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Global agricultural trade impact of the 2011 triple disaster in Japan: A gravity approach*

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We examine the evolution of global agricultural trade flows in the light of the 2011 earthquake, tsunami and nuclear accident in Fukushima, Japan. After the 2011 disasters, safety concerns led to the implementation of international surveillance measures on agricultural products from Japan. The physical damages, the domestic and foreign restrictions to production and trade, combined with actual and perceived health risks, affected consumer behaviour and reshaped production, consumption and trade. The existing literature has thoroughly examined individual sectoral effects, mainly through stylised facts and mainly for Japan; however, there is no analysis to date on the effects of the triple disaster on global trade flows of agriculture. With Japan holding 4.1 per cent of global exports of agricultural products and 0.4 per cent of global imports, transmission of the effects to global markets could lead to disruptions in global supply chains, worldwide distribution and trade. We use a gravity approach, together with 2000–2018 panel data and a Poisson Pseudo Maximum Likelihood (PPML) estimator to discuss the impact of the disasters on global trade flows of agriculture. Results for Japan indicate a negative effect on both exports and imports extending until 2014. Counterfactual analysis results suggest transmission of the negative effects to global exports of agricultural products.

Key words: agricultural products, counterfactual analysis, food products, GEPPML, gravity, nuclear accident, PPML, trade.

JEL classifications: Q17, F1, C33, Q50

1. Introduction

The 2011 'Great East Japan Earthquake (GEJE)', the tsunami that followed and the Fukushima Daiichi nuclear power plant accident comprise the 'triple disaster' that left a lasting impact on the economy of Japan. Agriculture was one of the most affected sectors of the economy, with physical damages to buildings/communities, flooding in agricultural land and radioactive contamination, imposing negative effects on production, consumption and trade of agricultural products. Radionuclide releases in the environment that dispersed over Honshu Island, affected plant and animal organisms as well as their byproducts (milk, meat, etc.). The consequent contamination of

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agricultural products led, amongst others, to exclusion areas and to a reduction of production in the agricultural sector but also to increases in demand for imports and decreases in export demand.

By 2013, safety inspections showed that many agricultural products were safe to consume. However, the implementation of restrictions, inspections and safety limits on Japanese exports of agricultural products had a lasting effect on consumption patterns, perceptions and choices. Japanese consumers reduced consumption and willingness to pay for products in which contamination was suspected (Matsumoto & Hoang, 2020). Announcements for product safety were not adequate in restoring sales, consumption and trade flows to normal pre-disaster levels, due to improper understanding of safety issues that resulted in avoidance of products from afflicted regions (Watanabe, 2013). Post-disaster effects on production, consumption and trade, therefore, reflect not only the direct impact of the triple disaster but also the dynamics of consumer trust for Japanese agricultural products.

The existing literature has concentrated on the impact of the disasters on Japan's trade flows. However, changes in economic aggregates were noted in other countries as well. Production halts and shortages in Japan led to disruptions in global supply chains. Globalisation and price interconnections affected production levels in other countries, while harmful rumours and the dissemination of inaccurate information affected consumer choices globally. Given the size of the disaster, which has been quoted as one of the largest and costliest in history, it is important to understand if, and to what extent, effects of the triple disaster were transmitted to global markets. We examine the *ceteris paribus* impact of the three disasters on global export and import values of agricultural products. We concentrate on whether relaxation of surveillance measures, lifting of restrictions and the implementation of strategies for the alleviation of harmful rumours were effective in stabilising trade flows, or whether effects from the triple disaster transmitted to global markets. The importance of the nuclear disaster's effects on the Japanese economy, the transmission of the effects on world trade as well as the possible unceasing impact on consumer choices, is what drives our question on the size and duration of the disaster's footprint on global agricultural trade flows.

Our approach employs the structural gravity model (Anderson & van Wincoop, 2003). The seminal article on the empirical estimation of structural gravity came from Santos Silva and Tenreyro (2006), who provided the major step towards producing a theory-consistent estimator, that can overcome the numerous problems the traditional log-linear gravity models faced, such as heteroscedasticity and zero trade flows. They proposed the use of the Poisson Pseudo Maximum Likelihood (PPML) estimator, which is consistent, robust to different types of heteroscedasticity and can account for zero trade flows in the estimation, as the dependent variable enters the specification in level values rather than logarithmic form. To allow for the estimation of country-specific effects related to the Fukushima disasters, we use the methodology by Heid et al. (2021), who propose panel data that employs both international trade flows as well as intra-national sales, to prevent absorption of country-specific effects from multilateral resistance terms. The impact to Japan and Japan's major trading partners is estimated through a counterfactual scenario and general equilibrium responses using the General Equilibrium PPML method by Anderson et al. (2018).

The article proceeds as follows: in Part 2, we provide a short description of the triple disaster, the effects it had on the economy of Japan and its major trading partners. Part 3 presents a literature review that discusses research related to the impacts of the triple disaster as well as articles related to the evolution of the gravity model of trade and the PPML estimator. Part 4 presents the model, the variables for our analysis, the intricacies of multiple-exporter/ multiple-importer panels as well as the identification process for country-specific variables when estimating effects of 'unilateral or non-discriminatory trade policy' in structural gravity models. Finally, parts 5 and 6 present the results, discussion and conclusions as well as policy implications, limitations and suggestions for future research.

2. The earthquake, tsunami and the nuclear accident at the *Fukushima Daiichi*: Effects on Japan and global trade

On 11 March 2011, a strong earthquake of magnitude 9.0 on the Richter scale occurred 130 km off the Pacific Coast of the Tohoku district affecting the eastern and north-eastern part of Japan. The tsunami that followed destroyed the electric system of the Fukushima Daiichi nuclear power plant resulting in a collapse of the cooling system of the nuclear reactors. Continuous explosions in the containment vessels of reactors 1, 3 and 4, between March 12 and March 15, released radioactivity in the agricultural plain of Kanto, one of the most popular lowland production areas of agricultural products, Tohoku and the Pacific Ocean. The radionuclides dispersed over Japan and deposited in Honshu and the western part of the North Pacific.

Agriculture was one of the most affected sectors of the economy. The triple disaster resulted in severe damages to the agricultural sector of Fukushima and the surrounding regions (Monma et al., 2015). Direct and indirect effects of the triple disaster became immediately evident in production, consumption and trade of agricultural products.

The direct effects of the earthquake and tsunami included structural damage to buildings, flooding and destruction of agricultural land and crops, agricultural communities, facilities, farms, livestock and wildlife. The initial estimate of the total physical damage Japan suffered ranged between ¥ 15.5 trillion ($195[1]) and ¥ 24.3 trillion ($305 billion) (Japan Ministry of Economy, 2011; Nanto et al., 2011), with ¥ 2.4 trillion ($30.4 billion) being

[1] US Dollars presented in parenthesis. These were estimated using 2011 World Development Indicators, Official Exchange Rate where 1USD = 79.807 Yen. Transformation to Australian Dollars can be made through 1AUD = 82.32 Yen.

the direct damage to Japan's fishery, agriculture and forestry sectors (MAFF, 2011). Final figures brought total damages to Japan's capital stocks to ¥ 16.9 trillion ($211.7 billion), damages to Agriculture to ¥ 1.9 trillion ($23.8 billion) and combined damages to Japan's Fishery, Agriculture and Forestry sectors to ¥ 2.34 trillion ($29.3 billion) (Fujita et al., 2012; MAFF, 2012).

The indirect effect of radioactivity and the infected soil and waters enhanced the problems created by the physical destruction. Restrictions were placed almost immediately after the disaster by the Director General of the Nuclear Emergency Response Headquarters on food distribution, vegetables, milk, rice, etc. Inspections for radioactive elements using stringent limits were also enforced on numerous products, soon thereafter. On top of the inspections and the strict safety limits, many countries imposed restrictions/surveillance measures on imports of agricultural products from Japan that took the form of import bans, bans in accordance with distribution restrictions in Japan, certificates of pre-export testing, certificates of place of origin and reinforced inspections (MAFF, 2019).

The reduced supply, combined with the restrictions that were placed, brought a temporary increase in demand for imports and a decrease in demand for exports. The impact can be seen in Japan's agricultural exports, which, by the end of 2011, and as compared to 2010 end-year values, had decreased by 7.31 per cent.[2] In 2012, exports showed signs of recovery increasing by 0.22 per cent; however, in 2013 they decreased by another 2.9 per cent. On the import side, we note a 21.3 per cent increase in 2011. In 2012, imports showed only a slight increase of 0.47 per cent and further recovered in 2013, when a 7.22 per cent drop was observed.

By 2013, inspections showed that many agricultural products were for the most part safe to consume. Some countries including Canada, Myanmar, Serbia, Chile, New Zealand, Malaysia, Mexico, Peru, Columbia and Guinea completely lifted radionuclide restrictions on food products, while others eased restrictions, except for products originating from the Fukushima area. By 2019, only a few countries kept some types of restrictions which were, however, for the most part, either product-specific or origin-specific (MAFF, 2019).

The restrictions, the production halts and the shortages affected economic activity in other countries through disruptions in global supply chains and changing consumer preferences, driven by fear and perpetuated by false

[2] Estimated using 2010 constant US dollar values from United Nations Comtrade data and the World Development Indicators. Although we employ Food and Agriculture Organization data for the econometric analysis, for the statistics presented here, we employ the complete set of agricultural products from the UN Comtrade data, downloaded from the Observatory of Economic Complexity (OEC) and the BACI International Trade Database (Gaulier & Zignago, 2010). These include product level data for HS categories 1 through 15 of Sections I, II and III of live animals, animal products, vegetable products animal or vegetable fats and oils, their cleavage products, prepared edible fats and animal or vegetables waxes.

information and 'harmful rumours'. Table 1 allows us to examine how global trade flows changed after 2011. It shows percentage changes in trade values of agricultural products for the years 2010 to 2012 for major trading partners of Japan, sorted by proximity to Japan.[3] After the disasters, and until the end of the year (2011), the value of imports increased in most of the countries, while in 2012 import values showed signs of contraction. The (simple) average growth rate for the sample of countries presented, decreased from 15.1 per cent in 2010 to 14.36 per cent in 2011, and to a mere 0.04 per cent in 2012. For the value of exports, we note decreases in the average, during both 2010 and 2011, equal to 2.98 and 6.39 per cent, respectively, but in 2012 we observe an increase of 1.37 per cent. Peaks and troughs that are noted in 2011, in many of the agricultural product time series of imports and exports, respectively, provide further evidence that global agricultural trade flows were affected by the 2011 disasters.

Different mechanisms affected trade in Japan versus the rest of the world. The impact on the trade flows of Japan can be attributed to the physical destruction, production shortages/halts, restrictions, surveillance measures and changes in consumer behaviour. The transmission of the effects to other countries can be partially attributed to globalisation, transportation cost declines that ease international transactions and promote the creation of networks, to market/price interconnections, prolonged dysfunctions of supply/industry/business chains and the dissemination of harmful rumours. The intensity of transmission to global markets is also related to Japan's share of global trade flows. In 2016, Japan' exports and imports comprised 2.1 and 3.4 per cent of global flows with agricultural product values reaching 4.1 and 0.4 per cent, respectively.

The disasters brought forward the inefficiencies and vulnerabilities of a dense global supply chain network. Fujita et al. (2012) notes that 2011 presented severe challenges to global supply chains caused by the Great East Japan Earthquake (GEJE). He estimated the production loss due to supply chain disruptions in the first half of 2011 to be equal to 0.25 trillion yen. Although the results presented by Fujita et al. (2012) concentrate on supply chain networks in the industry, we note that the agricultural sector has gone through a major transformation over the last few decades. While agricultural products used to be characterised by trade in bulk commodities, there has been an increase in value-added agricultural activities due to higher profit margins. The surface and growth of high-margin, value-added products, has led to networks and supply chains becoming of growing importance in the agricultural sector as well.

The 'transmission factor' rests only partially on the physical destruction, the effects on production, the global network and the disruption of supply chains. The proliferation of harmful rumours, the strategies adopted for their

[3] The list of countries presented in Table 1 incorporates 84% of Japan's imports of agricultural products and 77% of Japan's exports for the year 2016.

Table 1 Agricultural product trade flow changes for Japan's major trade partners from 2010 to 2012

	Imports			Exports			Distance
	2010	2011	2012	2010	2011	2012	
JPN	**11.79%**	**21.26%**	**0.47%**	**1.12%**	**−7.31%**	**0.22%**	
KOR	20.31%	30.06%	−6.09%	4.56%	−3.53%	−2.73%	952
CHN	25.93%	19.07%	17.22%	−0.39%	−6.13%	−0.80%	1,975
HKG	11.38%	13.26%	−0.54%	−2.07%	−0.61%	−4.97%	2,707
MAC	3.01%	21.92%	−3.66%	−24.16%	−23.04%	24.40%	2,945
PHL	18.97%	−11.26%	3.16%	−3.59%	−6.09%	0.44%	2,957
MNG	−2.62%	−1.27%	−4.98%	−24.85%	7.24%	−4.44%	2,958
PLW	−16.12%	17.13%	157.54%	−7.65%	−31.91%	102.56%	3,176
VNM	25.00%	62.35%	−20.78%	−4.65%	−34.67%	1.11%	3,903
KHM	−7.54%	15.26%	34.66%	2.63%	0.42%	55.16%	4,236
THA	17.72%	28.28%	8.92%	−3.05%	−3.08%	−2.47%	4,418
MMR	114.43%	−17.63%	−5.46%	29.38%	−34.24%	−0.63%	4,506
MYS	19.30%	22.91%	−2.80%	1.33%	−11.74%	5.96%	4,968
SGP	17.99%	15.23%	1.19%	−2.97%	−3.82%	−4.20%	5,168
IDN	40.15%	37.50%	−14.02%	27.32%	−5.46%	−0.32%	5,482
IND	−1.96%	11.93%	−9.49%	−7.13%	−5.80%	−8.21%	6,003
PAK	−5.75%	−0.71%	−16.73%	−8.86%	−1.94%	−9.10%	6,211
LKA	18.10%	16.64%	−30.76%	1.43%	−2.64%	−10.13%	6,601
RUS	16.51%	5.29%	−3.07%	−8.07%	3.12%	2.51%	6,683
FIN	4.84%	16.83%	−4.66%	2.16%	5.25%	−1.91%	7,676
ARE	22.55%	12.22%	−5.54%	12.82%	−10.12%	1.07%	7,768
AUS	12.78%	16.30%	2.36%	−4.60%	−10.14%	1.61%	7,827
QAT	115.19%	−36.80%	18.20%	−59.40%	−6.85%	35.12%	8,078
BHR	21.00%	15.03%	−34.73%	14.00%	2.96%	−71.35%	8,100
KWT	13.85%	1.78%	−16.86%	−56.76%	−34.18%	−43.09%	8,136
SWE	10.53%	8.62%	2.10%	1.12%	−2.31%	−1.43%	8,227
NOR	5.11%	19.21%	2.01%	−6.40%	−0.76%	−7.58%	8,333
DNK	6.77%	12.71%	−9.77%	−0.22%	−0.01%	6.04%	8,651
LBN	14.91%	2.68%	−5.65%	−5.90%	−6.27%	−1.46%	8,832
DEU	4.79%	20.86%	−7.40%	−3.05%	−1.42%	2.85%	9,086
NZL	4.48%	14.19%	5.28%	1.25%	−4.45%	1.85%	9,182
NLD	4.82%	23.74%	−5.51%	1.77%	−1.15%	−2.18%	9,229
GBR	2.38%	6.27%	−4.54%	2.38%	−1.76%	−0.61%	9,436
CHE	3.31%	20.82%	−8.62%	1.64%	1.55%	−1.18%	9,559
ITA	5.02%	13.02%	−12.67%	1.47%	−0.88%	−0.97%	9,711
CAN	9.19%	14.09%	1.48%	0.77%	−8.42%	−5.24%	9,756
FRA	3.85%	9.97%	−6.89%	3.56%	0.48%	−0.15%	9,803
USA	11.01%	14.50%	5.22%	−0.11%	−2.68%	−1.08%	10,286
ESP	2.34%	14.43%	−7.76%	2.33%	−0.03%	0.95%	10,685
MEX	9.36%	24.98%	−10.01%	3.61%	−1.56%	3.09%	11,099
ZAF	4.12%	36.07%	0.66%	−4.81%	−7.82%	−2.59%	13,618

Note: Author's estimates using UN Comtrade Data and World Development Indicators CPI data. Percentage changes were estimated using constant 2010 dollar values for trade flows.

alleviation and the dynamic characteristics of consumer perceptions, signify whether effects were short-lived or whether they carried to the long-run. The post-disaster effects on consumption and trade, therefore, reflect not only the direct impact of the triple disaster on production but also the dynamics of consumer trust for products from Japan. The negative consequences of 'harmful rumours', misinformation and consumer perceptions may still affect the recovery of agricultural trade values rather than the actual physical damage caused by the nuclear disaster on inputs, supply and production that the literature quotes as less important (Bachev & Ito, 2018). If the effect from harmful rumours and consumer perceptions is dominant and impacting on a global scale, holding everything else constant, we expect the effects on global exports and imports of agricultural products to persist well beyond the time required to overcome the physical damages.

The importance of the agricultural sector, the size of the disaster, the nature of the threat, which may recur in the future, and the worldwide impact of nuclear disasters mandate a thorough understanding of consequences, costs and the effectiveness of preventive measures. Changes in production and consumption patterns after the triple disaster affected trade flows of agricultural products. The question we need to answer is whether relaxation of surveillance measures and lifting of restrictions for agricultural products were adequate in assisting the agricultural sector back on its feet or whether effects from the nuclear accident persisted and transmitted to global trade flows.

3. Literature

Existing research on the impact of the Fukushima disaster concentrates on numerous aspects of the disasters, such as the effect on energy from nuclear power plants, soil degradation, the effect of radioactivity and social engagement.[4] However, there is not as much work related to the economic impact of the triple disaster on agricultural product trade, despite findings that agricultural output has not reached pre-disaster levels and despite the continuous concerns about contamination hindering the recovery of the region (Zhang et al., 2019). The existing literature, that is more closely related to the research scope of this article, has concentrated on the effect of reputation damage on the demand side and on the effect on supply chains, on the production side.

We build on two lines of research. We first concentrate on the economic impacts of the Fukushima disaster to help us understand the effect of reputation damage, the transmission to prices, trade flows and global supply chains. The second line of research concentrates on the structural gravity

[4] Examples of the diversity in the existing research include Rudolph and Schneider (2013), who examined how the disasters affected Japanese energy policy for the carbon market, Tanaka and Managi (2016), who estimated economic damages by examining land prices in prefectures near the nuclear power plant, Zhang et al. (2019), who examined economic recovery under the long-term impact of nuclear pollution and the effectiveness of industrial reconstruction, Okoyama and Inaba (2017) that studied how daily interactions of individuals were affected by the disaster, Rehdanz et al. (2013), who examined life happiness near the Fukushima Daiichi nuclear power plant and in areas where the tsunami hit.

model, to help us understand the empirical approach we employ to examine the disaster's effect on trade.

3.1 Impacts of the disasters

One of the few articles in the literature related to agri-food trade flows by Dadakas et al. (2021) examines trends and structural changes in post-2011, time series of imports and exports of 2-digit (HS) agri-food products of Japan. They studied the structural stability of the time-series to determine whether the drastic changes observed in trade flows, immediately after the disaster, were supported by endogenously determined, statistically significant changes in the evolution of the series. Only few of the 24 agri-food product import and export series exhibited structural changes near (and after) March of 2011. Their results support non-uniform changes in trade series evolution, mainly short-run impacts of the triple disaster but, more importantly, and related to the scope of this research, harmful rumours and reputation damage not having a lasting effect on either domestic or foreign consumers.

The importance of harmful rumours is stressed by Matsumoto and Hoang (2020) who quantified reputation damage using a Dixit-Stiglitz demand framework for the Japanese peach industry. They found that consumers' valuation of peaches from Fukushima decreased by 22.5–23.6 per cent immediately after the disasters, with farmers losing 13.1–18.9 per cent of sales due to reputation damage. Their results also indicated less reputation damage in regions where consumers of Fukushima peaches were present prior to the nuclear accident. Tajima et al. (2016) found that reputation damage resulted in a 10–36 per cent decrease in prices of vegetables after the nuclear accident in the Fukushima prefecture – as compared to counterfactual estimates that included absence of perceived radiation risk. The effect on prices lasted for four years. Moreover, their results indicated that proximity affected the magnitude of the impact. Ito and Kuriyama (2017), Ujie (2012), Ujie (2013), suggest that even when consumers are aware that the contamination risk from the consumption of products from affected and non-affected regions is the same, they tend to differentiate between agricultural products that originate from affected regions and products that originate from non-affected regions.

The factors that affect consumers' responses towards agricultural products from regions near the Fukushima power plant were examined by Aruga (2017) using survey data and contingent valuation methods. The purpose of the study was to provide information on the application of policies for the mitigation of the effects of rumours. Aruga found that consumers who prioritise food safety tend to live at greater distances from the nuclear power plant, they tend to live with children under the age of 15 and require a discount rate to accept agricultural products from regions near the power plant. Consumers who trust safety standards are knowledgeable about radiation and are more likely to accept products from the affected region.

The effects of the disasters extend to the supply side, impacting production and propagating to supply chains. Tokui et al. (2017) used regional input–output tables to examine supply chain disruptions and found that indirect damages were more important than direct damages. Indirect production losses were equivalent to 0.41 per cent of GDP as compared to the estimated direct damage to production, which was 0.11 per cent of GDP. Their results verify that concerns about the propagation of supply chain disruptions are valid and much larger than direct earthquake damage.

Carvalho et al. (2021) used a general equilibrium model and supply chain linkages among Japanese firms to examine the propagation and amplification of shocks, along supply chains. Their results suggest a 0.47 per cent decrease in real GDP growth one year after the disaster. Moreover, they found that inter-firm linkages resulted in a decrease in the growth rates of disaster-area firms' customers, suppliers and firms indirectly linked to them, and to the propagation of shocks to a significant fraction of firms in the economy's production network.

Abe and Thangavelu (2012) separate the damages to industrial activity to those that were direct and local, caused by ground tremors and the tsunami and those that were indirect that resulted in production halts, shortages of parts, materials and services in Japan and overseas. They suggest that private businesses coordinated efforts, resulted in supply chain disruptions being overcome faster than anticipated, within 4 months. They conclude that the search for supply chain efficiency leads to negligence, losses in reliability and safety through production concentration and that Japanese multinational manufacturers have already accepted having redundant suppliers in order to separate supply into more than one location.

This research follows a different approach towards the examination of the impacts of the disasters. We follow the impact on global trade flows of agricultural products that will allow us to study whether the effects of the disasters had a long-lasting effect on global import and export flows. Persistence of the effects on trade flows, beyond the time required to overcome the physical damages that affected production, implies an indirect effect on trade flows that can be associated to reputation damage and supply chain disruptions. Research-related policy implications and mitigation strategies need to take into account the direct effect of physical damage observed in the short-run and the indirect effect of harmful rumours that emphasise the need for building resilience in supply chains. To quantify the effects on global trade flows we employ the structural gravity literature that we discuss next.

3.2 Structural gravity model

The gravity equation for trade was first used in 1962 after the adaptation of Newton's law of universal gravitation (1962) by Jan Tinbergen. Later Anderson (1979) set the micro-foundations for the gravity model and the interest of the research community was raised. Since then, and owing to its popularity in its predictive power, the gravity model has become the workhorse of applied trade literature, with thousands of publications (Shepherd, 2013). It has been used to study Free Trade Agreements, exports, tariffs, subsidies, embargoes, trade sanctions but also the effect on trade from currency unions, foreign aid, immigration, foreign direct investment, cultural ties, sporting events, melting ice caps, etc. (Yotov et al., 2016). Numerous researchers assisted in the growth of the theory with Bergstrand (1985), Helpman and Krugman (1985), Deardorff (1998) and Eaton and Kortum (2002), providing some of the most important contributions.

In 2003, Anderson and van Wincoop further advanced gravity theory when they introduced the 'Multilateral-Resistance Terms' to the structural gravity model. Their approach solved McCallum's (1995) 'border puzzle', shaping the final form of the structural gravity equation, and providing solid theoretical foundations that justified the structural gravity's model title as the 'workhorse of trade economics'. The equation presented by Anderson and van Wincoop (2003) is,

$$X_{ij} = \frac{Y_i Y_j}{Y^w} \left(\frac{t_{ij}}{P_i P_j} \right)^{1-\sigma} \tag{1}$$

where X_{ij} represents the value of trade flows from country i to country j, Y_i, Y_j the economic mass of exporting country i and importing country j, respectively, and $Y^w = \sum_i Y_i$. The term $\left(\frac{t_{ij}}{P_i P_j}\right)^{1-\sigma}$ reflects the effect that trade costs have on exports with t_{ij} being the bilateral trade cost factor between countries i and j, σ the elasticity of substitution across varieties, and P_i, P_j the outward and inward Multilateral Resistances, respectively, that capture general equilibrium forces. In the structural gravity model, these are estimated as:

$$P_i^{1-\sigma} = \sum_j \frac{t_{ij}^{1-\sigma}}{P_j^{1-\sigma}} \frac{Y_j}{Y_w} \tag{2}$$

$$P_j^{1-\sigma} = \sum_i \left(\frac{t_{ij}}{P_i} \right)^{1-\sigma} \frac{Y_i}{Y_w} \tag{3}$$

The multilateral resistances proxy unobserved trade barriers, or the resistance the importing and the exporting countries face with all trade partners. They imply that trade flows depend on relative rather than absolute prices. The inclusion of Multilateral Resistances in the structural gravity model is considered one of the main 'innovations' in gravity theory with Baldwin and Taglioni (2006) referring to their omission in empirical models as a 'gold medal error'. They are also the key factor that separates naïve gravity specifications of the past with theory-grounded applications (Anderson & van Wincoop, 2003).

With solid foundations on the theoretical approach, the literature quickly turned to methods of estimation based on theory that dealt with the inherent problems in the gravity equation. The initial multiplicative specification of the model and the log-linearised estimation through OLS proved to be problematic in numerous aspects with the main problems being the presence of heteroscedasticity and zero trade flows. Heteroscedasticity is inherent in trade data and zero trade flows are common, especially when disaggregated data are employed. Hence, an approach that can take into account heteroscedasticity and zero trade flows, without excluding these observations from estimation, is necessary.

Numerous approaches have been tried to deal with those problems. These approaches have gradually evolved so that they not only solve the problems of heteroscedasticity and zero flows but also provide theory-consistent estimation of gravity. Non-linear estimation methods were employed as means to deal with zero trade flows since they allow the dependent variable to be included in levels. Support for non-linear estimators came from Santos Silva and Tenreyro (2006) who suggested that, in the presence of heteroscedasticity and due to Jensen's inequality, parameter estimates obtained through a log-transformed model lead to biased estimates of elasticity. They proposed the alternative Poisson Pseudo Maximum Likelihood (PPML) estimator for gravity models. The PPML estimator is robust to various types of heteroscedasticity, it provides consistent estimates given the use of the proper variables in the specification, it does not require data to be distributed as Poisson, and it can deal with zero trade flows as the dependent variable is included in levels rather than logs in the specification. Many articles surfaced after that, which provided support to the PPML. Schlueter et al. (2009) supported the PPML estimator with country fixed effects, suggesting that in the presence of zero trade flows, it does not create inconsistent estimates. Fally (2015) and Arvis and Shepherd (2013) show that the additive property of the PPML ensures that the fixed effects are consistent with the structural terms, the multilateral resistances. Anderson et al. (2018) show that PPML can estimate general equilibrium effects consistent with theory. Shepherd (2013) stated that from a '*policy research point of view, the desirable properties of Poisson suggest that estimates of policy impacts should generally be based on Poisson results rather than OLS*'. Further support for the use of PPML for the estimation of structural gravity models came from Piermartini and Yotov (2016), Yotov et al. (2016), Head and Mayer (2014) and others.[5]

One additional problem encountered in empirical gravity modelling is presented because of the necessary inclusion of multilateral resistances,

[5] Amongst others, criticism for the PPML estimator came from Burger et al. (2009) and Martin and Pham (2008). Santos Silva and Tenreyero (2009), Santos Silva and Tenreyero (2011) have answered most of the challenges presented allowing the PPML estimator to become one of the main tools of gravity analysis. Head and Mayer (2014) suggest that research should rely on multiple estimators that should be examined so that we can find the most effective one. For brevity purposes and within the scope of this research that concentrates on the PPML estimator, we refrain from expanding to other methodologies.

captured through time-varying fixed effects, in the specification (see Fally, 2015; Olivero & Yotov, 2012). The fixed effects absorb the coefficients of all country-specific variables and any variables employed to identify the effect from unilateral and non-discriminatory trade policies. Variables that carry only within variability cannot be estimated, which limits the applicability of structural gravity models (see Head & Mayer, 2014; Heid et al., 2021; Yotov et al., 2016). Heid et al. (2021) propose a panel formulation that includes international trade data combined with intra-national sales. In many cases, country-specific, non-discriminatory trade policies do not apply to intra-national trade but, rather, only to international flows. Since the fixed effects are defined for both international as well as intra-national observations, the identification of non-discriminatory trade policy variables becomes possible. Intra-national trade flows are captured through apparent consumption estimated by the difference in gross manufacturing production and total exports. This approach extends the applicability of structural gravity models by allowing the direct identification of country-specific policy variables and the impact of non-discriminatory and unilateral trade policies in the presence of multilateral resistances, without the need for transformations. Heid et al. (2021) emphasise that the literature has already employed intra-national trade flows in numerous articles, in order to identify bilateral variables within structural gravity models (see Anderson & van Wincoop, 2003; de Sousa et al., 2012; Anderson et al., 2018; Anderson and Yotov, 2010; Yotov, 2012; Dai et al., 2014; Bergstrand et al., 2015).

4. Methodology and data

The equation employed for PPML estimation was,

$$X_{ij,t} = \exp\left(\beta \log\left(Z_{ij,t}\right)' + \gamma\left(T_{ij,t}\right)' + \sum_{k=2011}^{2018} a_k F^k_{ij,t} + \chi'_{i,t} + \pi'_{j,t} + \mu_{ij}\right)\varepsilon_{ij,t} \quad (4)$$

where i represents the index for the exporting country in the data, j the partner country, and t is the year. Our panel data, therefore, includes, other than the dimension of time, multiple exporting countries and multiple importing countries. $X_{ij,t}$ refers to the nominal value of exports (or imports) from (to) country i to (from) country j at time t. We allow in $X_{ij,t}$, $i = j$ for those observations that represent domestic sales.

The $Z_{ij,t}$ vector includes variables for the economic mass of the country such as $GDP_{j,t}$ and $GDP_{i,t}$, which are measured through the (nominal value of the) Gross Domestic Product for each country. The $T_{ij,t}$ vector reflects bilateral trade costs between partner countries. It includes variables $Distance_{ij}$, which is the geodesic distance between the two capitals of countries i and j that enters in logarithmic form, $FTA_{ij,t}$ which represents a dummy variable that takes the value of 1 if any type of Free Trade Agreement between two countries is in place at time t, $CommonLanguage_{ij}$, a dummy variable that takes the value of 1 if the two countries share a common language that captures cultural characteristics and similarities/differences between two countries, $Contiguity_{ij}$, which takes the value 1 when two countries share borders and $Colony_{ij}$ that examines whether country-pairs have past colonial relationship.

Let μ_{ij} represent a country-pair of fixed effects indicated as *CP*. This is designed to take into account all time-invariant bilateral trade costs and the endogeneity of the *FTA* variable (see Baier & Bergstrand, 2007 and Yotov et al., 2016). The endogeneity arises because two countries that share high levels of trade are likely to sign agreements to liberalise trade resulting in reverse causality in the gravity model. Once *CP* fixed effects are included in the equation, it will not be possible to identify coefficients for any variables that vary bilaterally such as distance, common language and history of colonisation. However, Egger and Nigai (2015) and Agnosteva et al. (2014, 2019) find that the *CP* fixed effect can capture bilateral trade costs better than the variables usually employed in gravity model estimation (also see Piermartini & Yotov, 2016; Yotov et al., 2016). Equation 4 also includes exporter-time fixed effects denoted by χ_{it} and represented as *ET* and importer-time fixed effects denoted as $\pi_{j,t}$ and represented as *IT*. These are included to account for the multilateral resistances (Fally, 2015; Olivero & Yotov, 2012). Since multilateral resistances represent the time variant relative prices, the fixed effect that captures them also needs to be time variant. Once the *ET* and *IT* fixed effects are included in the model, it is not possible to identify the effect of variables that vary by country such as the economic mass of the countries or non-discriminatory trade policy variables. The use of the *ET* and *IT* fixed effects is not only the easiest method computationally to account for multilateral resistances in the empirical specification, but also a theoretically consistent method.

Finally, the variables of interest in this research are represented by $F^k_{ij,t}$ where $k = 2011–2018$. These are dummy variables that take the value of one (1) for export flows from Japan, for the respective year (k), and zero (0) for all other observations. Respectively, where import flows are estimated, the $F^k_{ij,t}$ variables take the value of one (1) for import flows to Japan, for the respective year (k), and zero (0) otherwise. Eight dummy variables are included to account for the effect of the triple disaster, one for every year from 2011 to 2018. Bergstrand and Egger (2011) consider as policy-based trade costs those costs that are 'man-made' or 'artificial', related to government policy that cause frictions and impede trade. The Fukushima 'dummy' variables represent an 'unnatural trade cost' given the impediments to trade, due to policy implemented after 2011. On top of those costs, we need to add costs from the physical damage to infrastructure and the additional time required for products to reach their destinations due to inspections, especially during the first two years after the triple disaster. Hence, our 'dummy' variables enter the gravity model specification without naïve augmentation practices of the past (see Shepherd, 2013). They represent increased post-2011 costs due to policies implemented that affected either the imports or the exports of Japan's agricultural trade. However, only one part of the increased costs originates from restrictions and the implied increase in costs. A second part originates from consumer perceptions advocated by harmful rumours. Once some of the measures were lifted after 2013, if domestic and foreign consumers continued to abstain from the consumption of Japanese agricultural products, due to harmful rumours, then an indirect effect on costs persists. Companies reaching out to new and existing markets will incur additional costs to control, inspect and market their own products in order to effectively alleviate harmful rumours that impede them from reaching their destinations. Therefore, the impact on trade and the length of the effect, relates to both additional trade costs and harmful rumours. However, after the lifting of restrictions in each product category, it relates mainly to the persistence of harmful rumours.

Our definition of the Fukushima disaster variables, therefore, merely represents increased post-2011 costs due to implemented policies and consumer perceptions. The model specification that employs the dummy variables to examine the disaster's effects from 2011 to 2018 allows us to capture effects from unnatural costs due to policy as well as effects from persisting rumours that affect consumption patterns. The temporal definitions of the expected impact originate from the existing literature for Japan that suggests that the long-term effects of the nuclear accident are negligible and it is only in the short-term when production, imports and exports were affected through damages, surveillance measures, restrictions on production and through consumer trust. During the first two years, physical damages, the nuclear accident and restrictions had a significant negative effect on agricultural products in Japan (Bachev & Ito, 2014, 2018).[6] The dummy variables for the first two years, therefore, examine whether there are significant differences in global trade values immediately after the disaster versus all the remaining years. If, for example, we find significance of the coefficients only for the variables capturing the years 2011 and 2012, then we note a return to 'normality', recovery of global supply chains and alleviation of harmful rumours, immediately after 2013 when more countries started lifting restrictions on Japan's exports of agri-food products. Significance of the remaining variables capturing the impact of the disasters implies persistence of the effects and persisting transmission of damages and/or restrictions from the triple disaster through global supply networks and harmful rumours.

[6] This is a simplified definition of the short-term impact of the triple disaster that serves our purposes. Import bans, bans in accordance to restrictions of distribution in Japan, certificates of pre-export testing of radionuclides, certificates of production of place and reinforced inspections are still implemented on specific product categories (see MAFF, 2019). Moreover, while many countries have already removed all types of restrictions some countries still have product-specific/ area-specific restrictions.

We emphasise that the effect the disaster variables capture reflects all types of impacts after the triple disaster. These include the direct effects from physical destruction such as damages to facilities from the earthquake and the tsunami, land exclusions due to radioactivity, impacts from the restrictions, etc., but also the indirect effects from harmful rumours and habit formation. The combination of direct and indirect effects led to the implementation of restrictive measures. Our approach cannot differentiate between the three disasters nor can it differentiate between the impact of physical destruction and harmful rumours. It merely captures differences in trade values in the pre- versus post-disaster period. Persistence of the effects will reflect not only the impact from restrictions, perceptions and harmful rumours but also any effects from damages not recovered, exclusion zones, etc., in other words the direct impacts of the earthquake and the tsunami. However, we must also note that the literature quotes the damage on inputs supply and production as less important so that any effects on trade values after the short-run would be attributed mainly to changes in consumer behaviour, perceptions and rumours that prevent consumption levels from getting back to 'normal' pre-disaster levels.

Furthermore, we must note that our approach cannot separate the effects on Japan's trade flows from the trade flows in the rest of the world. To deal with this problem, we employ the General Equilibrium PPML (GEPPML) methodology by Anderson et al. (2018) to create a counterfactual scenario. The solid theoretical foundations of the structural model allows the quantification of the effects on trade through counterfactual analysis (Larch & Yotov, 2016) and the estimation of the impacts of the disasters on other countries around the world including Japan's major trading partners. We first use the PPML estimator for a baseline model (equation 4) to retrieve estimates for trade costs, trade elasticities and baseline indices. Baseline (BLN) trade costs are estimated by,

$$\left(\hat{t}_{ij,t}^{BLN}\right)^{1-\sigma} = \exp\left(\hat{\mu}_{ij} + \hat{\eta}_1 FTA_{ij,t} + \sum_{k=2011}^{2018} \hat{a}_k F_{ij,t}^k\right) \tag{5}$$

We construct the multilateral resistances and we define a counterfactual 'no disaster' scenario where the triple disaster dummy variables are set to zero such that the counterfactual bilateral trade costs are equal to,

$$\left(\hat{t}_{ij,t}^{CFL}\right)^{1-\sigma} = \exp\left(\hat{\mu}_{ij} + \hat{\eta}_1 FTA_{ij,t}\right) \tag{6}$$

where *CFL* stands for counterfactual. Next, we obtain the conditional gravity model estimates that reflect the counterfactual scenario of 'no disaster' where we constrain the coefficients to the estimates obtained from equation 4. The conditional general equilibrium indexes allow for changes in trade costs and their respective effect on inward and outward multilateral resistances but do not account for output and expenditure changes as they are considered constant. Although output and expenditure are considered constant, the conditional general equilibrium results are considered 'general equilibrium' as they allow effects to '*ripple through the rest of the world via the general equilibrium Multilateral Resistance terms*' (Larch & Yotov, 2016) translating the effects to changes in trade and welfare for countries around the world. The final step involves the estimation of the full endowment general equilibrium effects using an iterative procedure that endogenises the value of output and expenditures by allowing changes in trade costs to affect factory gate prices. Iterations are repeated until factory-gate price changes are near zero so that we can construct the full endowment general equilibrium effects and the percentage differences between baseline and counterfactual indexes.

Estimations were conducted with an unbalanced panel that included trade data from 2000 to 2018 for a total of 210 exporting and importing countries. Agricultural product exports and imports were downloaded from the Food and Agriculture Organization (FAO) Database available in FAO Commodity List (FCL) classification. The analysis was conducted at the country level and sector level, employing a total of approximately 280 thousand and 2.6 mil observations, respectively. For the aggregate model, data were aggregated to annual per-country exports and imports. Each observation in the aggregate model, therefore, represents annual, bilateral, country-level export or import values of aggregated FAO agricultural product categories 1 through 20. Respectively, for the sectoral model, the data were aggregated to annual, per-country, per-sector exports and imports. 11 mil. observations were available at item level, which were aggregated to sector level (20 sectors) providing us with a total of 2.6 mil. usable observations for the sectoral regressions. The aggregate data presented 24.8 per cent zero trade flows on exports and 20.5 per cent on imports, while the sectoral data approximately presented 37.6 per cent on exports and 36.6 per cent on imports, stressing the need for an approach that can include zero flows in the estimations. Gross production data to estimate apparent consumption were also downloaded from the Food and Agriculture Organization database, allowing for correspondence between trade and production for the construction of intra-national sales. All variables that contain value are in nominal terms (US dollars) as they are deflated by the unobserved price indices captured by the Multilateral Resistances (De Benedictis & Taglioni, 2011; Shepherd, 2013). Trade data were filtered on *unit values* of exporter, importer and commodity groupings to 3 standard deviations and on *values,* of equivalent groupings, to 4 standard deviations. As a result, 174,000 observations were excluded from the export data set and 130,000 from the import data set (out of a total of 10.9 mil. observations) prior to aggregation.

Data for Free Trade Agreements were downloaded from the World Bank. We employed a 'catch-all' variable ($FTA_{ij,t}$) that captures all types of existing agreements between two countries during any given year. Although country-pair fixed effects absorb variables that do not vary over time, differences in the dates of entry into multilateral agreements between countries provide the necessary variability for the identification of this variable. The disaster dummy variables $\left(F^{k}_{ij,t},\ k = 2011\ldots2018\right)$ take the value one (1) for the respective years that define the effect of the disasters. These are defined unilaterally for Japan only, and only for international trade flows. For example, for the year 2011 $\left(F^{2011}_{ij,t}\right)$ a value of one (1) is coded where Japan is the exporter, while a value of zero (0) is used on both a) exports of other countries during the same year (2011) and b) all intra-national sales, that is 'exports' from Japan to Japan, during the same year. Heid et al. (2021) state that '*…the use of intra-national trade allows identification of unilateral and non-discriminatory trade policies even in the presence of importer and exporter fixed effects, since the trade policies apply only to international trade flows, while the fixed effects are defined for both international as well as intra-national observations'*. This differentiation in the coding of the disaster variables and the fixed effects is what allows the identification of the Fukushima Disaster dummy variables. Therefore, we assume that the triple disaster affected international trade, but it did not have an effect on domestic sales, which represents the main limitation of this research. This was necessary, however, in order to identify the coefficient on the disasters and obtain a theoretically consistent estimate for the post-disaster changes in trade flows. Summary statistics of the data employed are presented in the Appendix Table A1.

5. Results and discussion

Table 2 presents the PPML regression results. Models (1) through (4) show the estimates for exports of agricultural products and models (5) through (8) for imports. We first present the results before we discuss policy implications. The benchmark specification for exports (model 1) employs all of the data but does not incorporate intra-country sales. This specification cannot produce a coefficient for the effect of the disasters on agricultural trade flows; however, it allows us to contrast our results with past literature. The impact of Free Trade Agreements on exports of member countries is positive, equal to 9.4 per cent ($e^{0.09}$ −1) and within 1 standard deviation of Head and Mayer's (2014) meta-analysis of structural gravity models (0.36 with a 0.42 standard deviation). Model (2) that includes intra-country sales shows a higher impact of Free Trade Agreements, equal to 16.1 per cent. Similar magnitude coefficients are obtained with models (3) and (4) where we have included the triple disaster dummy variables. Our estimates support the expected conclusion that Free Trade Agreements had a positive impact on the level of exports of agricultural products for FTA member countries.

Table 2 PPML results for exports

		(1) Exports	(2)	(3)	(4)	(5) Imports	(6)	(7)	(8)
		Without intra-national sales	All data			Without intra-national sales	All data		
		Aggregate data			Sectoral	Aggregate data			Sectoral
FTA (coef.)		0.09***	0.15***	0.15***	0.14***	0.12***	0.15***	0.15***	0.15***
(s.e.)		(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	**(0.01)**	(0.02)
($e^{\beta i}$ −1)		0.094	0.161	0.161	0.150	0.127	0.162	0.162	0.162
Disasters ($F_{ijt,11}$)	11			**−0.17****	−0.28			−0.11	**−0.31***
				(0.07)	(0.19)			(0.08)	(0.19)
				−0.156	−0.244			−0.104	−0.267
Disasters ($F_{ijt,12}$)	12			**−0.11***	**−0.32***			**−0.22*****	**−0.42****
				(0.06)	(0.19)			(0.08)	(0.17)
				−0.104	−0.273			−0.197	−0.343
Disasters ($F_{ijt,13}$)	*13*			**−0.20****	**−0.49****			**−0.24*****	**−0.39****
				(0.10)	(0.20)			(0.09)	(0.19)
				−0.181	−0.387			−0.213	−0.323
Disasters ($F_{ijt,14}$)	14			**−0.17*****	**−0.40****			**−0.40*****	**−0.60*****
				(0.05)	(0.18)			(0.09)	(0.20)
				−0.156	−0.329			−0.330	−0.451
Disasters ($F_{ijt,15}$)	15			−0.12	−0.32			−0.07	−0.28
				(0.11)	(0.20)			(0.05)	(0.22)
				−0.113	−0.273			−0.068	−0.244
Disasters ($F_{ijt,16}$)	16			0.06	−0.19			−0.05	−0.28
				(0.08)	(0.20)			(0.08)	(0.20)

Table 2 (*Continued*)

	(1) Exports	(2)	(3)	(4)	(5) Imports	(6)	(7)	(8)
	Without intra-national sales	All data			Without intra-national sales	All data		
	Aggregate data			Sectoral	Aggregate data			Sectoral
			0.061	−0.173			−0.049	−0.244
Disasters 17 ($F_{ijt,17}$)			**0.21*** **	−0.06			0.09	−0.15
			(0.07)	(0.21)			(0.07)	(0.21)
			0.234	−0.058			0.094	−0.139
Disasters 18 ($F_{ijt,18}$)			0.11	−0.11			−0.15	**−0.47** **
			(0.08)	(0.19)			(0.19)	(0.20)
			0.116	−0.104			−0.139	−0.375
Constant	**13.82*** **	**22.19*** **	**22.19*** **	**20.52*** **	**13.86*** **	**22.19*** **	**22.19*** **	**20.52*** **
	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)
Observations	278,945	283,806	283,806	2,626,430	290,268	293,082	293,082	2,644,475
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Wald test	**0.00**	**0.00**	**0.00**	**0,00**	0.00	0.00	0.00	0.00
Restriction			**0.00**	**0.09**			**0.00**	**0.01**
ET $\chi_{i,t}$ (ETS)	2,769	2,888	2,888	50,395	3,001	3,010	3,010	53,770
IT $\pi_{j,t}$ (ITS)	3,507 (19)	3,507 (19)	3,507 (19)	70,798 (400)	3,505 (19)	3,505 (19)	3,505 (19)	64,666 (400)
CP μ_{ij}	19,690 (186)	19,838 (186)	19,838 (186)	20,199 (186)	20,916 (186)	21,058 (186)	21,058 (186)	21,440 (186)
Type of Fixed Effects	ET,IT, CP	ET, IT, CP	ET, IT, CP	ETS,,ITS, CP	ET,IT, CP	ET, IT, CP	ET, IT, CP	ETS,,ITS, CP

Author's estimates. The levels of significance are: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust standard errors in parentheses. All models include Country-Pair Fixed Effects (μ_{ij}), Exporter-Time Fixed Effects $\left(\chi'_{i,t}\right)$ and Importer-Time Fixed Effects $\left(\pi'_{j,t}\right)$. The number of fixed effects included is denoted in the lower part of the table. In parenthesis we indicate the number of fixed effects excluded from estimation.

Models (3) and (4) include both intra-country sales and dummy variables for the disasters. These employ aggregate and sectoral data, respectively.[7] The marginal impact of the disaster on Japan's exports of agricultural products shows a negative and statistically significant coefficient from 2011 to 2014. In model (3), we find that 2011 changes observed in Japan resulted in 15.6 per cent ($e^{0.15}-1$) decrease in Japan's export flows. The estimated impact for the years 2012 through 2014 was negative and equal to 10.4, 18.1 and 15.6 per cent, respectively. By 2015, export values started to recover. The 2015 effect, although not significant, was lower in size (−11.3 per cent). By 2016, we observe a positive, yet still not significant effect and by 2017, we find a significant and positive 23.4 per cent effect on Japan's exports of agricultural products.

Some differences are found in the model that employs sectoral data (4) with respect to the temporal impact of the disasters. The first difference is related to the significance of the coefficients, which is now observed only for the years 2012 to 2014. Moreover, the magnitude of the coefficients is larger (more negative) in the sectoral model. We now find a −27.3 per cent effect on Japan's agricultural product exports for 2012, −38.7 per cent for 2013 and −32.9 per cent for 2014. The lack of significance in the 2011 dummy variable and the difference in the sizes of the coefficients could be justified by a lagged transmission of the effects to production chains, captured by the additional variability presented with sectoral data. While the 2011 effect on exports was not different from zero, the accumulated effect on the remainder years was larger.[8] Finally, we do not find a significant or positive effect for the year 2017 on Japan's export flows of agricultural products. For both models (3) and (4), the Wald test is statistically significant and the restrictions, testing the null of the coefficients of the Fukushima disaster dummies being jointly equal to zero, are rejected.

To understand the impact of the disasters on Japan's exports of agricultural products, we start with the existing literature for Japan that indicates only short-term persistence of the effects. The value of Japan's farm and livestock product exports decreased by 11 per cent the first 10 months after the accident and by another 12.77 per cent in 2012 (Bachev & Ito, 2018; MAFF, 2012). Although we estimate a slightly larger *ceteris paribus* effect, these two values seem to be in line with the aggregate model (3) results. However, the literature also finds a subsequent rise in Japan's export values during the years 2013 and 2014. Our results do not support this conclusion as

[7] We examined additional specifications that differed in terms of the temporal effect of the 'Triple Disaster'. We considered a variable time frame for the effect of the disasters on the exports of the group of countries examined, defining the disaster period only for the year 2011, 2011–2012 and so forth. In all models, the coefficients were relatively stable. The Wald statistic testing the null of the coefficients of the Fukushima disaster dummies being jointly equal to zero was rejected in all cases, so we present only the specification with all the dummy variables included.

[8] The heterogeneity of the sectoral results and the lagged effect will discussed shortly with the sector estimates.

we observe that there is persistence of the negative effects until 2014, with the positive impact being limited to 2017. The partial elimination of surveillance measures and the efforts to alleviate harmful rumours in order to assist trade flows and foster confidence in Japan's agricultural sector were only partially successful, as exports of agricultural products of Japan took a long time to recover.

The second part of Table 2 presents the results for imports. Models (5) and (6) present the benchmark specifications, model (7) is estimated with aggregate data and model (8) with sectoral data. Our results show decreases in Japan's import values of agricultural products as a result of the disasters in Japan. We note that the absolute size of the coefficients is larger in both models (aggregate and sectoral data) as compared to the model for exports. For example, model (7) indicates a significant negative effect in 2012 equal to 19.7 per cent as opposed to 10.4 per cent in exports (model 3). Similar differences are observed for the other years.

Immediately after the disasters, there were numerous shortages in agricultural products due to restrictions as well as consumers avoiding domestic products. The literature documents post-2011 increases in the level of Japan's agricultural, forestry and fishery products imports (Bachev & Ito, 2018; MAFF, 2012) by 16 per cent, 10 months after the disaster. These effects, however, were temporary, with imports eventually decreasing. Dadakas et al. (2021) find that, for most agri-food HS product categories, the increase in imports was observed only in the short-run and it was followed by decreasing trends, which in some cases was also marked by level or trend structural breaks. Our results support decreases in import levels due to the triple disaster as early as 2012 (model 7). The decreases in imports may indicate an overall decrease in consumption or the effective implementation of mitigation policy, inspections and the timely dissemination of information on safety issues. If strategies for the alleviation of harmful rumours were effective, we expect increases in the consumption of domestically produced agricultural products and, in turn, a lower need for imports that can explain the negative coefficients we estimate. When we combine the a) short-run increase in Japan's imports of agricultural products indicated by the literature with b) the negative effect we find from 2012 to 2014 with the regression results (Table 2), c) the negative impact we estimated on exports (Table 2), d) the short-term impact of physical destruction and e) the Japanese government's immediate response, we find ample support for domestic consumers turning early towards domestic products and effective domestic policy towards the mitigation of harmful rumours. Our results support the decrease in import levels for Japan after 2012, highlighting the recovery soon after the disasters and the success of domestic policies targeted towards the alleviation of harmful rumours.

Not all sectors, however, were equally affected. We considered the literature that finds that some sectors were affected by the triple disaster more than others and estimated regressions for every sector (Table 3).

Table 3 Per sector regressions for exports

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
	Cereal	Roots and Tubers	Sugar Crops	Pulses	Nuts	Oil Bearing Pr.	Veg.	Fruits	Fibres	Spices	Stimulant Crops	Tobacco, Rubber	Pr. From Sl. Animals	Pr. From live Animals
	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Cat. 6	Cat. 7	Cat. 8	Cat. 9	Cat. 10	Cat. 12	Cat. 13	Cat. 17	Cat. 18
Exports														
FTA	**0.23*****	**0.45*****	**0.24*****	**0.10****	0.03	0.01	**0.24*****	**0.13*****	**0.19*****	**0.20*****	**0.12*****	**0.34*****	**0.16*****	**0.36*****
	(0.03)	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.02)	(0.02)	(0.06)	(0.05)	(0.02)	(0.04)	(0.06)	(0.03)
$F_{ijt,11}$	0.16	**−0.92*****	0.05	**1.66****	−0.37	−0.1	**−0.33*****	0.08	**1.97*****	**−0.41****	−0.03	0.41	−0.42	**−0.59*****
	(0.11)	(0.34)	(0.21)	(0.66)	(0.46)	(0.24)	(0,11)	(0.11)	(0.33)	(0.19)	(0.18)	(0.28)	(0.49)	(0.19)
$F_{ijt,12}$	**−0.69*****	**−0.84*****	−0.33	**1.30*****	−0.33	−0.33	**−0.71****	−0.12	**2.04*****	0.06	0.04	**0.54*****	0.21	**−0.77*****
	(0.15)	(0.21)	(0.24)	(0.50)	(0.28)	(0.25)	(0,32)	(0.13)	(0.35)	(0.19)	(0.11)	(0.20)	(0.39)	(0.26)
$F_{ijt,13}$	−0.22	**−1.25****	−0.04	**−1.41****	**−0.67***	−0.73	**−0.56*****	**−0.83***	**1.69*****	−0.17	0.16	**0.41***	−0.3	**−0.92*****
	(0.26)	(0.57)	(0.29)	(0.56)	(0.35)	(0.49)	(0,14)	(0.47)	(0.43)	(0.13)	(0.14)	(0.23)	(0.38)	(0.30)
$F_{ijt,14}$	**−0.67*****	**−0.48***	0.23	**−1.16****	**−0.53***	**−0.56***	**−0.57*****	−0.09	**1.30***	−0.24	0.29	0.31	0.26	**−0.60*****
	(0.16)	(0.26)	(0.16)	(0.51)	(0.29)	(0.29)	(0,12)	(0.11)	(0.68)	(0.30)	(0.18)	(0.31)	(0.43)	(0.16)
$F_{ijt,15}$	**0.98*****	−0.24	−0.05	−0.61	**−0.58***	−0.32	**−0.58*****	**−0.21***	0.03	**−0.91*****	**0.37****	**0.97*****	0.25	**−0.57****
	(0.16)	(0.27)	(0.17)	(0.62)	(0.33)	(0.25)	(0,09)	(0.12)	(0.40)	(0.21)	(0.16)	(0.31)	(0.45)	(0.27)
$F_{ijt,16}$	**0.29****	−0.02	**0.48*****	−0.63	−0.31	−0.37	**−0.53*****	−0.23	**−0.96****	**−0.91*****	**0.28***	**0.70****	**1.48*****	**−0.56*****
	(0.14)	(0.22)	(0.17)	(0.57)	(0.27)	(0.23)	(0,10)	(0.14)	(0.48)	(0.26)	(0.15)	(0.31)	(0.51)	(0.18)
$F_{ijt,17}$	**0.80*****	0.05	**0.69*****	−0.33	−0.49	−0.32	**−0.61*****	**−0.47*****	0.25	**−0.97*****	0.06	0.39	**1.53*****	**−0.41****
	(0.14)	(0.31)	(0.24)	(0.66)	(0.37)	(0.32)	(0,09)	(0.16)	(0.44)	(0.26)	(0.13)	(0.35)	(0.44)	(0.18)
$F_{ijt,18}$	**−0.45*****	0.41	**0.62****	−0.44	0.2	0.15	**−1.19*****	−0.25	−0.4	−0.36	0.22	**1.18*****	**1.10*****	−0.12
	(0.15)	(0.25)	(0.27)	(0.49)	(0.33)	(0.23)	(0,34)	(0.22)	(0.45)	(0.27)	(0.17)	(0.37)	(0.24)	(0.29)
Wald	**0**	**0**	**0**	**0**	0.1	0.23	**0**	**0.01**	**0**	**0**	0.23	**0**	**0**	**0**
Obs.	159,534	65,896	125,213	69,066	80,003	103,845	129,717	162,784	69,847	106,196	161,392	188,401	92,681	113,666
Imports														
FTA	**0.25*****	**0.46*****	**0.25*****	**0.11****	0.07	0.01	**0.24*****	**0.16*****	**0.24*****	**0.23*****	**0.13*****	**0.32*****	**0.22*****	**0.36*****
	(0.03)	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.02)	(0.02)	(0,06)	(0.05)	(0,02)	(0,04)	(0,06)	(0,03)
$F_{ijt,11}$	**0.19***	**−1.07****	0.11	**1.73*****	−0.2	−0.11	**−0.28*****	0.01	**2.07*****	−0.11	−0.02	**0.50****	−0.56	**−0.62*****
	(0.11)	(0.42)	(0.20)	(0.65)	(0.43)	(0.22)	(0.10)	(0.10)	(0.34)	(0.17)	(0.13)	(0.21)	(0.46)	(0.17)
$F_{ijt,12}$	**−0.66*****	**−0.74*****	−0.22	**1.46*****	−0.21	**−0.49***	**−0.30*****	**−0.18***	**1.99*****	0.08	0.11	**0.49****	0.15	**−0.79*****
	(0.14)	(0.21)	(0.21)	(0.54)	(0.29)	(0.27)	(0.10)	(0.09)	(0.35)	(0.17)	(0.15)	(0.19)	(0.35)	(0.27)
$F_{ijt,13}$	0	**−0.49****	0	**−1.16****	−0.33	−0.26	**−0.50*****	**−0.17****	**1.64*****	−0.13	0.2	**0.44****	0.01	**−0.82*****
	(0.18)	(0.22)	(0.23)	(0.53)	(0.29)	(0.28)	(0.09)	(0.08)	(0.44)	(0.13)	(0.16)	(0.21)	(0.23)	(0.28)
$F_{ijt,14}$	**−0.70*****	**−0.56****	−0.25	**−1.17****	**−0.51***	**−1.09****	**−0.89*****	**−0.26****	**1.20***	−0.25	0.1	0.26	**0.54****	**−0.62*****
	(0.19)	(0.22)	(0.17)	(0.56)	(0.31)	(0.48)	(0.31)	(0.10)	(0.65)	(0.25)	(0.28)	(0.32)	(0.24)	(0.16)

Table 3 (*Continued*)

	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
	Cereal	Roots and Tubers	Sugar Crops	Pulses	Nuts	Oil Bearing Pr.	Veg.	Fruits	Fibres	Spices	Stimulant Crops	Tobacco, Rubber	Pr. From Sl. Animals	Pr. From live Animals
	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Cat. 6	Cat. 7	Cat. 8	Cat. 9	Cat. 10	Cat. 12	Cat. 13	Cat. 17	Cat. 18
$F_{ijt,15}$	**0.94*****	−0.22	0.09	−0.45	**−0.54**	−0.29	**−0.57*****	**−0.86***	0.25	**−0.91*****	**0.46*****	**1.00*****	**0.53****	**−0.61*****
	(0.16)	(0.28)	(0.19)	(0.62)	(0.34)	(0.25)	(0.09)	(0.49)	(0.36)	(0.22)	(0.14)	(0.31)	(0.21)	(0.16)
$F_{ijt,16}$	**0.26***	−0.41	0.03	−0.43	**−0.47***	−0.38	**−0.51*****	**−0.30****	**−0.81***	**−0.83*****	0.19	**0.67****	**1.36*****	**−0.70*****
	(0.14)	(0.28)	(0.54)	(0.59)	(0.27)	(0.23)	(0.10)	(0.13)	(0.45)	(0.27)	(0.20)	(0.33)	(0.49)	(0.18)
$F_{ijt,17}$	**0.88*****	−0.04	**0.64*****	−0.04	**−0.70****	−0.23	**−0.63*****	**−0.47*****	0.27	**−0.91*****	0.03	0.51	**1.36*****	**−0.40****
	(0.12)	(0.29)	(0.24)	(0.65)	(0.28)	(0.25)	(0.09)	(0.17)	(0.41)	(0.27)	(0.14)	(0.32)	(0.43)	(0.18)
$F_{ijt,18}$	**−1.11*****	0.4	0.46	−0.32	0.11	−0.09	**−0.78****	−0.18	−0.33	**−0.63****	−0.11	**0.91****	**0.74****	−0.01
	(0.34)	(0.29)	(0.42)	(0.51)	(0.33)	(0.27)	(0.34)	(0.22)	(0.42)	(0.27)	(0.24)	(0.38)	(0.36)	(0.19)
Wald	**0**	**0**	**0.07**	**0**	**0.03**	0.31	**0**	**0.01**	**0.01**	**0**	**0.07**	**0.01**	**0**	**0**
Obs.	159,713	66,093	125,388	69,121	80,044	103,912	129,893	162,893	69,865	106,256	161,427	188,470	92,790	113,704

Author's estimates. The levels of significance are as follows: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Robust standard errors in parentheses. All models include Country-Pair Fixed Effects (μ_{ij}), Exporter-Time Fixed Effects $\left(\chi'_{i,t}\right)$ and Importer-Time Fixed Effects $\left(\pi'_{j,t}\right)$. Excluded categories are category 11 (Fodder Crops), 14 (Vegetable and Animal Oils), 15 (Beverages), 16 (Livestock), 19 (Hides and Skins) and 20 (Other Livestock).

Regressions were estimated for both imports and exports, for 20 sectors in the FAO Commodity List (FCL), where production data were available for Japan (Table 3).[9] Categories of vegetables (7) and products from live animals (17) exhibit the most persisting effects, with negative and significant coefficients extending until 2017 and 2018, respectively. Bachev and Ito (2018) note that farmers that specialised in vegetables saw the highest decreases in sales and income. The slow recovery is related to prolonged farmland restoration and high facility rebuilding costs (Ministry of Agriculture Forestry and Fisheries, 2014). Furthermore, the majority of highly contaminated items in the Fukushima, Ibaraki and Chiba prefectures were found amongst vegetables, fishery products and meats. The dissemination of harmful rumours for these products may be the explanation for the persisting impact. The persistence of the impact is also evident in current restrictions imposed in these products. In December of 2019, the category of Vegetables and the category for Meats (beef, pork and poultry) still had 15 countries that kept some type of restriction[10] (as opposed to 54 examined in 2011) (MAFF, 2019). Similar effects are observed in the same categories for imports, where we find the most negative and persisting effects. The significant and negative coefficients in exports suggest that foreign consumers were reluctant to consume products from Japan. On the other hand, the negative and significant coefficients in the results for imports support our earlier conclusion that consumers in Japan resorted to domestic products.

Exports for cereals showed a mixed effect, with negative impacts present until 2014, positive in the years 2015 to 2017 and then again negative in 2018. Fujita et al. (2012) suggest that among the main economic activities that were affected in the region were rice paddy fields (and fisheries). The negative coefficients estimated for the years 2012–2014 seem to support this conclusion. Bachev and Ito (2018), however, suggest that rice producers noted the fastest income growth due to restoration of farmland and augmentation of sales, explaining the positive coefficients in 2015 through 2017 on a local level. While recovery in all areas seemed to be the foremost target, in March of 2018 new restrictions were placed in Fukushima prefecture rice, which may be related to the negative coefficient estimated for the year 2018. Out of 54 countries that applied some type of restriction in 2011, 11 kept some of those restrictions as of December of 2019, with many of the restrictions imposed being area specific.

Roots and tubers (cat. 2) showed a negative, short-run impact until 2014, while a positive effect is found immediately after the disasters for categories for pulses (cat. 4), fibres (cat. 9) and tobacco (cat. 13). The variability in the

[9] Details on the products included in each category can be found in http://www.fao.org/waicent/faoinfo/economic/faodef/faodefe.htm

[10] Restrictions took the form of import bans, import bans in accordance with restriction of distribution in Japan, certificates of pre-export testing of radionuclides, certificates of production place, reinforced inspection (lot by lot, or sampling at the border) and regular inspection.

impacts per sector extends to imports of agricultural products, suggesting that any policy targeting the alleviation of effects from the triple disaster should be product specific, a conclusion also supported by Dadakas et al. (2021).

Our results so far tell us the average impact on Japan's exports and imports of agricultural products; however, they cannot tell us how other countries' economic indicators were affected by the disasters. Of special interest is the impact to countries in the vicinity of Japan as well as major trade partners of Japan around the world. The domestic impact on agriculture can easily, through misinformation and harmful rumours, be associated with neighbouring countries' products as well, therefore, affecting production, consumption, exports, prices but also GDP in other countries. To estimate the impact on other countries, we use a counterfactual scenario of 'no disaster' that will also allow us to decompose trade costs to consumers and producers around the world. Table 4 presents the results for the sample of countries included in the counterfactual analysis.[11] On the left panel, we see the results for 2014 with column (1) indicating the conditional equilibrium effect on exports of agricultural products and column (2) the full endowment general equilibrium effect on exports. Estimates for prices, Inward Multilateral Resistances (IMR), Outward Multilateral Resistances (OMR) and GDP follow. We have chosen the years 2014 and 2017 in order to examine the short- and long-run impact of the disasters. We first present the results before we discuss relevant policy implications.

The first thing we note is that the impact on Japan's exports is in line with regression results presented with the help of Table 2, where we found a 15.6 per cent negative impact for 2014 and a 23.4 per cent positive effect for 2017. Partial equilibrium and general equilibrium estimates for exports do not differ substantially, in either 2014 or 2017. The small differences are associated with small sized coefficients for the Fukushima disaster variables (e.g. $\hat{\beta}_{(Fi_{jt,2011})} = -0.17$) (see Yotov et al., 2016, p. 109). Additionally, they are associated with the small effect on producers that we observe through the Outward Multilateral Resistances (OMR) change estimate and the price change estimate, for countries around the world. The small size of the estimates indicates that producers and prices were not highly affected, which, in turn, implies a minimal impact on bilateral trade costs.

For 2014, the general equilibrium effects of the disasters on exports are negative for the majority of the countries included in the analysis. Japan noted the largest drop with 18.43 per cent lower exports due to the disasters. The effect on neighbouring China was also negative with exports showing a 1.55 per cent decrease. Korea noted a 4.13 per cent decrease, while a smaller impact was felt by Australia with a 1.03 per cent decrease, New Zealand, with a 0.44 per cent decrease and Indonesia with a 0.71 per cent decrease. Large

[11] The counterfactual scenario was estimated with a total of 53 countries in the sample, to allow PPML estimation without dropping additional fixed effects or observations.

Table 4 GEPPML Results for Exports for 2014 and 2017

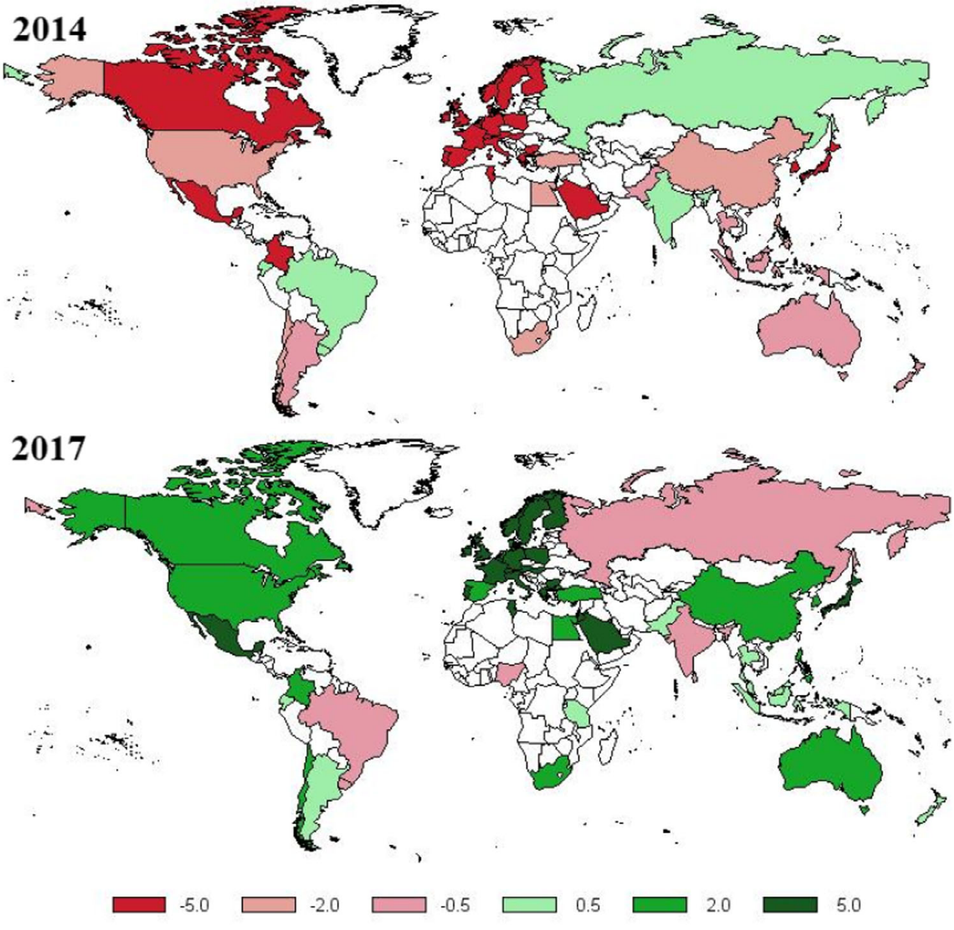
	2014						2017								
	C. Eq.	General Equilibrium					C. Eq.	General Equilibrium							
Country	(1) Exports	(2) Exports	(3) Price	(4) IMR	(5) OMR	(6) RGDP	(7) Exports	(8) Exports	(9) Price	(10) IMR	(11) OMR	(12) RGDP	Distance	% Exports	% Imports
ARG	0.02	−0.03	−0.04	−0.04	0.05	0.00	−0.01	0.06	0.07	0.07	−0.09	0.00	18,310	0.00	0.01
AUS	−1.06	−1.03	−0.15	−0.14	0.17	0.00	1.5	1.43	0.41	0.41	−0.48	0.01	7,827	0.02	0.08
AUT	−5.23	−5.27	−0.03	0.02	0.03	−0.05	4.97	5.03	0.07	0.02	−0.08	0.05	9,111	0.01	0.00
BEL	−4.27	−4.31	−0.2	−0.14	0.24	−0.06	4.04	4.12	0.22	0.16	−0.26	0.06	9,371		
BGR	−4.3	−4.31	−0.16	−0.15	0.19	−0.02	3.89	3.94	0.22	0.21	−0.26	0.02	8,951	0.00	0.00
BRA	0.06	0.06	−0.01	−0.01	0.01	0.00	−0.07	−0.05	0.03	0.03	−0.03	0.00	17,982	0.01	0.05
CAN	−3.64	−3.63	−0.05	−0.04	0.06	−0.01	3.37	3.38	0.14	0.13	−0.16	0.01	9,756	0.03	0.08
CHE	−4.95	−4.98	−0.02	0.1	0.02	−0.12	4.57	4.64	0.09	−0.02	−0.10	0.11	9,559	0.02	0.00
CHL	−1.9	−1.84	−0.41	−0.4	0.48	−0.01	1.86	1.84	0.4	0.4	−0.47	0.00	17,351	0.00	0.03
CHN	−1.53	−1.55	0.11	0.11	−0.13	0.00	1.92	1.96	−0.11	−0.11	0.12	0.00	1,975	0.03	0.10
COL	−3.57	−3.57	−0.22	−0.21	0.26	−0.01	2.61	2.63	0.34	0.33	−0.40	0.01	14,300	0.01	0.01
CYP							7.36	7.43	−0.44	−0.51	0.51	0.08	8,922	0.00	0.00
DEU	−5.17	−5.24	−0.02	0	0.02	−0.02	5.23	5.35	0.02	0	−0.02	0.02	9,086	0.03	0.01
DNK	−3.65	−3.58	−0.11	−0.09	0.13	−0.03	3.45	3.41	0.11	0.09	−0.13	0.03	8,651	0.01	0.02
ECU	0.08	0.02	−0.06	−0.06	0.07	0.00	−0.08	0.02	0.11	0.11	−0.13	0.00	14,652	0.00	0.00
EGY	−3.23	−3.27	0.08	0.08	−0.09	0.00	3.08	3.13	0.01	0	−0.01	0.00	9,421	0.00	0.00
ESP	−3.67	−3.66	−0.22	−0.21	0.26	−0.01	3.37	3.4	0.26	0.25	−0.30	0.01	10,685	0.01	0.01
FIN	−5.99	−5.98	0.36	0.4	−0.42	−0.04	6.03	6.05	−0.33	−0.37	0.39	0.04	7,676	0.01	0.00
FRA	−4.52	−4.56	−0.09	−0.08	0.11	−0.01	4.22	4.3	0.13	0.12	−0.15	0.01	9,803	0.03	0.01
GBR	−5.84	−5.92	0.17	0.19	−0.20	−0.02	5.9	6.03	−0.15	−0.18	0.18	0.03	9,436	0.02	0.00
GRC	−5.36	−5.41	0.04	0.06	−0.05	−0.01	4.83	4.89	0.03	0.02	−0.04	0.01	9,364	0.00	0.00
HUN	−4.19	−4.21	−0.21	−0.2	0.25	−0.02	3.79	3.84	0.26	0.24	−0.30	0.02	8,944	0.00	0.00
IDN	−0.7	−0.71	−0.15	−0.14	0.17	−0.01	0.6	0.65	0.22	0.21	−0.25	0.00	5,482	0.02	0.02
IND	0.09	0.06	−0.05	−0.05	0.06	0.00	−0.19	−0.13	0.11	0.11	−0.13	0.00	6,003	0.01	0.02
IRL	−4.28	−4.2	−0.04	0.02	0.04	−0.06	3.89	3.84	0.07	0.02	−0.08	0.04	9,575	0.01	0.00
ITA	−4.51	−4.54	−0.06	−0.04	0.07	−0.01	4.17	4.23	0.11	0.1	−0.13	0.01	9,711	0.01	0.01
JOR							6.16	6.23	−0.11	−0.14	0.13	0.02	8,931	0.01	0.00
JPN	**−18.49**	**−18.43**	**0**	**0.02**	**0.00**	**−0.01**	**17.05**	**17.02**	**−0.12**	**−0.13**	**0.14**	**0.01**			
KOR	−4.09	−4.13	0.4	0.41	−0.47	−0.01	3.44	3.46	−0.34	−0.35	0.40	0.01	952	0.03	0.02
KWT	−4.9	−4.91	−0.11	−0.02	0.13	−0.09	4.87	4.89	0.07	−0.03	−0.08	0.10	8,136	0.01	0.00
LKA	0.22	0.18	−0.06	−0.06	0.07	0.00	−0.32	−0.24	0.12	0.13	−0.14	0.00	6,601	0.01	0.00
MEX	−5.45	−5.47	−0.02	0.01	0.03	−0.04	4.35	4.38	0.2	0.17	−0.23	0.03	11,099	0.01	0.02

Table 4 (*Continued*)

	2014						2017								
	C. Eq.	General Equilibrium					C. Eq.	General Equilibrium							
Country	(1) Exports	(2) Exports	(3) Price	(4) IMR	(5) OMR	(6) RGDP	(7) Exports	(8) Exports	(9) Price	(10) IMR	(11) OMR	(12) RGDP	Distance	% Exports	% Imports
MYS	−0.94	−0.95	−0.14	−0.12	0.16	−0.02	0.99	1.03	0.19	0.17	−0.22	0.02	4,968	0.03	0.01
NGA							−0.39	−0.34	0.11	0.11	−0.13	0.00	13,025	0.00	0.00
NLD	−3.79	−3.8	−0.18	−0.15	0.21	−0.04	3.24	3.27	0.25	0.21	−0.29	0.03	9,229	0.03	0.01
NOR	−7.62	−7.62	0.58	0.63	−0.67	−0.05	7.41	7.42	−0.49	−0.54	0.58	0.05	8,333	0.01	0.02
NZL	−0.47	−0.44	−0.25	−0.24	0.29	0.00	0.52	0.52	0.45	0.45	−0.52	0.00	9,182	0.02	0.03
PAK	−0.38	−0.4	−0.06	−0.06	0.07	0.00	0.37	0.43	0.12	0.12	−0.14	0.00	6,211	0.01	0.00
PHL	−1.64	−1.63	−0.02	−0.02	0.02	0.00	1.62	1.62	0.07	0.07	−0.09	0.00	2,957	0.02	0.02
POL	−4.33	−4.34	−0.15	−0.13	0.17	−0.01	3.83	3.87	0.21	0.2	−0.24	0.01	8,599	0.01	0.00
PRT	−5.97	−6.09	0.05	0.09	−0.06	−0.04	5.59	5.75	0.03	0	−0.04	0.04	11,035	0.01	0.00
QAT	−6.31	−6.38	0.09	0.13	−0.11	−0.04	6.46	6.55	−0.14	−0.17	0.16	0.04	8,078	0.01	0.00
RUS	0.41	0.46	−0.02	−0.02	0.02	0.00	−0.37	−0.37	0.05	0.05	−0.06	0.00	6,683	0.02	0.02
SAU	−4.54	−4.54	−0.04	−0.04	0.05	0.00	3.7	3.64	0.1	0.09	−0.11	0.00	8,854	0.01	0.00
SGP	−1.4	−1.48	−0.19	0.04	0.22	−0.23	1.13	1.26	0.25	0.04	−0.29	0.21	5,168	0.05	0.00
SWE	−5.9	−5.82	0.25	0.33	−0.29	−0.08	5.81	5.76	−0.21	−0.29	0.25	0.07	8,227	0.01	0.00
THA	−0.94	−0.89	−0.24	−0.23	0.27	0.00	0.89	0.85	0.28	0.27	−0.32	0.00	4,418	0.04	0.03
TUN	−4.31	−4.37	0.1	0.11	−0.12	−0.01	3.91	4.01	0.01	−0.01	−0.01	0.01	10,374	0.00	0.00
TUR	−3.05	−3.08	0.07	0.07	−0.08	0.00	3.01	3.08	−0.03	−0.03	0.03	0.00	8,718	0.00	0.00
TZA							−0.05	0.02	0.1	0.1	−0.11	0.00	11,369	0.00	0.00
URY	0.06	0.05	−0.01	−0.01	0.01	0.00	−0.05	−0.01	0.03	0.04	−0.04	0.00	18,746	0.00	0.00
USA	−2.5	−2.49	−0.01	−0.01	0.01	0.00	2.32	2.36	0.05	0.05	−0.06	0.00	10,286	0.03	0.26
ZAF	−2.58	−2.58	−0.03	−0.02	0.03	0.00	2.21	2.25	0.07	0.07	−0.08	0.00	13,618	0.01	0.00

Author's estimates.

negative impacts on export values are noted for European countries, where drops of approximately 4–6 per cent are observed. Russia and India, on the other hand, saw increases in trade equal to 0.46 and 0.06 per cent, respectively. Other countries where a positive effect is noted are Brazil, Ecuador, Sri Lanka and Uruguay. The heterogeneity of the impacts and their magnitude is related to the size, geography but also trade ties with Japan. Weak trade ties can explain the small effect on some of the countries. The situation is reversed in 2017, where the direct effect of the changes from Japan's shock is now positive for most of the countries in our analysis. Japan seems to recover, showing the largest gains in exports, equal to 17.02 per cent, with European countries also gaining the losses suffered. The results for exports are reproduced with the help of Figure 1, to help us visualise the variability in the impact for exports. The top panel shows the impact for the



Notes: Author's estimates.

Figure 1 GEPPML impact on 2014 and 2017 exports.Notes: Author's estimates. [Colour figure can be viewed at wileyonlinelibrary.com] year 2014, whereas the lower part shows the impact for 2017. For the most part, countries that showed decreases in export values in 2014 were on the positive side of the effects in 2017, emphasising the importance of trade ties for the transmission of the effects.

Using the fixed effects and the trade cost coefficients, Anderson et al. (2018) provide us with the method to measure exports change, changes in multilateral resistances and real consumption for each one of the countries included in the analysis. Table 4 results suggest that despite the impact on export values, the effect on GDP, prices, consumers and producers is small for all of Japan's trading partners included in the analysis.[12] The country with the most losses in real consumption in 2014, but also the biggest winner in 2017 is Singapore with −0.23 and 0.21 per cent impact, respectively (relative to the effect in Germany). Despite that, the impact on GDP is marginal during both years, even for Japan. The Inward Multilateral Resistances (IMR) represent the weighted average bilateral trade costs that fall on consumers in each country, equivalent to each country buying all goods from one single world market (Anderson et al., 2018). They can be used to evaluate the effect on consumers in each country with a drop in IMR signifying gains for consumers. While most of the IMRs are negative in 2014, Japan's IMR, although small, is positive suggesting that consumers were negatively affected. The opposite is found for 2017 when even Japan's IMR is negative[13]. The Outward Multilateral Resistances, on the other hand, are the weighted average aggregate of all bilateral trade costs for the producers of goods in a country, equivalent to each country shipping its product to a single world market (Anderson et al., 2018). They can be used to evaluate the effect on producers in each country with lower OMRs signifying gains for producers. Japan's OMRs are negative for 2014 and positive for 2017; however, the overall impact for all countries, again, is small.

Results of the counterfactual analysis indicate a short-run negative impact of the triple disasters on global exports of agriculture and a minimal impact on consumers, producers and real consumption. To understand the negative impact of a local event on global exports, we focus on the effect that harmful rumours and disruptions in supply/network chains have on consumption and production. Overreactions to harmful rumours for agricultural products, that do not necessarily originate from Japan but also from neighbouring countries, can justify any excessive transmission of negative effects. After the triple disaster, the government of Japan concentrated on providing

[12] The elasticity of substitution is assumed $\sigma = 7$ for the estimation of real GDP (see Felbermayr et al., 2014). We can estimate the Multilateral resistances only up to a scalar. Therefore, a normalization is necessary. Similar to Anderson et al. (2018), we choose Germany as the normalizing country. The choice of the country is related to reliability of the data. Alternatively, we could choose a country that is not affected much by the counterfactual shock so that relative counterfactual changes can be close to absolute changes (see Anderson et al., 2018).

[13] Changes can be consistently compared across countries during a given year; however, over time we need to interpret the changes subject to our normalizing country.

accurate and timely information on the effect of radionuclides on agricultural products in order to minimise the impact of harmful rumours in the domestic markets. These efforts were successful in minimising the impact in domestic markets. While such efforts may successfully spill over across borders, confronting negative consumer perceptions as well as alleviating damaging information in other countries, is a task that is left mainly to businesses. Companies outside of Japan, reaching out to new and existing markets, faced additional costs to control/inspect and market their own products and change any perceptions advocated by harmful rumours. A second explanation, also related to the dissemination of harmful rumours, concentrates on consumers globally relying more on domestically produced products from agriculture to avoid any exposure to products affected by radionuclides. Consumers recognise the global interconnections in production chains and avoided products from afflicted regions. Worries about the impact on agricultural products due to radionuclide depositions can easily, through misinformation and harmful rumours, be associated to neighbouring countries' products as well, therefore covering a large range of global production. When we combine these harmful rumours with the effect on global supply chains, we can find support for consumers resorting to domestic production as a safer outlet, compared to imports of unknown characteristics, leading to a lower demand for exports, globally.

Harmful rumours represent only one part of the transmission mechanism, however. Fujita et al. (2012) note that when disruption in complex supply chains occur, it is almost impossible to find replacements by other suppliers in the short-run. While the impact on supply chains is more prevalent for processed products, higher profit margins resulted in value-added activities that pre-empted the growth of differentiated and processed agricultural products, in recent decades (Dadakas, 2019). Efforts required to find substitute products and alternative trade routes, translate to additional costs businesses had to confront. Affected networks can quickly transmit the impact to global trade flows and explain the post-2011 drop we observe in global export values. The estimated impact highlights the need for building network/supply chain resilience, businesses changing operations to depend on multiple suppliers for their inputs, developing product stock and further promoting FTAs to decrease costs.

However, and similar to the effects estimated earlier for Japan, the impact on global exports was short-lived. By 2017, we find that either consumers were better informed, mitigation strategies for the alleviation of rumours were successful on a global scale or that supply chains adapted. The values in the post-2015 coefficients in both models for exports and imports (Table 2) and the positive marginal changes in the counterfactual analysis (Table 4) indicate that networks/supply chains adapted. They learned to operate with multiple suppliers and multiple destinations, built safety stocks, making networks and supply chains more resilient to changes. The impact of reputation damage, which is the main source of the negative impacts in the long-run, also decreased. The recovery noted after 2015, therefore, can be attributed to either the successful communication of actual dangers of radionuclide depositions or to changing perceptions in the light of businesses adapting their operations to new suppliers/destinations.

Overall, on a global scale, our results point towards negative effects on exports of agricultural products until 2015, and a post-2016 recovery. Exports of Japan were negatively affected until 2015 while imports showed recovery as early as 2012. Trade flow recovery is related to both better organisation of networks but also to consumers being better-informed on the effects of nuclear accidents on food products. The importance of information can further be stressed through the emphasis the International Atomic Energy Committee has placed on proactive and timely communication in cases of disaster. The Government of Japan and TEPCO should communicate with the public on matters relevant to public concerns by disclosing data and information in an easy-to-understand manner on a regular basis, in order to explain the potential impact, health and safety concerns for the public and the environment. Past experience and the Chernobyl Forum Health Experts of the World Health Organization also conclude that timely and accurate communication of information to the public is most important (Chernobyl Forum, 2006). The strategy of providing timely information was the communication strategy selected by Japanese government (Fukushima Prefectural Government, 2016; Zhang et al., 2019).

Conclusions for policy implementation stress the need for effective communication with the public, domestically and internationally, to alleviate any effect that misinformation and harmful rumours may have. Exporters need to be better prepared to overcome affected long-term relations and be able to quickly reach alternative routes/ substitute products for inputs to production. Easing trade through Free Trade Agreements can positively impact the recovery of exports, decreasing costs and providing more outlets for alternative routes to producers. Given a global and networked system of production, Fujita et al. (2012) note that developing countries must make supply chains more resilient under international cooperation. Building safety stocks, where possible, can also assist businesses. Finally, change of network/supply chain operations through use of multiple suppliers and multiple locations for business facilities can provide resilience to supply chains.

6. Conclusions

We used panel data for the years 2000 to 2018 with a structural gravity model that employs the Poisson Pseudo Maximum Likelihood (PPML) estimator (Santos Silva & Tenreyro, 2006), to estimate the impact on Japanese trade flows from agriculture. We employed the method by Heid et al. (2021), who proposed the use of a panel data that combines international trade flows with intra-national sales. The inclusion of intra-country trade data allowed the identification of the coefficient for the 'disaster' dummy variable. We also employed the method by Anderson et al. (2018) to create a counterfactual scenario that allowed us to expand our discussion to the impact of the triple disaster on agricultural product trade flows around the world.

Our results indicate that the earthquake, the tsunami and the nuclear accident affected Japan's exports and imports negatively. The negative effects on exports ranged between 10.4 and 18.1 per cent and extended until 2014. The lasting impacts suggest that harmful rumours for Japan's agricultural products, prevented export demand from getting back to normal, pre-disaster levels within the time required to overcome physical damages. We found the most persisting effects in vegetable products and products from live animals where significant negative coefficients on exports were noted until 2017 and 2018. Imports, on the other hand, significantly decreased between 2012 and 2014, with the size of the effect ranging between 19.7 and 33 per cent. The significant decrease in imports indicates that consumers in Japan were better informed about the dangers of radionuclides through effective domestic policies for the alleviation of harmful rumours. A counterfactual scenario that examined the transmission of the effects to global exports of agricultural products suggested heterogeneity in the size of the effects related to distance and trade ties. Negative effects were noted in 2014 and recovery in 2017. Only marginal changes were noted on prices, GDP and costs.

The effect on exports suggests transmission of the impact of the triple disaster to global agricultural product markets through supply chains and harmful rumours. Supply chains needed time to recover, to find alternative routes and substitute inputs. International consumer perceptions and choices were affected, leading to increased costs to market and promote products. Results highlight the need for building resilience in supply chains, relying on multiple suppliers, developing stock, promoting Free Trade Agreements as well as timely and effective communication with the public in cases of crisis, to avoid consumer overreactions to harmful rumours. Effects on imports were short-lived and can be mainly attributed to harmful rumours.

Future research should concentrate on confronting one of the limitations presented by the approach proposed by Heid et al. (2021). The methodology we employed allows the estimation of effects from 'non-discriminatory trade policy' variables, when policy applies to international trade flows but not domestic sales. Our assumption in this research was that the triple disaster affected trade flows, but it did not affect domestic sales. This presents one of the limitations of this study that needs to be corrected as the triple disaster affected domestic sales as well.

Conflict of Interest

None.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix

Table A1 Summary statistics for variables included in the regressions

Variable	Mean	Std. Dev.	Bet. Std. Dev	With. Std. Dev	Min	Max	N
Exports	4,258,219	2.07E+08	1.54E+08	7.82E+07	0	2.58E+10	308,833
Imports	4,283,453	2.08E+08	1.54E+08	7.89E+07	0	2.63E+10	308,814
FTA	0.178	0.382575	0.309	0.184	0	1	308,833

Author's estimates.