibrium analysis generally find negative welfare effects of non-tariff measures and suggest that fewer such measures usually promote the overall national welfare. Calvin and Krisoff (1998), for example, estimate the welfare consequence of SPS measures imposed by Japan. They show that when the number of non-tariff measures declines, the growth of the consumer welfare could offset the reduction of producer welfare. Thus, Japan's total national welfare increases. Beghin *et al*. (2012) offers similar insights with a welfare-based system for the shrimp trade.

2.4 Environmental effects of agricultural non-tariff measures

Compared with welfare consequences, studies are relatively more controversial with regard to environmental effects of non-tariff measures. On the one hand, trade liberalization tends to induce production expansions, intensified resource utilization, longer transportation, transboundary pollution, as well as relocation of production activities towards areas with less restrictive environmental regulations that is known as the pollution haven hypothesis. It may therefore increase pollution and accelerate environmental degradation. For instance, Lee and Zhang (2009) reveal greater energy uses and increasing carbon emissions associated with trade liberalization, particularly in less developed countries. Moon (2011) argues that free trade tends to complicate the issue of identifying countries and regions that are key emitters and polluters. In addition, Chakravorty *et al*. (2007) and Drabo (2017) propose the urgency for developing countries to establish inspection and enforcement mechanisms during the process of globalization in order to minimize the adverse trade impacts on the environment. On the other hand, positive environmental impacts can be associated with free trade for the economy of scale and efficiency gains. Carter (1993) and Dang and Konar (2018), for example, find trade liberalization to result in less water and soil uses in agriculture. Hassan *et al*. (1999) argues that agricultural production itself can generate environmental co-benefits. Based on forecast analysis, Hallstrom (2004) show that trade plays a critical role in achieving climate goals. Balogh (2022) further confirms the existence of an emission reduction role of trade and FTAs in agricultural trade and distinguishes the role of specific FTAs in emission reduction. Both Beghin *et al.* (1997) and Bourgeon and Ollivier (2012), however, find insignificant environmental impacts of agricultural trade overall and argue that the effects might depend on regional comparative advantages.

3. Method and data

3.1 Ad valorem *equivalent estimates*

In this paper, we rely on the gravity model approach developed by Kee (2006) to estimate AVEs for different types of non-tariff measures and quantify the average level of trade restrictions by product and region. Specifically, we first build the following gravity model of agricultural trade to estimate the impact of non-tariff measures on the volume of bilateral trade at the product level.

$$ln(m_{ijht}) = \beta_{0h} + \beta_{1h} ln(1 + Tariff_{ijht}) + \sum_{n=1}^{N} \beta_{2h}^{n} NTM_{ijht}^{n} + \beta_{3h}\boldsymbol{C_{ijt}} + \omega_{ht} + \omega_{ijh} + \mu_{ijht} \quad (1)$$

In Equation 1, subscripts i, j, h and t respectively denote the importing country, exporting country, product and time. m_{ijht} represents country i's import quantity from country j, while $Tariff_{ijht}$ and NTM_{ijht}^{n} respectively represent the tariff rate and non-tariff measures of type n associated with the import flow. The vector C_{ijt} includes country characteristics that are conventional determinants of bilateral trade in the gravity model, which contain: (1) gross domestic products (GDPs) of trade partners; (2) the difference of labor forces between partners; (3) the geographical distance between partners; and (4) whether both countries are (a) EU members, (b) WTO members, or (c) belonging to the same Regional Trade Agreement (RTA). ω_{ht} and ω_{ijh} respectively capture time and country-pair fixed effects, while μ_{ijht} is the usual error term.

We then use import demand elasticities at the product level (Ghodsi, 2016) to convert coefficients of β_{2h}^{n}, which are estimated from Equation 1, into *ad valorem* equivalents.

$$AVE_{ih}^{n} = \frac{e^{\beta_{2h}^{n}-1}}{\varepsilon_{ih}} \quad (2)$$

In Equation 2, ε_{ih} is country *i*'s import demand elasticity for product h, while AVE_{ih}^{n} represents the estimated *ad valorem* equivalents. We can then estimate the average tariff equivalents faced by importer *i* in product h by averaging AVEs across different types of non-tariff measures using import volumes as weights, as illustrated by Equation 3.

$$Mean\ AVE_{ih} = \sum_{h} \frac{AVE_{ih}^{n} * m_{ih}}{m_{i}} \quad (3)$$

3.2 Model setup and simulation strategy

The GTAP model developed by Purdue University is one of the workhorse frameworks for economic and environmental impact analysis of international trade. There are typically two approaches to introduce trade barriers into the GTAP model. The first is to directly model tax impacts using the *tms* variable that captures all levels of tariff rates and equivalents. The second is to consider trade barriers as transport costs that are affected not only by trade policies, but also more broadly technological progress. Previous studies often rely on this latter approach by incorporating the number of non-tariff measures into the *ams* variable of trade costs in the GTAP model (Helble *et al.*, 2009). The AVE is estimated using a dataset with a time span of 2001-2019, and the AVE is estimated at the year-country-import product level. With our AVE estimates, non-tariff measures can be modeled as additional tariffs, which not only can distinguish them from other institution- or technology-driven trade costs, but are also able to reflect fundamental differences across non-tariff measures with heterogenous trade restriction effects. In other words, the AVEs estimated from the last section will be introduced to the GTAP model through the tms variable. The GTAP Model 9.0 database[2] provides a baseline of 2011, so the average of AVEs over the period from 2001 to 2019 is used in this study to include AVEs in the GTAP model for analysis.

3.3 Environmental impact analysis

The GTAP model lacks the necessary module to estimate emission impacts along the agri-food value chain, which impedes the assessment of total emissions from the agri-food system. Therefore, we introduce an international input-output database to establish inter-sectoral linkages within the agri-food system. Currently, global MRIO databases such as Eora[3], WIOD[4] and EXIOBASE[5] are most widely used to evaluate the environmental linkages across sectors. However, for carbon emissions, discrepancies among estimates from these MRIO databases for most major nations is less than 10% (Moran and Wood, 2014). In this paper, matrices of direct consumption coefficients and carbon emission intensity in the Eora26 database will be combined with the final output matrix derived from the GTAP model to calculate the carbon emissions along the agri-food value chain, seeing that compared with alternative databases, Eora has the longest time span (from 1990 to 2016) and the widest regional coverage (189 economies). To supplement with the Eora26 database, however, it is necessary to transform its regional and sectoral divisions with a new input-output table that is consistent with the GTAP model. There are two mainstream approaches in the literature. One is to reclassify all industries and sectors and set up a new classification system. But the problem is that this approach will be destructive to the original data such that essential sectoral characteristics may be lost.

[2] https://www.gtap.agecon.purdue.edu/databases/default.asp
[3] https://worldmrio.com
[4] http://www.wiod.org/new_site/home.htm
[5] https://www.exiobase.eu

The other is the common classification (CC) system approach (Owen *et al*., 2014), which could preserve original sectoral characteristics while provide credible conclusions. Therefore, we aggregate the Eora26 by region and sector to match with GTAP following the CC method. We found the common division of sectors and regions between the two databases while preserving the original classification of sectors and regions in the Eora26 and GTAP models, and accordingly performed a small-scale aggregation of Eora26 to ensure a minimum of distortion.

Let $X = [x_1, ..., x_n]'$ be the total output matrix of the world with x_i denoting the output vector of country *i*, and A be the technical coefficient matrix specified as follows in Equation 4, with each element A_{ij} denoting inputs from country *i* into the production of country *j*.

$$A = \begin{bmatrix} A_{11} & \cdots & A_{1n} \\ \vdots & \ddots & \vdots \\ A_{n1} & \cdots & A_{nn} \end{bmatrix} \quad (4)$$

According to the balance of trade, the basic input-output relationship holds as $AX + Y = X$. Following Fang *et al.* (2021), the consumption-based carbon emission can thus be calculated by the following formula:

$$CE_f = ELY = EX \quad (5)$$

In Equation 5, CE_f reflects emissions from the final demand. E is the matrix of emission intensity with elements e denoting emissions per unit of output by country and sector. $L = (I - A)^{-1}$ is the Leontief inverse matrix, with element l_{ij}^{nm} capturing direct and indirect outputs from sector *i* of country *n* used in per unit final demand of sector *j* in country *m*. Finally, the consumption-based carbon emissions can thus be calculated by summing up each column of CE_f, in which diagonal and non-diagonal elements are respectively direct and indirect emissions.

3.4 Data

To estimate *ad valorem* equivalents of agricultural non-tariff measures, annual volumes of bilateral trade at the harmonized system (HS) 6-digit level are first derived from the CEPII-BACI[6] database. Following Beestermöller *et al.* (2018), agricultural products are defined as those falling below the first 24 chapters in the HS coding system. For each trade flow, we match non-tariff measures provided by the WTO I-TIP[7] database, which records all types of measures by the imposing country, partners affected, and detailed products during 2001-2019. Nevertheless, seeing that 75% agricultural non-tariff measures are either SPS (52%) or TBT (23%), we classify remaining measures as a single category denoted by 'others (OTH)', such that three groups of non-tariff measures would be eventually considered in Equation 1. In fact, while both SPS and TBT are technical measures to trade that concern standards and safety regulations, measures in the remaining OTH group are traditional non-technical measures such as quotas and anti-dumping duties which include 12 subcategories each containing only about 2% NTM incidents in our sample on average. Further breaking down the OTH group could result in inefficient estimates due to the 'zero problem'. Control variables of the gravity model include product-level tariff rates provided by the WTO-IDB[8] database and country characteristics obtained from the CEPII Gravity[9] database. Our final dataset includes 704 products traded between 149 importers and 227 exporters during 2001-2019. Table 1 shows the statistical summary of variables used to estimate *ad valorem* equivalents of agricultural non-tariff measures. Among all country pair-product-year triplets, 71% have received non-tariff measures, with 53% subject to SPS and 30% subject to TBT. We exclude country pair-product duplets that have never received non-tariff measures throughout the entire sample period, so the final dataset includes 4.91 million observations.

[6] http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=37
[7] https://www.wto.org/english/res_e/statis_e/itip_e.htm
[8] https://www.wto.org/english/tratop_e/tariffs_e/idb_e.htm
[9] http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele_item.asp?id=8

Table 1. Statistical summary of variables in the gravity model.[1]

Variable	Label	Obs	Mean	Std. dev.	Min	Max
lnm	Logarithm of the amount of trade	4,911,745	3.24	2.52	0	20.37
SPS	Number of SPS	4,911,745	0.94	2.08	0	404
TBT	Number of TBT	4,911,745	0.40	1.30	0	690
OTH	Number of other NTMs	4,911,745	0.44	1.52	0	339
Tariff	Tariff rate	4,911,745	10.08	19.11	0	827
gdp_o	Importer GDP	4,911,745	1.51e+09	3.12e+09	9.24e+05	1.95e+10
gdp_d	Exporter GDP	4,911,745	1.48e+09	2.99e+09	1.55e+04	1.95e+10
wto	Are they all WTO members?	4,911,745	0.94	0.23	0	1
eu	Are they all members of the EU?	4,911,745	0.29	0.45	0	1
rta	Are they all RTA members?	4,911,745	0.53	0.49	0	1
Labor	Labor distance	4,911,745	-9.57	1.30	-11.67	-4.68
distance	Economic distance at the per-capita level	4,911,745	0.10	0.12	0	0.48
elasticity	Import demand elasticity	4,911,745	-1.13	1.46	-24.99	-0.01

[1] SPS = sanitary and phytosanitary measures; TBT = technical barriers to trade; NTMs = non-tariff measures; GDP = gross domestic product; WTO = World Trade Organization; RTA = regional trade agreement.

To further assess economic and environmental impacts of non-tariff measures, we introduce both estimated *ad valorem* equivalents and the Eora26 database to the GTAP model. The GTAP model has been reclassified to nine regions to better reveal environmental benefits, which include: (1) United States of America (USA); (2) China (CHN); (3) European Union (EU27); (4) Japan (JPN); (5) other Annex I countries (RoA1); (6) energy exporting regions (EEx); (7) India (IND); (8) other countries of Eastern Europe (EEFSU); and (9) rest of the world (RoW). Among them, China and India represent the two major emerging countries, and the United States and Japan represent major developed countries. Other Annex I countries represent Annex I countries of the United Nations Framework Convention on Climate Change (UNFCCC) that are expected to mitigate GHG emissions. This regional division allows us to measure environmental impacts by focusing on critical players in the world. To introduce estimated *ad valorem* equivalents from the gravity equation, we note that the GTAP model considers 12 product categories in the agricultural sector. As a result, we aggregate product-level AVE estimates by import weights using the concordance in Table 2. In terms of the sectoral division, we consider nine sectors according to the GTAP 9.0 and Eora26 database. These sectors include agriculture, food processing, storage and transportation, light industry, heavy industry, energy and mining, textile industry, facility construction, and other services. To introduce estimated *ad valorem* equivalents from the gravity equation, we note that the GTAP model considers 12 product categories in the agricultural sector. As a result, we aggregate product-level AVE estimates by import weights using the concordance in Table 2. In terms of the sectoral division, we consider nine sectors according to the GTAP 9.0 and Eora26 database. These sectors include agriculture, food processing, storage and transportation, light industry, heavy industry, energy and mining, textile industry, facility construction, and other services.

4. Results

4.1 AVEs of agricultural non-tariff measures

Estimation results of Equation 1 reveal that in general, *ad valorem* equivalents associated with agricultural non-tariff measures are positive, indicating extra barriers to trade. According to Table 3, the average AVEs of TBT are the highest, with each additional measure equivalent to a 0.032 percentage point import tariffs. In contrast, each additional SPS measure and that of other non-tariff measures (OTH) would respectively impose a 0.017 and 0.025 percentage point import tariffs on average. However, as demonstrated by the

Table 2. Mapping between HS and GTAP agricultural products.[1]

Category	Number	HS products	Content
Cereals	1	HS10	paddy rice, wheat, cereal grains
F_V	2	HS07\08\20	vegetables, fruits, nuts
oil seeds	3	HS12	oil seeds
Pbf	4	HS14	plant-based fiber
Csgh	5	HS01	cattle, sheep, goats, horse, etc.
Ap	6	HS02/03/05	animal products
raw milk	7	HS04	raw milk
Vof	8	HS15	vegetable oils and fat
Pr	9	HS19	processed rice
Sugar	10	HS17	sugar
beverages	11	HS22	beverages
Fd	12	others	food products, etc.

[1] HS = harmonized system; GTAP = Global Trade Analysis Project.

Table 3. Marginal effects of agricultural SPS, TBT and other non-tariff measures on estimated AVEs.[1]

Variable	Mean(%)	Std. dev.	P10	P90
SPS	0.017	0.32	-0.752	0.894
TBT	0.032	0.77	-0.947	1.742
Other	0.025	0.65	-1.643	1.869

[1] SPS = sanitary and phytosanitary measures; TBT = technical barriers to trade; AVEs = *ad valorem* equivalents.

standard deviations as well as estimates at the 10th and 90th percentiles, *ad valorem* equivalents of each type of non-tariff measures are also notably heterogenous across agricultural products.

We then aggregate *ad valorem* equivalent estimates both by types of non-tariff measures and for all the three types of measures across countries in each region, to quantify the overall extra inter-regional barriers to trade. Table 4 reports estimation results. For comparison, we also show the average tariff rates of agricultural imports in the last column. The results reveal that for developed countries such as the EU, US and Japan as well as major developing markets such as China, the overall equivalents of import tariffs when all non-tariff measures are considered together are larger than the regional average tariff rates of agricultural imports. However, import tariff rates still remain higher than *ad valorem* tariff equivalents of non-tariff measures for India, other industrialized countries in Annex I, and the rest of the world.

To further investigate the geographic and product distribution of estimated *ad valorem* equivalents of non-tariff measures, we first calculate country-specific overall equivalent tariffs for each importing country using its import structure of agricultural products as weights and for each exporting country based on its export structure. We visually present estimation results in Figure 1, where the EU, US, China and Russia as main implementing economies of agricultural NTMs are found to entail the greatest additional import barriers according to the darker color that they have.

Similarly, Figure 2 presents aggregate country-specific *ad valorem* equivalents of non-tariff measures by exporters. Exporters that receive the most import barriers are concentrated in Asia, Africa, Australia, and South America. In particular, according to the darker color that they have, China, Japan, Korea, Australia,

Table 4. Aggregated AVEs of SPS, TBT, and other NTMs by regions (%).[1]

	SPS	TBT	Others	All NTMs	Tariff rate
EU27	16.58	8.39	3.72	28.69	8.03
CHN	11.74	5.67	5.20	22.61	15.2
IND	2.25	2.13	1.14	5.52	13.84
USA	7.41	14.57	2.65	24.63	15
EEx	0.78	2.67	3.12	6.37	5.32
RoA1	0.86	0.63	1.14	2.63	10
JPN	2.36	6.03	5.74	14.13	9
EEFSU	5.48	3.03	13.82	22.03	11
RoW	2.11	0.67	9.32	12.1	17.44

[1] AVEs = *ad valorem* equivalents; SPS = sanitary and phytosanitary measures; NTMs = non-tariff measures; TBT = technical barriers to trade; EEx = energy exporting regions; RoA1 = other Annex I countries; EEFSU = other countries of Eastern Europe; RoW = rest of the world.

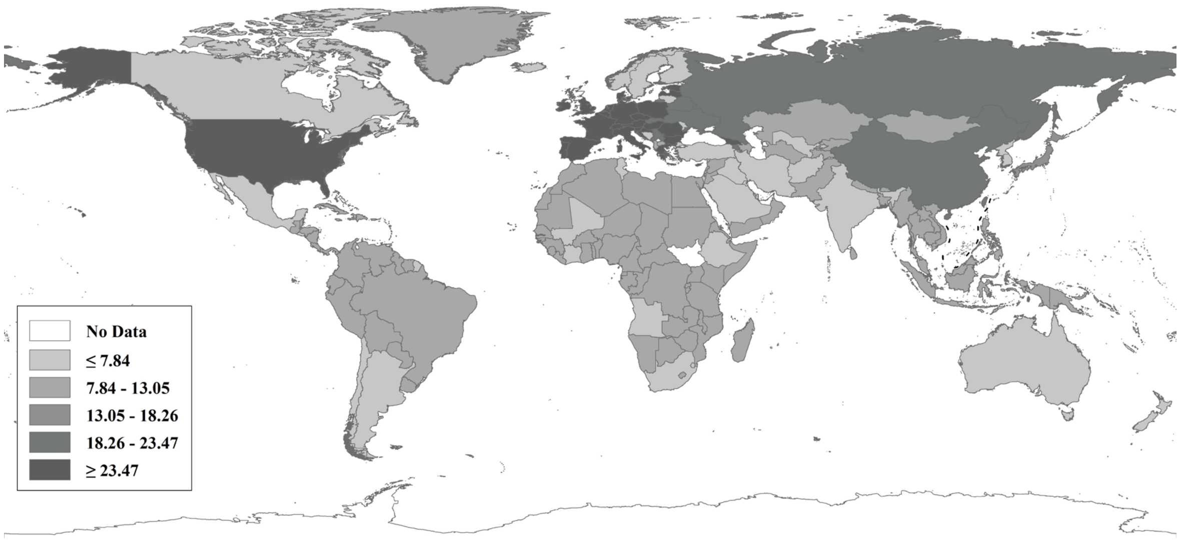

Figure 1. Aggregate *ad valorem* equivalent estimates of non-tariff measures by importers (%).

Argentina, Brazil, Chile, Norway and Sweden are countries with products most heavily restricted by non-tariff measures of importing partners.

Finally, to examine the product distribution of estimated *ad valorem* equivalents of non-tariff measures, we aggregate AVEs for each NTM category estimated at the HS 6-digit level to the 12 product groups demonstrated in Table 2, using the structure of import flows in each product group as weights. Figure 3 shows that for either SPS, TBT or other non-tariff measures, *ad valorem* equivalents of an additional measure are substantially different across product groups. However, for all the three types of non-tariff measures, the group of food products always entail the highest *ad valorem* equivalents. Specifically, the AVE is 0.16 in this group for each additional SPS measure, 0.25 for each TBT, and 0.21 for each other non-tariff measures. Aside from the group of food products, greater tariff equivalents of SPS measures are also found in groups of vegetable oils and fat, processed rice, raw milk, and cereals. In contrast, relatively larger tariff equivalents of TBT measures are revealed in groups of oil seeds, animal products, and sugar. For certain combinations of products and NTMs such as TBTs in the product group of cattle and horse, however, the aggregate estimated

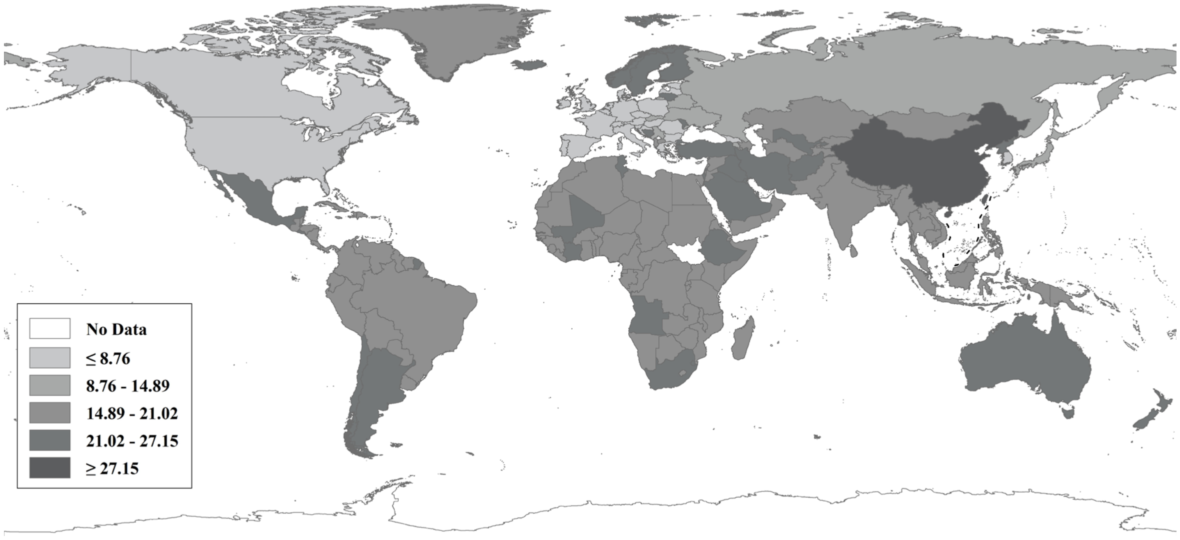

Figure 2. Aggregate *ad valorem* equivalent estimates of non-tariff measures by exporters (%).

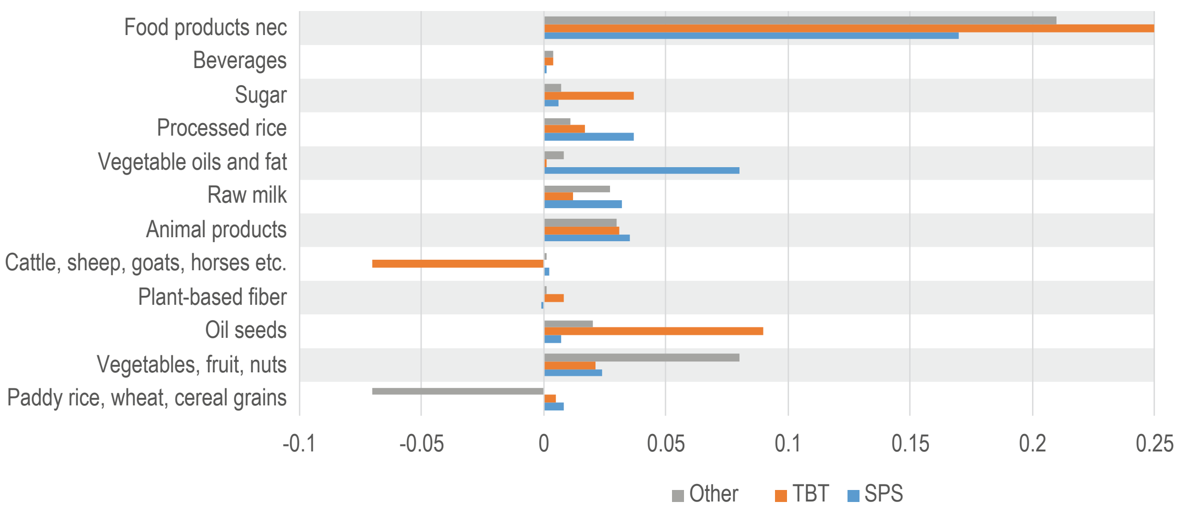

Figure 3. Marginal effects on of non-tariff measures *ad valorem* equivalent estimates by products (%). TBT = technical barriers to trade; SPS = sanitary and phytosanitary measures.

AVEs turns out to be negative, which imply import facilitating effects as non-tariff measures may address information asymmetry and regulate product quality.

4.2 Economic impacts of non-tariff measures

We introduce estimated AVEs as additional import tariffs into the GTAP model, to examine subsequent output changes of the agriculture sector, the food system, as well as agricultural imports and exports, and then to investigate the overall welfare consequences. According to Table 5, simulation results indicate increased agricultural outputs and a greater food system which is defined by the IO relationships with the agriculture sector from agricultural NTMs in the majority of agricultural importers. In contrast, agriculture outputs and food systems in most agricultural exporters decline. To be specific, major imposing countries of non-tariff measures such as China, Japan, the US, and the EU suffer from notable import reductions due to the extra barriers of trade, and thus would experience expansions of agricultural production and the food system. For

Table 5. Economic impacts of agricultural non-tariff measures.[1]

		EV (million $)	Change of agriculture output (%)	Change of food system output (%)	Change of import value (%)	Change of export value (%)
Tariff	CHN	-1,467.63	0.08	1.38	-26.2	-50.33
	IND	-1,941.13	-0.48	-0.91	-28	-42.49
	JPN	-1,508.57	5.85	1.37	-15.6	-38.32
	USA	-5,853.66	3.21	0.53	-24.5	-44.64
	EU27	-4,754.95	3.61	1.08	-3.9	-10.87
	RoA1	-2,698.41	-2.6	-1.81	-24.2	-21.75
	EEx	-852.77	2.33	2.09	-15.9	-2.91
	EEFSU	-1,879.88	1.14	0.74	-18.8	-26.93
	RoW	-10,593.14	-2.18	-2.78	-20.9	-41.73
NTMs	CHN	-2,403.7	0.2	2	-28.2	-57.02
	IND	-947.1	0.7	1.2	-22.1	-1.01
	JPN	-2,753.1	7	1.7	-16.4	-41.97
	USA	-12,299.3	5.8	1	-24.3	-55.63
	EU27	-10,274	5.1	3.7	-5.3	-1.39
	RoA1	-1,193.7	-7.9	-7	-24.2	-12.27
	EEx	-3,641.9	3	3.2	-18	-3.54
	EEFSU	-3,141.2	1	1	-24.7	-40.45
	RoW	-8,607.6	-0.4	-0.5	-21.1	-24.53

[1] EV = equivalent variation to measure the change in social welfare caused by non-tariff measures; NTMs = non-tariff measures; RoA1 = other Annex I countries; EEx = energy exporting regions; EEFSU = other countries of Eastern Europe; RoW = rest of the world.

most agricultural exporters, non-tariff measures result in fewer exports and thus smaller agriculture-related sectors.

Noticeable welfare distortions caused by non-tariff measures are also observed both at the aggregate level and across countries. According to simulation results, the global welfare would decline by 16 million US dollars for each additional non-tariff measure imposed on average, with a greater reduction in implementing economies such as the EU and the US. For example, a total welfare loss of 10,274 million dollars is found in the EU, seeing that non-tariff measures that it imposes on import partners would reduce its consumer welfare in spite of the protection provided to its domestic producers on the one hand, and welfare losses in the export sector from non-tariff measures imposed by export partners on the other. Main developing economies such as China and South America are top targets of non-tariff measures imposed by their developed import partners. As a result, they also experience notable welfare declines.

While the global welfare loss from agricultural non-tariff measures accounts for only about 0.3% of the world GDP, the importance to regulate these measures should not be overlooked since the output and welfare distortions that they cause are much larger than those from agricultural import tariffs. In the upper panel of Table 5, we present estimated economic impacts of tariffs, in comparison with those for the *ad valorem* equivalents of non-tariff measures at the bottom. It shows that both import tariffs and non-tariff measures produce net welfare losses in each region around the world. However, the global welfare loss from import tariffs is roughly 70% of that caused by non-tariff measures. Besides, in most regions, the distortions to the agri-food system and agricultural trade are also relatively larger for non-tariff measures. These results imply that compared to import tariffs; non-tariff measures are now more important barriers in agricultural trade.

4.3 Environmental impacts of non-tariff measures

Finally, we introduce estimated *ad valorem* equivalents of agricultural non-tariff measures into the GTAP model to identify their environmental impacts based on the direct consumption coefficient matrix from the IO table of the Eora26 database. We consider agriculture, food processing, and storage and transportation as three major sectors of the food system, and present estimated emissions from each sector as well as the entire food system in Table 6. Our results indicate that in general, agricultural non-tariff measures would increase carbon emissions since they tend to expand the domestic food systems which are one of the largest contributors of carbon emissions. Compared to those from other sectors, emissions from food processing are notably higher in most regions. In 2016 for example, estimated carbon emissions from food processing would account for 43% of the total emissions by the food system around the world. In certain regions such as Japan, the US, and the EU, this ratio could even exceed 50%. In Table 6, the results also shows that storage and transportation sector is not a contributor but an offset item to emission changes in the agri-food system. The possible reason is that increased trade barriers of non-tariff measures lead to decreases of storage and transportation activities related to import and export, which reverse the increase of storage and transportation caused by the expansion of domestic production and food processing.

Figure 4 shows the geographic distribution of estimated carbon emissions that are entailed from agricultural non-tariff measures. Major NTM imposing economies including the EU, the US and China are found to be associated with increased overall carbon emissions from the food system. For other industrialized countries in Annex I and countries in the rest of the world, carbon emissions decline with fewer domestic agricultural productions and smaller food systems. It is also evident in the last column of Table 6 that shows the total rate of change in carbon emissions from the agri-food systems. To be specific, the figure indicates percentage point changes of the share of agri-food system emissions in total emissions with and without considering non-tariff trade measures, which shows the share would increase by about 1-3 percentage points in major NTM imposing economies.

4.4 Comparison with the conventional non-tariff measures modeling approach

Although GTAP is one of workhorse simulation models for changes in the trade environment, previous studies typically treat non-tariff measures as a counted variable that is directly translated as transport costs. This modeling approach will thus not only confound non-tariff measures with other trade cost determinants like institutions and technologies, but may also suffer from aggregation biases since increasing distortions with more NTMs are overlooked. In this section, we demonstrate simulation results of welfare distortion, agriculture-related output, and carbon emission of agri-food system when non-tariff measures are modeled

Table 6. Estimated carbon emissions in the food system attributed to non-tariff measures (Gg).[1]

	Agriculture	ProcFood	TransComm	Total	Total rate (%)
CHN	25,732.13	350,901.28	-11,900.76	364,732.64	0.86
IND	41,714.40	58,469.61	-8,774.90	91,409.11	0.60
JPN	17,259.27	45,097.29	-1,588.39	60,768.17	1.35
USA	95,772.55	102,749.13	3,790.77	202,312.46	1.04
EU27	96,547.27	290,660.12	-5,547.47	381,659.91	2.50
RoA1	-67,416.08	-187,538.55	-3,123.59	-258,078.23	-5.07
EEx	350,210.28	294,744.54	-17,961.69	626,993.12	2.33
EEFSU	20,192.85	65,001.98	-5,358.92	79,835.91	0.71
RoW	-35,203.46	-39,432.09	-10,807.85	-85,443.41	-0.39
Total	544,809.22	980,653.32	-61,272.83	1,464,189.71	0.90

[1] RoA1 = other Annex I countries; EEx = energy exporting regions; EEFSU = other countries of Eastern Europe; RoW = rest of the world.

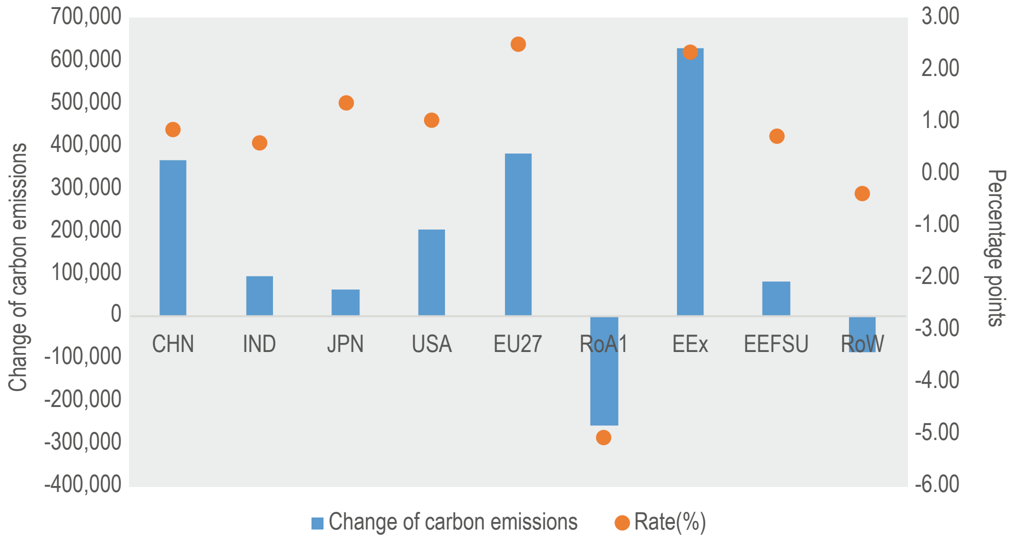

Figure 4. Changes of estimated carbon emissions from non-tariff measures by regions in 2011. EEFSU = other countries of Eastern Europe; RoW = rest of the world; RoA1 = other Annex I countries; EEx = energy exporting regions.

in GTAP with the conventional approach, and compare them with our simulation results based on the AVE approach above. Table 7 shows the comparison result.

In Table 7, A represents simulation results based on the conventional approach, and B represents those based on the AVE approach. From the results shown in Table 7, the degree of distortions based on the AVE approach is much greater by accounting for increasing distortionary effects of NTMs with relatively larger AVEs, although the direction of changes remains the same between these approaches. Similarly, a greater expansion or contraction of agriculture-related outputs has also been found from the AVE approach. Finally, the results also indicate that with the AVE modeling approach, the estimated carbon emissions effects of non-tariff trade measures would be greater. Such evidence confirms that the increasing distortion of non-tariff measures has been ignored in the conventional GTAP modeling approach.

Table 7. Comparative analysis with the conventional modeling approach.[1]

	EV (million $)		**Change of agriculture output (%)**		**Change of food system output (%)**		**Change rate of carbon emissions (%)**	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**
CHN	-1,612.77	-2,403.70	0.11	0.24	0.77	2.45	0.29	0.86
IND	-1,031	-947.1	0.14	0.73	0.3	1.22	0.12	0.6
JPN	-1,068.24	-2,753.10	3.17	7.45	0.88	1.74	0.47	1.35
USA	-2,936.88	-12,299.30	0.91	5.82	1.6	1.38	0.43	1.04
EU27	-5,378.81	-10,274	0.71	5.13	1.89	3.74	0.67	2.5
RoA1	-3,397.87	-1,193.70	-3.56	-7.94	-3.06	-7.43	-2.16	-5.07
EEx	-2,500.08	-3,641.90	0.77	3.47	1.05	3.21	0.58	2.33
EEFSU	-1,554.87	-3,141.20	0.54	1.29	0.61	1.19	0.22	0.71
RoW	-7,498.68	-8,607.60	-1.95	-0.44	-1.81	-0.54	-1.03	-0.39

[1] EV = equivalent variation to measure the change in social welfare caused by non-tariff measures; EEFSU = other countries of Eastern Europe; RoW = rest of the world; RoA1 = other Annex I countries; EEx = energy exporting regions.

4.5 Sensitivity analysis

For sensitivity analysis, we will consider three scenarios in which the *ad valorem* equivalents of agricultural non-tariff measures are respectively set at 0, 50 and 100% (Stevanovic *et al.*, 2016), such that economic and environmental impacts can be compared for various degrees of trade liberalization. According to Table 8 showing estimation results, we find that when non-tariff measures decline to tariff equivalents of 0%, the total welfare would improve in all regions around the world. Meanwhile, for major agricultural importing countries, free trade would reduce the domestic production and their food systems. In contrast, the agricultural production in major exporting countries tends to expand. When the tariff equivalents of non-technical measures increase, the global welfare as a whole would decline, although the rate slightly slows with further AVE increases as the base of world's total welfare decreases. Besides, with higher tariff equivalents of non-tariff measures, the agricultural sector and food system in agricultural importing countries tend to expand, while those in exporting countries tend to shrink.

Figure 5 shows estimated regional carbon emissions across the three scenarios of sensitivity analysis. When tariff equivalents of non-tariff measures drop to 0%, the total carbon emissions would decline in most regions around the world. As the level of non-tariff measures increases, carbon emissions grow in all regions except that of the rest of the world. When the tariff equivalents of non-tariff measures increase to 100%, carbon emissions around the world would grow by 5% on average. The results thus suggest that trade liberalization is crucial to promote the global carbon emission reduction mission.

5. Conclusions

In this paper, we quantify agricultural non-tariff measures based on estimates of *ad valorem* equivalents with the gravity model approach, and examine economic and environmental impacts of these measures by incorporating tariff equivalents into the GTAP model. Results show that for the three broad groups of agricultural non-tariff measures, estimated *ad valorem* equivalents are positive which indicate additional barriers to the international agricultural trade. This result validates the findings of Kee (2006), Ghodsi (2016) and other scholars and provides further solid support for the trade deterrent effect of agricultural NTMs. Simulation results indicate that these measures tend to expand the domestic agriculture sector and food system, which is defined by input-output relationships with the agriculture sector, in most agricultural importers. In contrast, the agricultural sector and food system in exporting countries tend to decline. Noticeable welfare distortions caused by NTMs are observed both at the aggregate level and across countries. Welfare losses are particularly noticeable in major NTM implementing economies such as the EU and the US. This result partially validates

Table 8. Sensitivity analysis for economic impacts of agricultural non-tariff measures.[1]

	EV (million $)			**Change of agriculture output (%)**			**Change of food system output (%)**		
	0%	**50%**	**100%**	**0%**	**50%**	**100%**	**0%**	**50%**	**100%**
CHN	1,196.6	-7,605.3	-13,407.7	-0.7	2.2	3.3	-1.5	4.5	8.2
IND	3,990.6	-2,187.7	-3,268.4	-2.4	0.1	0.2	-7.5	0.4	0.5
JPN	282.6	-6,094.8	-12,344.8	-8.4	17.7	27.8	-2.1	3.7	6.5
USA	3,953.8	-8,696.6	-15,269.3	-1.7	2.2	2.5	-1.4	4.7	9.6
EU27	2,160.5	-27,676.2	-58,841.7	-0.1	5	9.7	-0.4	6.5	11.6
RoA1	3,147.4	-5,814	-9,430.9	5.1	-7.9	-10.2	3.5	-6.6	-12.3
EEx	29.4	-13,541.4	-25,882.9	-1.1	2.8	4.9	-1.2	2.3	3
EEFSU	1,049.1	-5,657.5	-9,898.4	-0.1	4.2	6.6	-2.9	1.3	2
RoW	3,277.2	-15,421.1	-26,930.9	-0.1	0.9	2	1.1	-0.3	-0.5

[1] EV = equivalent variation to measure the change in social welfare caused by non-tariff measures; RoA1 = other Annex I countries; EEx = energy exporting regions; EEFSU = other countries of Eastern Europe; RoW = rest of the world.

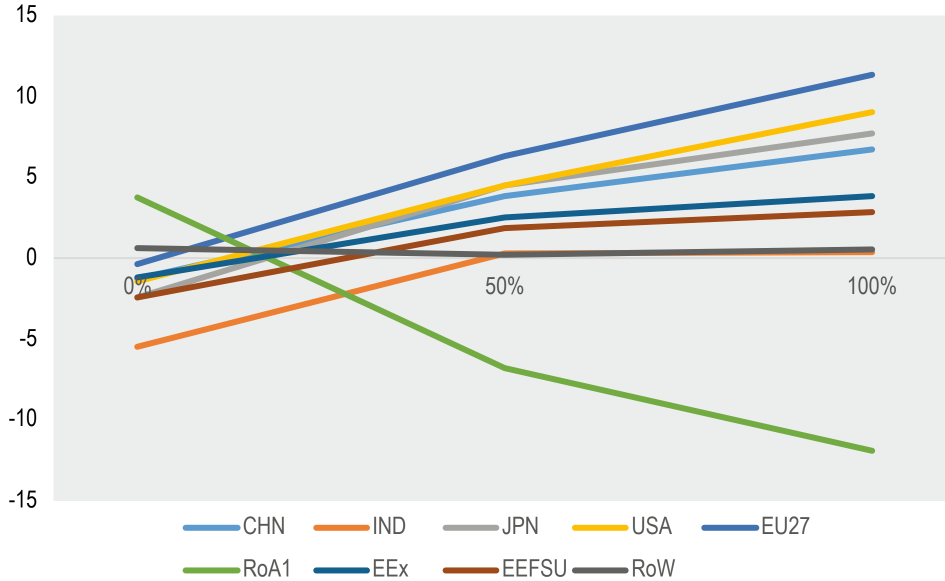

Figure 5. Sensitivity analysis for environmental impacts of agricultural non-tariff measures. EEFSU = other countries of Eastern Europe; RoW = rest of the world; RoA1 = other Annex I countries; EEx = energy exporting regions.

the findings of Calvin and Krisoff (1998) and Beghin *et al*. (2012) on the welfare distribution of NTMs, that is, the negative impact of NTMs on social welfare, and further extends the discussion of the international distribution of welfare and welfare distortions of NTMs in existing studies to verify, on a factual basis, the distortion of social welfare between major importers and exporters of agricultural products, and between implementers and receivers of NTMs. We then take the IO table of Eora26 to the GTAP model to identify environmental impacts of agricultural NTMs. Simulation results reveal that NTMs tend to increase global carbon emissions from agri-food sectors, particularly from the food processing industry. NTM imposing economies are observed with relatively more emission increases.

This paper provides first-hand evidence that non-tariff measures, nowadays the most important barriers to the international agricultural trade, would result in both economic and environmental losses to the world as a whole and in major players of the global agri-food system as well. In order to facilitate a both more liberalized and more sustainable agricultural trade, this paper thus provides several implications to agricultural practitioners and policymakers to meet multiple SDGs of the UN ranging from integrated and inclusive growth to carbon neutrality. First, with the observation of growing non-tariff measures amid pandemic outbreaks and international conflicts, enhanced global governance of food safety standards and regulations is needed to reduce agricultural trade barriers caused by NTMs, which can limit both welfare and emission distortions. Particular attention should be paid to developed economies as well as emerging markets which are relatively large agricultural producers and major imposers of non-tariff measures. In the meantime, it is also essential to enhance the harmonization of food safety and product standards between these economies and their major import partners, especially those less-developed ones that are in general more vulnerable to extra trade barriers imposed by non-tariff measures.

Second, seeing that the food system is a significant contributor to the global carbon emissions and is subject to the challenge of increased non-tariff measures being imposed around the world, it is urgent for agricultural practitioners to adopt green production measures regarding all aspects of the value chain to promote the green transformation of the entire food system. Incentives and assistance should be provided not only to practitioners in agricultural production, but also to those in related industries such as food processing as well as storage and transportation (Wang *et al.*, 2022a,b). For example, the concept of controlled environment agriculture (CEA) has emerged in recent years to provide a new paradigm for sustainable development of agri-food systems. CEA, specifically advanced greenhouses, plant factories, and vertical farms, has a significant role to play in the urban agri-food landscape through provision of fresh and nutritious food for urban populations. Given the large share of emissions attributed to agricultural production, investing in agricultural productivity improvement appears to be effective to ensuring food availability and sparing land-use related emissions (Wang *et al.*, 2020). The green transformation of the agri-food production could bring coupled environmental benefits, since it would not only reduce direct emissions from the agriculture-related sectors, but may also reduce non-tariff barriers to agricultural trade related to health, safety and environmental concerns which tend to result in additional environmental distortions.

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