〔*Jpn. J. Agric. Econ.* Vol.23, pp.1-17, 2021〕

Trends and Structural Changes in Japanese Post-2011 Agri-Food Trade Flows

Dimitrios Dadakas,[1*] Christos Karpetis[2] and Stevi Tatsi[3]

The 2011 earthquake, tsunami and nuclear disaster in Japan affected imports and exports of agri-food products. Following the disasters, the implementation of international surveillance measures on exports of agri-food products and the restrictions on domestic production resulted in a decrease of exports and an increase in the level of imports. While restrictions were gradually lifted, levels of imports and exports did not adjust immediately as consumers were reluctant to consume products from afflicted regions. We examine Japan's agri-food exports and imports for the presence of structural breaks to endogenously determine whether there were any permanent post-2011 changes in the evolution of the time series of trade flows. We use the endogenous structural break literature and examine 2-digit trade series for the presence of up to 3 structural changes in the series' trends. Results indicate non-uniform post-2011 level and trend changes for both imports and exports of agri-food products.

Key words: nuclear disaster, multiple breaks, endogenous structural breaks, agricultural and food products, Japan

1. Introduction

On March 11, 2011, an earthquake of magnitude 9.0 on the Richter scale hit Japan. The epicenter of the earthquake was located on the northeastern part of Japan, 130 km of the Pacific Coast of the Tohoku District. The earthquake impacted the northeastern and the eastern part of Japan causing a 10-meter tsunami (Mori *et al*., 2011)[1)] that traveled 10 km inland covering approximately 560 square kilometers of land. The tsunami destroyed the electric system of the Fukushima Daiichi Nuclear power plant and led to explosions in the containment vessels of reactors 1, 3 and 4, releasing radioactivity in the agricultural plain of Kanto, Tohoku and the Pacific Ocean. The total damage to Japan's capital stocks, that immediately created exclusion zones for production and soon thereafter faced international surveillance measures,[2)] was ¥16.9 trillion ($211.7 billion) while the damages to Japan's agriculture were ¥1.9 trillion ($23.8 billion)[3)] (Fujita *et al*., 2012; MAFF, 2012). Damages to Japan's fishery, agriculture and forestry sectors reached ¥2.34 trillion ($29.3 billion).[4)]

Releases of radionuclides in the environment dispersed mostly over the Pacific Ocean but about 20% dispersed over Japan and deposited on Honshu, resulting in areas of significant deposit (Mathieu *et al*., 2018; MEXT, 2011). Among the many radioactive substances that were released into the environment radiocesium (134 and 137) was the most dangerous for

[1] Department of Economics, University of Ioannina
Corresponding author*: ddadakas@uoi.gr
[2] Department of Balcan, Slavic and Oriental Studies, University of Macedonia
ckarpet@uom.edu.gr
[3] Department of Economics, University of Ioannina

1) 10 meters was the mean inundation height of the tsunami near the shorelines. The maximum inundation height was 19.5 meters and maximum run-up height 39.7 meters. Maximum run-up heights above 10 meters were distributed along 425 km of coastline and greater than 20 meters along 290 km of coast (Mori *et al*., 2011).

2) Different types of "Surveillance measures" were adopted such as import bans, import bans in accordance with distribution restrictions in Japan, certificates of pre-export testing for radionuclides, certificates of production place and reinforced inspections.

3) These figures do not include damages created by exclusion zones for agricultural production or damages caused by international surveillance measures.

4) $1 = ¥79.807 for 2011 (World Development Indicators: WDI).

the local population due to both the quantity that was released and the relatively long half-life (Evrard *et al*., 2019; Steinhauser, 2014). Releases and deposits of radionuclides however, presented only a small part of the problems that Japan would have to confront in the near future. Maintaining energy security, production halts, shortages of parts and materials, disruption of supply chains, decontamination, clean-up costs and decommissioning costs added, amongst others, to the long list of challenges the Japanese government and the people would have to confront.

The effects of the triple disaster were evident in all sectors of the Japanese economy; however, agriculture was amongst the most affected sectors. Production exclusion zones, consumption warnings and international surveillance measures affected production, consumption and trade. Consumers heeded the warnings for products originating from the infected radioactivity zones, resulting in increases in food imports and decreases in food exports. By the end of 2011, and as compared to 2010 year-end values, agri-food exports (HS categories 1–24; Appendix Table A1) had decreased by 12.61% while food imports in the respective categories had increased by 22.46% (estimated using constant values from UN Comtrade data).

The existing literature related to the impact of the disasters on Japan's agri-food sector (Bachev and Ito, 2014, 2017; Johnson, 2011; Liou *et al*., 2012; Nakanishi and Tanoi, eds., 2013; Todo *et al*., 2015) recognizes that the slow recovery of agriculture from the Great East Japan Earthquake (GEJE), the tsunami and the nuclear disaster, as well as the consequent physical damage, the radiation and the harmful rumors regarding Japan's products, need to be thoroughly evaluated in every aspect for policy purposes, disaster prevention and strategic planning. Moreover, the current literature has, in the most part, presented stylized facts, assuming that observed drastic changes in the economic time series relate to impacts of the triple disaster. However, there is no reference to date that allows the data to endogenously determine whether there were any permanent structural changes in the evolution of the time series. We contribute to the understanding of the post-2011 changes in Japan's economy by concentrating on agri-food trade flows and examining the disaggregated 2-digit (HS) trade series for the presence of structural changes related to both level and trend. Permanent changes in the evolution of each series are expected to differ for each product category depending on input use, the spatial distribution of production, the degree of processing required, and the ability to preserve, as well as other economic factors affecting the evolution of trade flows.

Our results and conclusions can be employed for the evaluation of the effectiveness of policy. Structural changes in either the export or the import series combined with observed changes in the trend of each series in the vicinity of the triple disaster may indicate destruction of capital or adoption of restrictive measures for production/trade that permanently affected each time series. Moreover, the identification of possibly multiple structural breaks in the series allows for the identification of more accurate ARIMA (p, d, q) models, which could be used to predict the future evolution of the magnitudes under investigation, providing in this way degrees of freedom to state planners regarding the formation of the appropriate state agricultural strategies. Finally, the estimation of the parameters of the dummy variables in the selected break equation could also be employed to measure the effect of the estimated structural break on the dependent variables of the respective trade flows.

We employ the endogenous structural break literature and we follow Kapetanios (2005) to examine the stationarity of each time series under the presence of m structural breaks, concentrating on the estimated dates of the breaks. The endogenous determination of structural break dates implies that we do not exogenously define the break date in each series before we test for the presence of a structural break. Rather we follow a methodology that allows the data to determine "endogenously" the date when the evolution of the series implies a structural break and a permanent change in the data generating process.

The remainder of this article is set as follows: section 2 presents a review of the effects of the triple disaster on Japan's agriculture and a review of the literature on endogenous structural breaks. The discussion will allow us to better understand the evolution of the literature that started with the examination of stationarity under the presence of only one exogenous structural break (Perron, 1989a) and led to an m-(endogenous) break process presented by Kapetanios (2005). Section 3 presents a detailed description of the methodology we employ, as well as the data that we use. Finally, sections 4 and 5 present the results, the discussion and the conclusions.

2. Literature

1) The impact of the GEJE, the tsunami and the nuclear disaster on agriculture

The 2011 disasters resulted in a contraction in Japan's GDP by approximately 4% (March to January 2011) with economic losses reaching $211 billion (Kajitani *et al*., 2013). An area of 1,700 km^2 was contaminated with nuclear material, 19,824 people lost their lives and 10 million were evacuated (Government of Japan, 2012; Zhang *et al*., 2019). In Fukushima alone, by May of 2012, 164,865 people were evacuated. The disasters affected production levels, supply chains, industry, agriculture and trade.

The agricultural sector had to confront the impact on soil, flora and fauna, the coastal ecosystem, agricultural communities, farms and properties. Initial estimates of the direct economic losses were about 16.9 trillion yen, with the anticipated damages in the agricultural sector accounting for 11.24% of this amount (Bachev and Ito, 2017). A total of 24,500 ha of agricultural land were damaged, with the majority of damages in Miyagi and Fukushima Prefectures (Ministry of Agriculture, Forestry and Fisheries). Damages reached were 69% and 23.6% of total value in Miyagi and Fukushima respectively (Bachev and Ito, 2017: p.27). In Fukushima, Iwate and Miyagi, 85 municipalities were damaged, while there were also reports for 36,092 registered damages in land facilities (Bachev and Ito, 2017).

Damages such as physical destruction of land and properties were immediately confronted by the government; however, the management of radionuclide depositions required inspections of food samples and decontamination practices. Over the years, the number of agricultural products that exceeded accepted values of deposits for radioiodine and radiocesium decreased as strategies for absorption were adopted, such as application of potassium (K) fertilizer and decontamination activities. Decontamination guidelines were first adopted on November of 2011 (and later updated in 2013) with the "Act on Special Measures Concerning the Handling of Pollution by Radioactive Materials." The guidelines were released to reduce the impact of radioactive substances on humans and the environment (Yasutaka and Naito, 2016). Decontamination included removal of contaminated soil and remediation practices, river channel decontamination, forest decontamination and others. Activities generated 20 million m^3 of contaminated soil by 2019 that will have to be stored, in the most part, for 30 years. The costs for decontamination from 2013 to 2019 reached 3 trillion JPY (Evrard *et al*., 2019). Recultivation of decontaminated farmland however, raises "additional questions related to the fertility of remediated soils and the potential transfer of residual radiocesium to the plants" (Evrard *et al*., 2019).

The effectiveness of decontamination can be studied with the latest inspections of food samples. In the months of February and March of 2018, only 0.06% and 0.04% of food samples, respectively, were found to exceed acceptable limits of cesium 134 and 137.[5)] In the Fisheries products and Marine Fish Species the number of samples containing more than 100 Bq/kg was one in 11,435, while in freshwater species 5 out of 2,083 (May 2018 to April 2019). Yamaguchi *et al*. (2016), however, find that 5 years after the nuclear accident, agricultural soil-plant cesium (137) long-term monitoring and management was still important and the uneven decontamination of fields remained unsolved.

The effect on trade was not negligible either. Total merchandise trade exports showed a 14.5% drop in volume and 13.3% drop in value terms two months following the disaster (CEIC database). Trade of agricultural products was severely affected with many countries still holding some type of restrictions on Japanese products. The MAFF (2019) report summarizes the 2011 vs. 2019 restrictions on rice, vegetables and fruits, tea, medicinal plants, milk and dairy products, fishery products and processed foods for 54 countries. Immediately after March of 2011, numerous countries imposed either import bans on products or products from specific prefectures, import bans on Japanese agricultural products in accordance to restrictions of distribution in Japan, required certificates of pre-export testing for radionuclides, certificates of production place or reinforced inspection. However, as early as 2011 some countries had lifted restrictions. Canada, Myanmar, Serbia and Chile lifted all import measures by 2011, and Mexico, Peru, Guinea, New Zealand and Colombia by 2012, while others followed. Some of the more important trade partners for Japan, such as Australia, lifted all bans in 2014 and India in 2016. Most of the countries that retained restrictions after 2019 have done so in a number of products. The countries that retained most of the restrictions in 2019 were Egypt, Polynesia, Indonesia, Morocco, Lebanon, Macau, Mainland China, the Philippines, Russia, Taiwan, South Korea, Hong Kong, Israel and Singapore.

Despite the gradual lifting of restrictions, a trade deficit was observed for the first time after many years in Japan, due to both increased imports and decreased

5) In February 2018, no new restrictions were imposed while restrictions were removed for Chestnuts in Nasu-machi, Tochigi prefecture. In March of 2018 rice of Fukushima prefecture was newly restricted while removal of restrictions was implemented on wasabi in Date-shi, and raw milk in Kawamata-machi, Tomioka-machi, Namie-machi and Iitate-mura. Other products were also included in the report for the month of April of 2018 which are beyond the scope of this paper. The main point focuses on the constant re-evaluation and inspection of products in infected areas.

Table 1. Summary of the results for imports and exports

Category	Exports		Imports	
	Mar. 2011–Jan. 2012	Jan. 2011–Jan. 2012	Mar. 2011–Jan. 2012	Jan. 2011–Jan. 2012
1	−68.49%	45.72%	102.08%	**84.89%**
2	−23.21%	−21.39%	7.28%	19.93%
3	−14.34%	−17.31%	27.13%	25.84%
4	−76.57%	**−81.17%**	13.12%	17.58%
5	189.87%	−55.64%	27.84%	**34.61%**
6	24.34%	59.07%	18.51%	14.57%
7	−24.25%	−32.18%	4.65%	6.61%
8	−78.10%	−79.20%	8.63%	19.78%
9	6.10%	3.31%	−0.36%	1.08%
10	−80.34%	**−86.72%**	28.23%	17.70%
11	−0.73%	13.44%	−1.98%	17.71%
12	−9.58%	−2.46%	0.55%	6.96%
13	−18.82%	−31.16%	60.18%	88.84%
14	−16.74%	4.29%	−26.87%	48.90%
15	−21.75%	−11.09%	5.62%	17.17%
16	−28.09%	−10.50%	15.87%	32.78%
17	−10.96%	7.51%	7.31%	7.27%
18	−21.84%	−25.95%	10.57%	16.56%
19	−35.80%	−36.16%	12.38%	16.88%
20	−7.31%	−8.06%	0.77%	14.90%
21	−10.85%	−12.24%	7.92%	9.24%
22	1.82%	1.87%	18.67%	25.18%
23	15.49%	18.03%	8.88%	15.59%
24	−14.17%	−13.84%	30.85%	**77.12%**
All	−12.61%	−11.85%	15.12%	22.46%

exports. In the agri-food sector, the effects of the triple disaster are evident in many product categories with exports of dairy products (cat. 4) exhibiting an 81.17% decrease in the 9 months following the disaster and as compared to previous year values, and cereals (cat. 10) an 86.72% decrease (Table 1). Some products, on the other hand, were positively affected with the largest increases seen in category 6 of live trees and category 1 of live animals. Imports, on the other hand, showed the largest increases in category 1 (live animals), category 13 (lac, gums, and resins) and category 24 (tobacco) during the same period.

Zhang *et al.* (2019) concentrate on the Fukushima area and try to answer the question of how Fukushima can recover, given the long-term impacts of pollution, and how effective the industrial reconstruction was after the disasters. Using filed surveys and unstructured interviews they investigated agriculture among other sectors. They found that local farmers cannot yet effectively rely on their land for their livelihood, especially those farmers closer to the nuclear power plant. However, even farmers who can produce their crops have difficulty selling them, as "region battles" resulted in increased concerns about contamination, thus preventing recovery. Soilless agriculture, hydroponic crop farming, aeroponics, biotech crops, and genetically modified crops have all come to assistance in dealing with land shortages. Overall they find that output from agriculture has not reached pre-disaster levels.

These results are supported by the conclusions of Bachev and Ito (2017). Despite the quick response of the government in matters of reconstruction, assistance, inspection and mitigation, six years after the disaster, the value of agricultural, forestry and fisheries products in the Fukushima prefecture still exhibited significant declines as compared to the pre-disaster period with only a few signs of recovery (Bachev and Ito, 2017: p.17).

While the mitigation of economic impacts is at the forefront of policy, the impact of the disasters also extends to the long-term well-being of individuals near Fukushima. Rehdanz *et al.* (2015) find that life happiness declined in places affected by the tsunami as well as places that were near the power plant. They estimate the decrease in life happiness to range between 72% and 240% of annual income, with estimates increasing with proximity to the nuclear power plant. However, they could not establish an effect from the level of radiation, which is likely to be long-term in nature.

2) Endogenous structural break methodologies

Our investigation of the time series of agri-food exports and imports rests on the existing tests on stationarity. The original test for stationarity by Dickey and Fuller (1979, 1981) has limitations in the presence of a structural break. When a structural break is present and it is ignored, the null hypothesis for a unit-root is more difficult to reject. The literature on the examination of the unit-root hypothesis, using endogenous structural breaks, started in 1989 with the seminal work by Perron (1989a), who suggested that failure to reject the null hypothesis in a time series may be due to the presence of structural breaks in the data. These tests are therefore biased towards accepting the null of a unit-root in the presence of a break. In his application, Perron exogenously specified the break date for the Great Depression to examine the stationarity of the series. The study had important policy implications, as it differentiated between a stochastic unit-root process and a segmented trend-stationary process around a specific break.

Future work went one step further, concentrating on examining the stationarity of the data using an endogenous data-dependent procedure to determine the break date, by working through a grid-search of repeated Dickey-Fuller type tests. The literature includes a rich debate that produced different grid-search procedures for the examination of an endogenous single structural break in the data (Banerjee *et al*., 1992; Zivot and Andrews, 1992; Perron, 1989a, b, 1994, 1997; Perron and Vogelsang, 1992a, b, 1998). These methodologies, were later adapted by Lumsdaine and Papell (1997), to examine the stationarity of a time series, allowing for the presence of two endogenous structural breaks.

Following the procedure proposed by Lumsdaine and Papell (1997), who recognized the problem of narrowly specifying the number of breaks in a series as being limited to two, Kapetanios (2005) proposed to examine the stationarity of a series, in the presence of a minimum of two up to *m* breaks, using unspecified break dates that are, similarly to the past literature, chosen endogenously by the data. The proposed procedure employed significantly less computing time, as for a series of *n* observations, it required $n-2$ estimations as opposed to n^2 that were necessary in previous methods, such as the one presented by Lumsdaine and Papell (1997).

These models belong to the innovative outlier literature, where structural changes do not present themselves at a specific point in time (additive outlier), but rather in multiple times. This implies that any structural changes that results capture are changes that have a rather permanent effect on the data generating process.

Articles that examined stationarity under *m*-structural breaks using the methodology of Kapetanios (2005) include Herzer *et al.* (2006) who studied the export-led growth hypothesis using data from Chile. Working in a production function framework they verified the order of integration by testing the variables for unit roots against the hypothesis of trend stationarity in the presence of two endogenously determined breaks. Tang (2011) conducted Granger causality tests on health care spending, income and relative prices in Malaysia using multivariate cointegration and error correction models. To verify the order of integration in the possible scenario of structural breaks being present in their time series, they re-confirmed the order of integration using 3-break unit-root tests. They found no additional evidence for the presence of unit roots under *m*-breaks compared to standard unit-root tests. Gomez-Zaldivar *et al*. (2013) used a modified version of the procedure proposed by Kapetanios (2005), by eliminating the trend and trend breaks to examine the purchasing power parity hypothesis for the Mexican peso/US dollar exchange rate, using monthly data from 1969 to 2010. Modified critical values were proposed through a Monte Carlo procedure. Their results suggest evidence for qualified and trend-qualified purchasing power parity for the Mexico-US real exchange rate. Vaughan (2013) studied the diffusion process of permanent disinflationary shocks in the Mexican economy, using price data for 283 goods in 46 cities from 1995–2012. By testing for multiple structural breaks in the price indexes, he found that more than 80% of the series exhibited a break. Finally, Narayan *et al*. (2015) examined whether the efficient market hypothesis is dependent on the day of the week by employing NYSE listed banking sector firms. To examine the efficient market hypothesis they imposed two endogenous structural breaks on the data series. Results rejected the unit-root null on all five trading days for 21 out 34 firms.

The procedures proposed did find resistance in the literature. Lee and Strazicich (2003, 2013) criticized all ADF-type tests that endogenously determine a unit-root in the presence of structural breaks. They suggested that critical values are estimated under simulation procedures, by assuming no breaks exist under the unit-root null. In other words, a rejection of the unit-root is limited to a rejection of a unit-root without breaks – therefore not allowing rejection of a unit-root that includes breaks. They propose a minimum unit-root test which allows a null hypothesis of a unit-root with or without breaks. Teng and Liang (2010) employ the methodology by Lee and Strazicich (2003, 2013) to examine causality between economic growth and finance development in a structural break framework. They find that, while conventional unit-root tests indicate a unit-root, the tests that endogenously determine the presence of a unit-root in the presence of a structural break suggest most of the examined series present segment stationarity around structural breaks, as opposed to a stochastic unit-root process.

3. Methodology

We examine the time series of 2-digit (HS) exports and imports of agri-food products (HS categories 1 through 24) for Japan, for stationarity allowing up to $m = 3$ structural breaks in each of the series examined. We choose $m=3$ to allow for possible breaks related to other factors present in the Japanese economy, unrelated to the triple disaster, that may have affected exports and imports of agri-food products. Monthly data, for exports and imports, was available from January 2009 to September 2017 ($T = 105$ observations for each of the trade series included in the analysis) from the UN Comtrade Database and the Japanese government statistics. A total of 48 series were examined, 24 two-digit series for exports and another 24 two-digit series for imports.[6] The data was deflated using Japan's CPI index (2010 base) and deseasonalized using the *X11* methodology, originally provided by the US Bureau of the Census.

The basic OLS estimation for each series in model *C* of Kapetanios (2005) is

$$y_t=\mu_0+\mu_1 t+ay_{t-1}+\sum_{i=1}^{k}(\gamma_i\Delta y_{t-i})+\sum_{j=1}^{m}(\varphi_j DU_{j,t})+\sum_{j=1}^{m}(\psi_j DT_{j,t})+u_t \qquad (1)$$

where y is the series of imports or exports examined, t is the time period and Δ refers to the backward difference operator. $DU_{j,t}$ and $DT_{j,t}$ represent the intercept and trend break dummy variables respectively, which are adjusted for every break in the analysis and for every partition during the search process. $DU_{j,t}=1(0)$ and $DT_{j,t}=1(t-T_{b,j})$ if $t>T_{b,j}(t\leq T_{b,j})$ where $T_{b,j}+1$ is the date of the i-th structural break.

Starting with the first structural break, equation 1 is estimated over all possible partitions of the sample. The first sum $\left[\sum_{i=1}^{k}(\gamma_i\Delta y_{t-i})\right]$ is included to control for autocorrelation in the estimation of equation 1. For each partition examined, the lagged difference of the dependent variable is included for a maximum of 12 lags, following Schwert's (1989) rule, with $T=105$ observations, that is, $k_{\max}=\text{int}\left[12\left(\frac{T+1}{100}\right)^{\frac{1}{4}}\right]=12$.

The determination of the lag parameter uses a backward selection process following the general to specific recursive procedure by Perron (1989a, b), to ensure that residuals are not correlated. We start by including all $k_{\max}=k_{12}=12$ lags and we examine the significance of the last lag, comparing the t-statistic $T_{\gamma_{12}}=\hat{\gamma}_{12}/se(\hat{\gamma}_{12})$ with the critical value 1.6 derived from the $N(0,1)$ distribution, for a two sided test at 10% significance level. If the last lag is insignificant ($|T_{\gamma_{12}}|<1.6$), then the procedure is repeated by decreasing the lag length to $k_{\max}-1$ or to $k_{11}=11$ lags in our case. If the γ_{11} parameter is again statistically insignificant ($|T_{\gamma_{11}}|<1.6$), the sequential selection procedure is continued by lowering the upper limit of the sum $\sum_{i=1}^{k}(\gamma_i\Delta y_{t-i})$ by one, until a significant lag is retrieved $\left(k_i^{sig}, i=1, \ldots, 12\right)$.

The residuals resulting from equation one (1), for $k=k_i^{sig}$, are examined for the presence of autocorrelation using the Ljung-Box q-statistic $Q(z)$, allowing for $z=\frac{T}{4}$ lags in the identification process. If the null of no autocorrelation is not rejected using z lags, the process stops at k_i^{sig} for the specific partition. If the Ljung-Box statistic suggests that residuals are autocorrelated, then equation (1) is estimated for $k=k_i^{sig}+1$ and the residuals are checked again. If the problem of autocorrelation is not solved, then we run equation (1) for $k=k_i^{sig}+2$ and we test again. This procedure is continued by increasing the value of k_i^{sig} by one until we find the lag length for which the residuals are not correlated. If the residuals are correlated for $k=k_i^{sig}, \ldots, k_{max}$, then we use the estimation results coming from equation (1) for a lag value equal to k_i^{sig}.

The above process is repeated for all possible partitions in order to obtain a total of $t-2$ estimates of equation 1. However, only the middle 90% of the t equations are examined as the top and bottom 5% are excluded from the analysis so that the total number of equations estimated, which also excludes the first and last partition, are $0.9 \cdot t$. The first break date is then chosen as the one that shows a minimum value for the

6) 2-digit HS Categories range from 1-99. Category 77 and 98 are excluded from classifications. In this study, we employ categories 1-24 which represent live animal and animal products (1-5), vegetable products (6-15), animal or vegetable fats (15) and food and preparations (16-24) consisting of prepared foodstuffs, beverages, spirits, vinegar and tobacco products.

Table 2. Summary of the results for exports and imports

		Exports				Imports			
	Category	T-Value	Break 1	Break 2	Break 3	T-Value	Break 1	Break 2	Break 3
Animal products	1	−8.31***	**Nov-11**	Sep-14	Jan-16	−10.44***	Jul-15	Aug-10	May-13
	2	−8.65***	Jul-13	May-10	Jun-12	−6.39	May-15	Dec-12	Mar-12
	3	−8.78***	Jan-10	Mar-13	Apr-14	−16.49***	Sep-15	Jan-12	Dec-12
	4	−9.19***	**Apr-11**	Jun-12	Mar-13	−13.12***	Nov-15	Oct-13	May-10
	5	−9.54***	May-12	Mar-15	Mar-13	−14.11***	Nov-14	Jan-12	Jun-10
Vegetable products	6	−7.81***	Aug-13	Mar-12	Aug-15	−6.47	Dec-15	Oct-10	May-12
	7	−9.80***	Jan-10	Oct-15	Feb-15	−21.57***	Mar-14	Dec-12	Feb-16
	8	−7.49***	Jan-12	**Apr-11**	Sep-12	−18.92***	Dec-12	Nov-14	Oct-10
	9	−10.31***	Jan-11	Aug-15	May-10	−17.13***	Oct-10	**Aug-11**	Nov-15
	10	−6.83**	Dec-10	Sep-13	Jan-12	−5.34	**Apr-11**	Jul-12	May-15
	11	−8.17***	Mar-15	Jun-10	**Mar-11**	−6.18	May-10	Oct-14	Jan-13
	12	−6.29	May-15	**May-11**	Feb-12	−17.89***	Jun-12	Jan-16	**May-11**
	13	−7.86***	Jan-10	Apr-12	Feb-16	−7.35**	**Aug-11**	Jan-15	Aug-13
	14	−8.22***	Mar-10	Jan-15	Oct-13	−7.23**	Feb-16	Feb-14	Jan-12
	15	−10.86***	Sep-10	Jan-15	**May-11**	−6.78*	Dec-12	Apr-12	Sep-15
Foodstuff, Spirits, Beverages, Tobacco	16	−12.10***	Aug-10	Jan-14	Feb-15	−9.71***	Aug-15	Dec-12	Jan-12
	17	−9.64***	**May-11**	Feb-16	Sep-10	−8.32***	**Mar-11**	Sep-14	Feb-16
	18	−6.48***	Jan-12	Dec-12	**Apr-11**	−12.65***	Jul-13	Aug-12	Feb-16
	19	−7.37**	**Jul-11**	Nov-12	Feb-16	−16.99***	Jul-14	Jul-13	Feb-15
	20	−8.87***	**Sep-11**	Jan-16	Nov-10	−8.53***	Nov-14	Dec-12	Jul-13
	21	−10.89***	Apr-12	Dec-12	Sep-15	−6.92*	Aug-15	Oct-10	Nov-14
	22	−10.67***	Feb-13	**Jun-11**	Jan-12	−6.02	Nov-14	Aug-10	**Apr-11**
	23	−10.54***	Jan-10	Dec-12	Dec-14	−6.34	Jul-14	Mar-15	Jun-10
	24	−4.69	Dec-10	Sep-15	May-14	−5.69	Mar-14	Feb-11	Feb-12

Note: Author's Estimates. Critical values according to Kapetanios (2005) Table 1 and for a = 0.05 are for one break −5.081, two breaks 6.113 and three breaks 7.006.

Sum of Squared Residuals (SSR), among the $0.9 \cdot t$ equations selected with the backward process described. The break date is denoted as t_{b1}. The t-statistics of the hypothesis $a=1$ for all partitions in $0.9 \cdot t$ estimates are stored in a vector and denoted τ^1.

The process is repeated for the second break by imposing the dates of the first break on the estimation of equation 1. We add $DU_{j,t}^{t_{b1}}$ and $DT_{j,t}^{t_{b1}}$ as independent variables and then select the equation with the minimum SSR and create the set τ^2 that includes all t-statistics of the hypothesis $a=1$ for a total of $(0.9 \cdot t)-3$ equations. We exclude some of the possible dates during the estimation of break 2, which are the dates $t_{b1}-6<t_{b1}<t_{b1}+6$, to prevent the case of continuous breaks occurring within one year. Similarly for break number 3. The union of the t-statistics estimated for the hypothesis $a=1$ from the three breaks $(T^3=\cup_{i=1}^{3}\tau^i)$ is examined and the minimum value is contrasted to the critical values presented for the C-model by Kapetanios (2005) for the respective number of breaks ($m = 3$). If the value estimated is less than the critical value, the unit-root is rejected.

4. Results

Table 2 presents the results for stationarity and the estimated breaks for both exports and imports. Most of the deflated and deseasonalized series are stationary after 3 breaks (22 out of 24 export series). Break dates that appear within 9 months of the disaster, that is after March 2011 but within 2011, are indicated in bold. As indicated in Table 2 and Appendix Tables A2 and A3, only 11 out of 24 export series and 6 out of 24 import series showed a break within this time frame. Initial evidence suggests few structural changes in the evolution of agri-food trade flow series immediately after the triple disaster. To better understand those changes in agri-food trade flows, we separately examine the break dates for each product category together with the series trends.

The break dates are presented with the help of Figures 1 (for exports) and 2 (for imports), where we indicate the HS category in each panel.[7)] The trade flows depicted are constant values that have not been

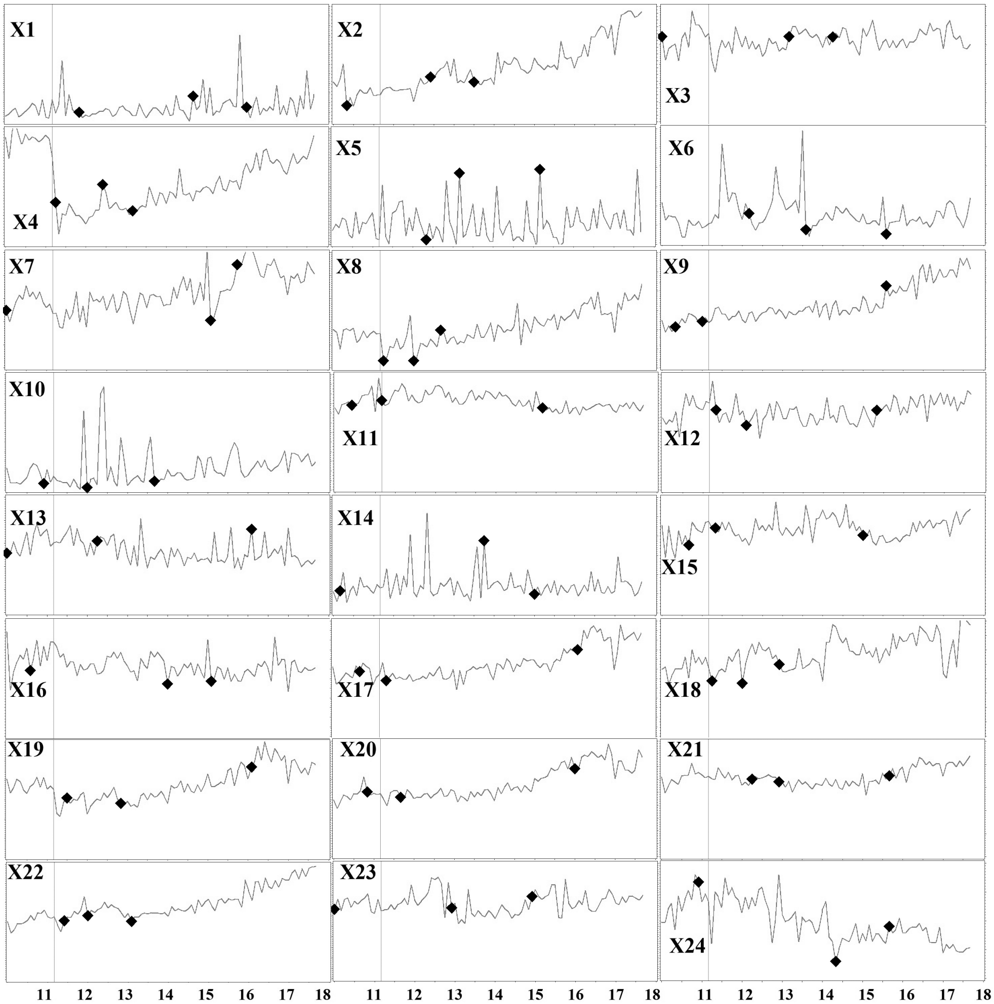

Figure 1. Breaks of exports for HS categories 1-24

Note: Author's estimates.

deseasonalized. The vertical lines mark the date for the March 2011 disaster and the "diamond" shaped indicators the break dates estimated for each one of the export and import series. We examine only a selection of categories that will help us draw conclusions on the effectiveness of policy and the prevention/spreading of harmful rumors.

In the Animals categories (HS 1 through 5), we first examine export category 2 (meats) that did not show an immediate reaction after the triple disaster, retaining a mild increasing trend that started as early as May of 2010. The first, post-disaster break, which is also the dominant break, appears in June of 2012 and it is associated to a change in export levels and a decrease in the series' trend coefficient (see Appendix Table A2). Imports, on the other hand, exhibited initially a positive trend, also retained from the pre-disaster period. A short-run increase after March 2011 was followed by a drop that was marked by a structural break. After March of 2012 a mild negative trend was realized that persisted until May of 2015, where the dominant break for imports indicates an estimated 23% decrease in the level of imports (Appendix Table A3). Following the disasters and by May of 2011, 52 countries had adopt-

7) Regression coefficients and the dominant break for each series can be seen for both exports and imports in Appendix Tables A2 and A3. Some of the coefficient estimates in these tables are employed in the discussion that follows.

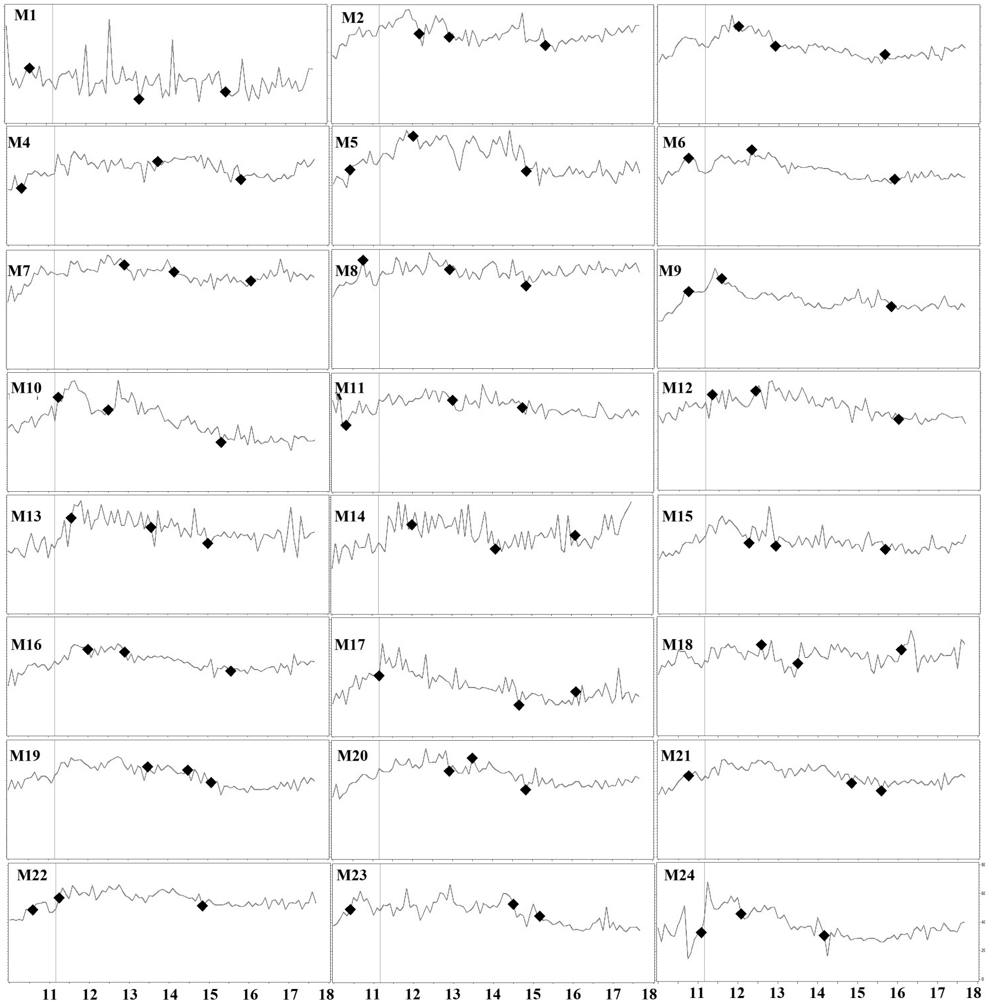

Figure 2. Breaks for imports for HS categories 1-24

Note: Author's estimates.

ed surveillance measures that were either recorded as import bans (17 countries), certificates of pre-export testing for radionuclides (24 countries) or reinforced inspections (11 countries)[8] (MAFF, 2019). By December of 2019 only 4 countries had maintained import bans, 1 had import bans in accordance to Japan's distribution restrictions, 7 required certificates of pre-export testing, 2 required certificate of production and another 2 required reinforced inspections. The increase in exports, combined with break dates that do not appear near the triple disaster, and the simultaneous decrease in imports, together indicate an effective policy for the mitigation of negative effects and the alleviation of harmful rumors. Any effects that can be associated to the destruction of capital (see Table 1, 23.21 % drop in exports and 7.28% increase in imports from March 2011 to January of 2012) and any shortages that could have had a negative impact on imports (increase) were short-lived. The constant rise in the export series further suggests that foreign importers thoroughly trusted the inspection/surveillance system implemented by the Japanese government. The gradual drop in imports on the other hand, suggests that domestic consumers gradually shifted back to products from Japan, once short-lived shortages were dealt with. Hence, domestic consumers also trusted the safety/in-

8) EU countries are recorded as one destination.

spection mechanisms employed and did not present any permanent changes in their consumption habits.

Similar conclusions can be reached for other product categories in agri-food trade. Fish products (category 3) showed overall stability in terms of exports with breaks appearing after 2013. The dominant break for exports does not appear until April of 2014 when an estimated 18% increase on exports is noted (see Appendix Table A2). A short-run decrease in exports was turned around within two months after the disaster. Despite the stability in the export series, category 3 product exports had the largest number of countries still imposing some type of restrictions by 2019 (21 countries). This is in accord with Fujita *et al.* (2012), who suggests that rice paddy fields and fisheries were the main economic activities affected in the region. The impact of radioactivity on sea waters and the continuous discussion on increasing numbers of radioactive water storage facilities, may have impacted the effectiveness of policy on fish products and the international opinion. An increased number of countries retained some type of restrictions; however, the data suggest that it did not have an impact on the total level of exports as they remained rather constant. Imports, on the other hand, show a first break in January of 2012 and carry a negative trend. Similar to meat products, an initial post-disaster increase in fish imports was followed by a gradual decline. The January 2012 structural break is related to a switch in the series trend from positive to negative, marking an effective policy response, with the next (dominant) break in December of 2012 indicating a decrease in imports and a decrease in the rate of import decline (Appendix Table A3).

Exports of dairy products, eggs, honey and edible animal products (category 4) were the most affected agri-food export category, showing break dates immediately after the triple disaster. Despite the sudden drop, a subsequent increasing trend gradually brought exports back to regular levels by 2017. This immediate impact may be due to the perishable nature of the products that belong in this category, and the destruction of stock related to both the destruction of capital and destruction of products affected by the radioactive releases. The break dates coincide with the drop and the subsequent rise of export values. On the other hand, imports showed an increase, not marked by a structural break though, with a subsequent mild downturn. Break dates are not observed in the immediate vicinity of the triple disaster. Fifty-four nations imposed some type of a restriction, with 16 remaining by 2019.[9] Policy in category 4 products also seemed effective in terms of alleviating rumors as post-disaster increases in exports and short-term decreases in imports indicate.

Overall, animal products categories 1 through 5 exhibited either stability or a rise in exports. Imports of animal products, on the other hand, exhibited a short-lived, post-disaster increasing trend with breaks for categories 2, 3 and 5 signifying return to normality and decreasing levels of import quantities. No long-term effects seem to be affecting the series trends, indicating that harmful rumors did not have a lasting effect on either domestic or foreign consumers.

For Vegetable and Fruit products that belong in categories 6 through 15, we observe variable reactions of the trends after 2011. Fifty-three countries had some type of restriction/ban immediately after the triple disaster, but by 2019, only 17 had some type of ban/restriction/reinforced inspection, in the most part directed towards specific regions in Japan (MAFF, 2019). Export categories 8 (edible fruit), 11 (milling products), 12 (oil seeds and oleagic fruits) and 15 (vegetable fats and oils) showed a break date near March of 2011 with a concurrent short-term decrease in exports. The dominant break for milling products is estimated in March of 2011 when an increase in exports is noted; in April of 2011 for edible fruit and for vegetable fats and oils we find a dominant break in May of 2011, accompanied by a decline in exports (Appendix Table A2). These changes were complemented with increases in imports in the respective categories, which were, however, also short-lived. Breaks in the import series are presented in categories 9, 12 and 13; however, they signify a drop in imports. Only category 10 shows two structural breaks, one for the initial post-disaster break increase and one for the subsequent decrease in imports. Category 22 (beverages, spirits, and vinegar) is the only import category that shows a dominant break immediately after the disaster (April 2011), accompanied by an increase in imports (Appendix Table A3).

Overall, in Vegetable and Fruit categories we observe large variability in export trend and level changes. None of the export series suggest lasting drops that can be associated to harmful rumors impacting international consumer preferences. Most affected categories were 12 (oil seeds and oleagic fruits) and 13 (lac, gums resins and vegetables saps). In category 12, the immediate negative effect observed on May 11 was retained until February of 2012; however, catego-

9) Most of the countries that have retained restrictions after 2019 have done so in a number of products. The countries that retain most of the restrictions in 2019 are Egypt, Polynesia, Indonesia, Morocco, Lebanon, Macau, Mainland China, the Philippines, Russia, Taiwan, South Korea, Hong Kong, Israel and Singapore.

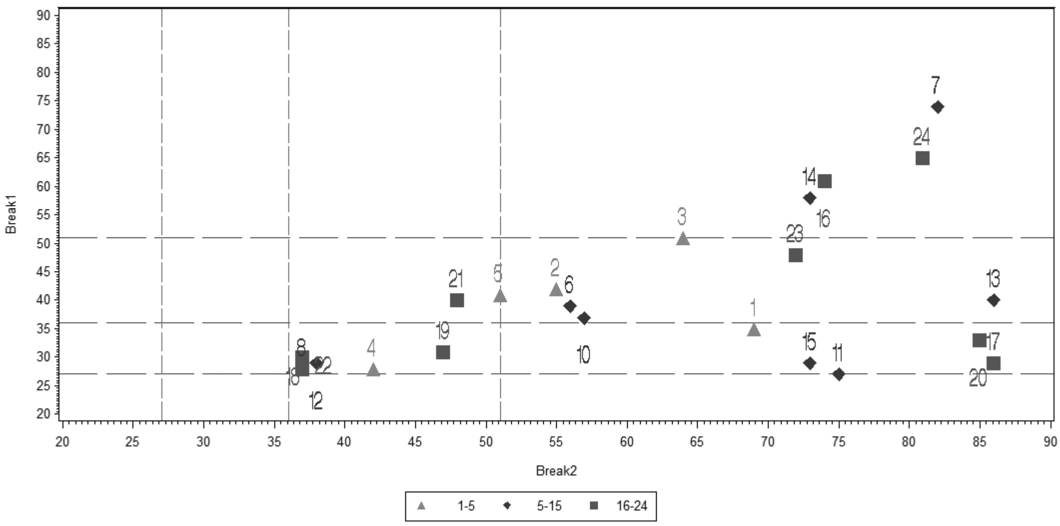

Figure 3. Breaks for exports for HS categories 1–24

Note: Author's estimates, Animal and Animal Product Categories (1–5) labeled with a triangle, vegetable products (6–15) with a diamond and foodstuff products (16–24) with a square. Vertical and horizontal lines indicate the March 2011, January 2012 and March 2013 dates.

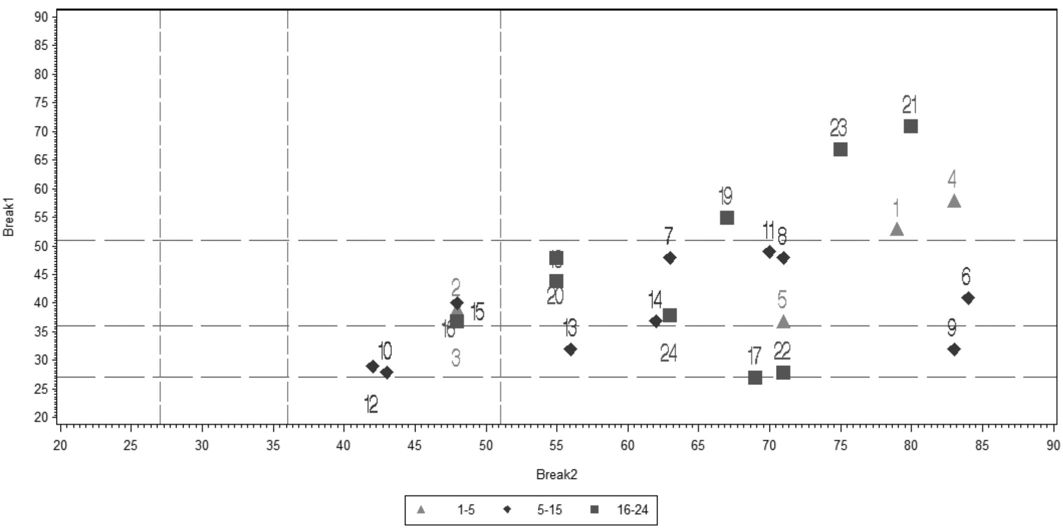

Figure 4. Breaks for imports for HS categories 1–24

Note: Author's estimates, Animal and Animal Product Categories (1–5) labeled with a triangle, vegetable products (6–15) with a diamond and foodstuff products (16–24) with a square. Vertical and horizontal lines indicate the March 2011, January 2012 and March 2013 dates.

ry exports gained momentum one year after the disasters. On the import side, all vegetable and fruit categories showed short-term increases with subsequent longer-term drops signified by structural breaks.

Similar conclusions can be reached for foodstuff product categories 16 through 24 as well, where short-lived negative effects are observed with decreasing exports and increasing imports. For most of the export series, subsequent increases were marked with structural changes. Similarly, for the import series a short-lived rise in imports is followed by a subsequent longer-term decrease that, in many cases, is marked by a structural break. Exceptions to this rule for exports are found in categories 21 (misc. edible preparations) and 24 (tobacco) where effects lasted longer. The post-disaster breaks in both categories 21 and 24 signify the rise in export values which for category 21 came on April of 2012 and for category 24 on May of 2014. Mitigation policy towards the impact of the effects of the disasters seemed to have been effective, with increased exports and constant imports signifying an improvement. Breaks that mark an increase in imports or a decrease in exports near the March 2011 date were short-lived for the most part.

We examine all the breaks for exports together with the help of Figures 3 and 4 where, on the horizontal and vertical axes, we plot the months after the beginning date of the sample, which is January 2009. On the vertical axis, we measure the first break date out of three which is closest to the period following the triple disaster. The horizontal axis shows the second break date closest to the triple disaster, but after the first break date. Important dates are noted in Figure 3 with dashed lines that represent the March 2011, January 2012 and March 2013 marks. These allow us to classify structural changes into those that were felt in the very short-term (March 2011 to January 2012) after the disasters, the short-term (March 2011 to March 2013) and the long-term (March 2013 and after). We only plot the 2 (out of 3) most "relevant" break dates for all of Japan's exports of agri-food product categories 1 through 24. The term "relevant" implies that out of the three breaks obtained from the analysis, only the two are depicted in the diagram, that are sequentially observed after the March 2011 triple disaster. These diagrams however do not depict the trends of each series, that is, whether the break occurred on an upward or downward part of each one of the trade-value time series. It merely points to products categories that showed drastic changes near the disaster period.

For exports, presented with Figure 3, we observe a high dispersion of the break dates throughout the 2011–2017 range. The varying changes on imports and exports of agri-food products could be linked to intensity of factor production, the distribution of total category production in disaster-afflicted regions as well as other economic factors not included in the analysis. Not all products show drastic changes near 2011, as many product categories are located far from the horizontal March 2011 dashed line, indicating breaks linked to other factors. The high dispersion of breaks emphasizes the need to study the impact of the triple disaster for policy purposes, disaster prevention and strategic planning at a disaggregate level.

For imports we note a high dispersion of the break dates and only few categories of products that exhibit permanent changes in their evolution immediately after the triple disaster. Only 6 out of 24 categories present a first break date before 2012. The changes are mostly related to an initial drop and a quick return to normality. Similar to the exports case, we have high dispersion that implies a need for per-category analysis of impacts.

Our conclusions are in accord with Fujita *et al.* (2012), who discuss the prompt response of the Japanese government in order to stabilize markets and ensure a quick recovery. Effects of the triple disaster manifested themselves through sales volume decreases, selling price decreases, costs of input increases, increased difficulties in the procurement of ingredients, lower overall demand, shortages, and disruption of networks. Irrespective of the transmission mechanism on the level of imports and exports, the overall trend shows that the policies adopted were effective in quickly bringing back trade values to normal levels for most of the import and export trade series.

The quick response raises the question whether the negative consequences of "harmful rumors," misinformation and consumer perceptions are more important in the slow recovery than damaged input supply and decreased production. Bachev and Ito (2017: p. 34) consider that harmful rumors had the leading role in the slow recovery. They find that 35% of the country's food companies were still negatively affected at the beginning of 2014. Our research adds to this conclusion, by showing that, for most agri-food product categories, there is a consistent post-disaster rise in exports and drop in imports. For many product categories, the rise (drop) in exports (imports) is complemented with structural changes that signify the positive change in the series trend (increases in exports, decreases in imports). Hence, the road to recovery started soon after the disasters. The quick recovery of the series trends and the consistency in the trends for both imports and exports suggest that it was mainly in the immediate post-disaster period when negative impacts were felt. The leading role for the impact on the agri-food sector is held by physical destruction and damaged inputs while misinformation seems to be merely slowing down the return to normality.

In terms of policy, these results imply that domestic efforts to convince consumers about the safety of products were for the most part positively embraced. Domestic consumers, who were directly affected by the nuclear disaster, were better informed, and had a better understanding of real dangers, of the effectiveness of inspections and product safety. That is the reason that for most import series we observe only a short-term increase in imports related to the destruction of capital and a subsequent drop that in some cases is complemented by a structural break. These results show that, on a domestic level, harmful rumors about radioactivity did not permanently impact consumption levels. Moreover, imports were not uniformly affected, suggesting the need for product category policy adjustments.

Similarly, on the export side, our analysis shows that not all exports were uniformly affected but, moreover, that not all products showed structural changes immediately after 2011. For many product categories, exports returned to pre-disaster levels, gaining momentum with an increasing trend immediately after the triple disaster. Harmful rumors and misperceptions did not dominate over announcements about product safety. Although for many categories of agri-food exports, some type of surveillance measures by a few number of countries are still imposed, those countries did not result in a negative long-term impact on the total level of exports. Our results suggest that consumer perceptions in destination countries gradually reversed after the lifting of surveillance measures.

5. Conclusions

We examined the exports and imports of agri-food products for Japan for the presence 3 structural breaks, using the methodology of Kapetanios (2005). Our analysis, conducted through an endogenous examination of the structural stability of a time series, allows policy formulation to concentrate on trade series that present permanent and negative changes in their evolution. For most of the cases examined, changes in the evolution of the series were observed mainly in the short-run. Two-digit HS analysis indicated large variability in the estimated break dates; many product categories did not show drastic changes after the triple disaster and a small number of products with structural breaks were, however, on the recovery side of the time series examined.

The Japanese government promptly responded to the impacts of the GEJE in order to prevent further damages to the economy. The effectiveness of the response was not only observed in agri-food trade values but also in financial and currency markets that by June of 2011 had recovered one third of their losses, the industrial sector where reconstruction led to a minimization of long-term impacts with a 99.1% recovery in activity, households and business through approvals of supplementary budgets, liquidity (Fujita *et al*., 2012), and energy supply disruptions. However, further addressing policy gaps and highlighting new policies for disaster management is important for successful response and crisis prevention. The successful alleviation of harmful rumors can play an important role in the composition of demand. Information seems to be the key towards the quick recovery of consumption and exports, especially for products that allow a higher degree of preservation, and for increasing exports and alleviating any safety concerns still affecting foreign consumption levels. Import patterns and communication of domestic policy with respect to inspections and product safety can serve as an example to formulate communication strategies in target countries. The International Atomic Energy Committee has placed a special emphasis on proactive and timely communication of the Government of Japan and TEPCO with the public on matters relevant to public concerns such as disclosing data and information in an easy-to-understand manner on a regular basis, explaining the potential impact, health and safety concerns for the public and the environment. Further support for the importance of information comes from past experience and the Chernobyl Forum Health Experts of the World Health Organization, who conclude that timely and accurate communication of information to the public is most important (WHO, 2006). Timely information was the communication strategy selected by Japanese government (FPG, 2016).

Future research concentrates on extending the analysis by destination countries and on separating the results by afflicted areas in Japan to consider the proximity to the Fukushima nuclear power plant as well as the severity of radionuclide deposits. Furthermore, a structural gravity approach towards estimation of the impact of the triple disaster on the values of agri-food trade for the Japanese economy is on the way, one which will allow us to discuss the ceteris paribus effects of the triple disaster on export values.

JEL Classifications: F10, F14, Q17, C10

Compliance with ethical standards: Declarations of interest: none.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Bachev, H. and F. Ito (2014) Implications of Fukushima Nuclear Disaster for Japanese Agri-Food Chains, *International Journal of Food and Agricultural Economics* 2(1): 95–120. https://doi.org/10.22004/ag.econ.163713.

Bachev, H. and F. Ito (2017) Agricultural Impacts of the Great East Japan Earthquake – Six Years Later. https://ssrn.com/abstract=2977972 or http://dx.doi.org/10.2139/ssrn.2977972.

Banerjee, A., R. L. Lumsdaine, and J. H. Stock (1992) Recursive and Sequential Tests of the Unit-root and Trend-break Hypothesis: Theory and International Evidence, *Journal of Business and Economic Statistics* 10(3): 271–288. https://doi.org/10.2307/1391542.

Dickey, D. and W. A. Fuller (1979) Distribution of the Estimators for Autoregressive Time Series with a Unit-root, *Journal of the American Statistical Association* 74: 427–431. https://doi.org/10.2307/2286348.

Dickey, D. and W. A. Fuller (1981) Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root, *Econometrica* 49(4): 1057–1072. https://doi.org/10.2307/1912517.

Evrard, O., P. J. Laceby, and A. Nakao (2019) Strategies and Effectiveness of Land Decontamination in the Region Affected by Radioactive Fallout from the Fukushima Nuclear Accident: A Review, *Soil* 5(2): 333–350. https://doi.org/10.5194/soil-2019-43.

FPG, Fukushima Prefectural Government (2016) Steps for Revitalization in Fukushima, http://www.pref.fukushima.lg.jp/uploaded/attachment/233344.pdf (accessed on April 4, 2019).

Fujita, M., N. Hamaguchi, and J. Sagara (2012) Cluster 6. The Economics of Disaster Risk, Risk Management, and Risk Financing – Earthquake Risk Insurance, Global Facility for Disaster Reduction and Recovery, The World Bank, https://www.recoveryplatform.org/outfile.php?id=921&href=https://www.recoveryplatform.org/assets/publication/GFDRR/drm_kn6-2.pdf (accessed on April 4, 2019).

Gomez-Zaldivar, M., D. Ventosa-Santaularia, and F. H. Wallace (2013) The PPP Hypothesis and Structural Breaks: The Case of Mexico, *Empirical Economics* 45: 1351–1359. https://doi.org/10.1007/s00181-012-0653-6.

Government of Japan (2012) Road to Recovery, http://www.kantei.go.jp/foreign/policy/documents/2012/__icsFiles/afieldfile/2012/03/07/road_to_recovery.pdf (accessed on April 4, 2019).

Herzer, D., D. F. Nowak-Lehman, and B. Soliverstovs (2006) Export-Led Growth in Chile: Assessing the Role of Export Composition in Productivity Growth, *The Developing Economies* 44(3): 306–328. https://doi.org/10.1111/j.1746-1049.2006.00019.x.

Johnson, R. (2011) Japan's 2011 Earthquake and Tsunami: Food and Agriculture Implications, Congressional Research Service, https://www.everycrsreport.com/reports/R41766.html.

Kajitani, Y., S. E. Chang, and H. Tatano (2013) Economic Impacts of the 2011 Tohoku-Oki Earthquake and Tsunami, *Earthquake Spectra* 29(S1): S457-S478.

Kapetanios, G. (2005) Unit-root Testing against the Alternative Hypothesis of Up to *m* Structural Breaks, *Time Series Analysis* 26(1): 123–133. https://doi.org/10.1111/j.1467-9892.2005.00393.x.

Lee, J. and M. C. Strazicich (2003) Minimum Lagrange Multiplier Unit-root Tests with Two Structural Breaks, *Review of Economics and Statistics* 85(4): 1082–1089. https://doi.org/10.1162/003465303772815961.

Lee, J. and M. C. Strazicich (2013) Minimum LM Unit-Root Test with one Structural Break, *Economics Bulletin* 33(4): 2483–2492. https://EconPapers.repec.org/RePEc:ebl:ecbull:eb-13-00296.

Liou, Y., H. Sha, T. Chen, T. Wang, Y. Li, Y. Lai, M. Chiang, and L. Lu (2012) Assessment of Disaster Losses in Rice Paddy Fields and Yield after Tsunami Induced by the 2011 Great East Japan Earthquake, *Journal of Marine Science and Technology* 20(6): 618–623.

Lumsdaine, R. L. and D. H. Papell (1997) Multiple Trend Breaks and the Unit-root Hypothesis, *Econometrica* 64(2): 413–430. https://doi.org/10.1162/003465397556791.

MAFF (2012) FY2011 Annual Report on Food, Agriculture and Rural Areas in Japan, Ministry of Agriculture, Forestry and Fisheries, https://www.maff.go.jp/j/wpaper/w_maff/h23/pdf/e_all.pdf (accessed on April 4, 2019).

MAFF (2019) Lifting of the Import Restrictions on Japanese Foods Following the Accident of Fukushima Daiichi Nuclear Power Plant (54 Countries and Regions), December 2019, Food Industry Affairs Bureau, Ministry of Agriculture Forestry and Fisheries.

Mathieu, A., M. Kajino, I. Korsakissok, R. Perillat, D. Quelo, A. Querel, O. Saunier, T. T. Sekiyama, Y. Igarashi, and D. Didier (2018) Fukushima Daiichi-Derived Radionuclides in the Atmosphere, Transport and Deposition in Japan : A Review, *Applied Geochemistry* 91: 122–139.

MEXT (2011) Results of the Fourth Airborne Monitoring Survey by MEXT, http://radioactivity.nsr.go.jp/en/contents/4000/3179/24/1270_1216.pdf (accessed on April 4, 2019).

Mori, N., T. Takahashi, T. Yasuda, and H. Yanagisawa (2011) Survey of 2011 Tohoku Earthquake Tsunami Inundation and Run-up, *Geophysical Research Letters* 38(7).

Nakanishi, T. and K. Tanoi, eds. (2013) *Agricultural Implications of the Fukushima Nuclear Accident,* Springer.

Narayan, P. K., S. Popp, and H. A. Ahmed (2015) Is the Efficient Market Hypothesis Day-of-the-Week Dependent? Evidence from the Banking Sector, *Applied Economics* 47(23): 2359–2378. https://doi.org/10.1080/00036846.2015.1005828.

Perron, P. (1989a) The Great Crash, the Oil Price Shock and the Unit-root Hypothesis, *Econometrica* 57 (6): 1361–1401. https://doi.org/10.2307/1913712.

Perron, P. (1989b) Further Evidence on Breaking Trend Functions in Macroeconomic Variables, *Journal of Econometrics* 80(2): 355–385. https://doi.org/10.1016/S0304-4076(97)00049-3.

Perron, P. and T. J. Vogelsang (1992a) Testing for a Unit-root in a Time Series with a Changing Mean: Corrections and Extensions, *Journal of Business and Economic Statistics* 10 (4): 467–470. https://doi.org/10.2307/1391823.

Perron, P. and T. J. Vogelsang (1992b) Nonstationarity and Level Shifts with an Application to Purchasing Power Parity, *Journal of Business and Economic Statistics* 10 (3): 301–320. https://doi.org/10.2307/1391544.

Perron, P. (1994) Trend, Unit-root and Structural Change in Macroeconomic Time Series, in B. B. Rao, ed., *Cointegration for the Applied Economist*, New York: Mac Millan Press.

Perron, P. (1997) Testing for a Unit-Root in a Time Series with a Changing Mean, *Journal of Business & Economic Studies* 8 (2): 153–162.

Perron, P. and T. J. Vogelsang (1998) Additional Tests for a Unit Root Allowing for a Break in the Trend Function at an Unknown Time, *International Economic Review* 39 (4): 1073–1100.

Rehdanz, K., H. Welsch, D. Narita, and T. Okubo (2015) Well-Being Effects of a Major Natural Disaster: The Case of Fukushima, *Journal of Economic Behavior and Organization* 116: 500–517.

Schwert, G. W. (1989) Tests for Unit Roots: A Monte Carlo Investigation, *Journal of Business and Economic Statistics* 7 (2): 147–159. https://doi.org/10.2307/1391432.

Steinhauser, G. (2014) Fukushima's Forgotten Radionuclides: A Review of the Understudied Radioactive Emissions, *Environmental Science Technology* 48 (9): 4649–4663. https://doi.org/10.1021/es405654c.

Tang, C. F. (2011) Multivariate Granger Causality and the Dynamic Relationship between Health Care Spending, Income and Relative Price of Health Care in Malaysia, *Hitotsubashi Journal of Economics* 52 (2): 199–214.

Teng, J. Z. and Q. Liang (2010) Reassessment of the Finance-Growth Nexus in the Presence of Structural Breaks, *Applied Economics* 42 (8): 977–988. https://doi.org/10.1080/00036840701721059.

Todo, Y., K. Nakajima, and P. Matous (2015) How Do Supply Chain Networks Affect the Resilience of Firms to Natural Disasters? Evidence from the Great East Japan Earthquake, *Journal of Regional Science* 55 (2): 209–229. https://doi.org/10.1111/jors.12119.

Vaughan, D. (2013) An Analysis of the Process of Disinflationary Structural Change: The Case of Mexico, Working Paper, 2013–12.

WHO, World Health Organization (2006) Health Effects of the Chernobyl Accident and Special Health Care Programmes, http://www.who.int/ionizing_radiation/chernobyl/who_chernobyl_report_2006.pdf (accessed on April 4, 2019).

Yamaguchi, N., I. Taniyama, T. Kimura, K. Yoshioka, and M. Saito (2016) Contamination of Agricultural Products and Soils with Radiocesium Derived from the Accident at TEPCO Fukushima Daiichi Nuclear Power Station: Monitoring, Case Studies and Countermeasures, *Soil Science and Plant Nutrition* 62(3): 303–314. https://doi.org/10.1080/00380768.2016.1196119.

Yasutaka, T. and W. Naito (2016) Assessing Cost and Effectiveness of Radiation Decontamination in Fukushima Prefecture, Japan, *Journal of Environmental Radioactivity* 151(2): 512–520. https://doi.org/10.1016/j.jenvrad.2015.05.012.

Zhang, H., C. Dolan, S. M. Jing, J. Uyimleshi, and P. Dodd (2019) Bounce Forward: Economic Recovery in Post-Disaster Fukushima, *Sustainability* 11(23): 6736. https://doi.org/10.3390/su11236736.

Zivot, A. and W. K. Andrews (1992) Further Evidence on the Great Crash, the Oil Price Shock, and the Unit-root Hypothesis, *Journal of Business and Economic Statistics* 10(3): 251–270. https://doi.org/10.2307/1391541.

(Received April 4, 2019; accepted October 14, 2020)

Appendix

Table A1. Definition of second level HS categories of agri-food products 1 through 24

HS 2nd level cat.	Number of 6 digit products included	Description
1	23	Live animals
2	57	Meat and edible meat offal
3	91	Fish, crustaceans, molluscs, aquatic invertebrates
4	27	Dairy products, eggs, honey, edible animal product nes
5	8	Products of animal origin, nes
6	11	Live trees, plants, bulbs, roots, cut flowers, etc.
7	60	Edible vegetables and certain roots and tubers
8	54	Edible fruit, nuts, peel of citrus fruit, melons
9	29	Coffee, tea, mate and spices
10	15	Cereals
11	29	Milling products, malt, starches, inulin, wheat gluten
12	41	Oil seed, oleagic fruits, grain, seed, fruit, etc.
13	12	Lac, gums, resins, vegetable saps and extracts
14	8	Vegetable plaiting materials, vegetable products nes
15	44	Animal, vegetable fats and oils, cleavage products, etc.
16	25	Preparations of meat, of fish or of crustaceans, molluscs or other aquatic invertebrates
17	16	Sugars and sugar confectionery
18	11	Cocoa and cocoa preparations
19	18	Cereal, flour, starch, milk preparations and products
20	49	Vegetable, fruit, nut, etc. food preparations
21	14	Miscellaneous edible preparations
22	18	Beverages, spirits and vinegar
23	23	Residues, wastes of food industry, animal fodder
24	9	Tobacco and manufactured tobacco substitutes

Note: Author's estimates using UN Comtrade Data. nes: not elsewhere specified.

Table A2. Estimated coefficient of test equation for exports

$$y_t=\mu_0+\mu_1 t+a y_{t-1}+\sum_{i=1}^{k}(\gamma_i \Delta y_{t-i})+\sum_{j=1}^{m}(\varphi_j DU_{j,t})+\sum_{j=1}^{m}(\psi_j DT_{j,t})+u_t$$

Series	$\hat{\mu}_0$	$\hat{\mu}_1$	$\hat{a}$	$\hat{k}$	$\hat{\varphi}_1$	$\hat{\psi}_1$	$\hat{\varphi}_2$	$\hat{\psi}_2$	$\hat{\varphi}_3$	$\hat{\psi}_3$	Time of dominant change
(1)	36.44***	0.11**	−1.79***	13	−1.15***	−0.08*	−1.48***	−0.1**	0.26	0.1***	2-Sep-14
(2)	1.89	0.63**	0.31**	13	0.36***	−0.03*	−0.09	0.03**	−0.94***	−0.62**	3-Jun-12
(3)	12.09***	0	0.34***	13	0.08	0.01*	0	0	0.18**	−0.01	3-Apr-14
(4)	31.61***	0.09*	−1.23***	13	0.21*	0.09***	−1.18***	−0.21**	0.69***	0.08	2-Jun-12
(5)	43.1***	0.08**	−1.97***	13	0.86	−0.16*	−1.93***	−0.02	1.74***	0.14***	2-Mar-15
(6)	49.4***	0.18***	−2.51***	13	−0.74***	0.06***	−0.89***	−0.08***	−0.74***	−0.12***	2-Mar-12
(7)	15***	0.01***	−0.11***	10	−0.47***	0.08***	1.15***	0	0.09	−0.09***	1-Jan-10
(8)	32.51***	0.09*	−1.17***	13	−0.21	−0.17***	−1.86***	0.04	−1.84***	0.08	**2-Apr-11**
(9)	26.08***	−0.48**	−0.24**	13	0.49***	0.5	0.02	−0.01	0.21***	0.01*	1-Jan-11
(10)	43.82***	0.72***	−3.27***	13	−1.68***	0.1	−0.29	−0.64***	−1.86***	−0.09***	3-Jan-12
(11)	17.75***	−0.08	−0.07***	13	−0.32***	−0.04	−0.13***	0.01***	0.43***	0.12	**3-Mar-11**
(12)	42.07***	0.18***	−1.85***	13	−0.24***	−0.02	0.11*	0.02***	−0.27***	−0.16***	3-Feb-12
(13)	8.12***	−0.03***	0.46***	10	0.28***	−0.02**	0.89***	0	0.15	0.03**	2-Apr-12
(14)	9.29***	0.42***	−0.31***	9	0.77***	−0.04*	1.06***	−0.43***	−0.14	0.06***	2-Jan-15
(15)	17.17***	−0.1*	0.04***	13	−0.13	−0.03	0.27	0.13**	−0.26***	0.01**	**3-May-11**

Table A2. Continued

Series	$\hat{\mu}_0$	$\hat{\mu}_1$	$\hat{a}$	$\hat{k}$	$\hat{\varphi}_1$	$\hat{\phi}_1$	$\hat{\varphi}_2$	$\hat{\phi}_2$	$\hat{\varphi}_3$	$\hat{\phi}_3$	Time of dominant change
(16)	18.09***	0.07	−0.1***	13	−0.21**	−0.01	0.19	−0.07	−0.17*	0.02	1-Aug-10
(17)	11.76***	0.12**	0.13***	13	−0.2	−0.12**	−0.24***	0.01	0.19***	−0.01	2-Feb-16
(18)	29.27***	0.13***	−1.13***	13	−0.23*	−0.07	−0.28**	−0.03	−0.27***	−0.02	2-Dec-12
(19)	14.43***	−0.04	0.21***	13	−0.16***	0	0.12	0.05	0.16***	−0.02***	1-Jul-11
(20)	1.85	−0.02	0.94	13	−0.44***	0	−0.02	0.02	0.02	−0.01**	1-Sep-11
(21)	12.34***	−0.01**	0.33***	13	0.09**	0	0.08	0.01	−0.11**	0	3-Sep-15
(22)	10.16***	−0.05***	0.48***	13	−0.11**	−0.07***	−0.04	0.02***	0.05	0.1***	1-Feb-13
(23)	11.12***	0.34	−0.02***	9	0.18***	0	0.92***	−0.33*	−0.3***	−0.01**	2-Dec-12
(24)	16.13***	0.07*	−0.01***	12	−0.54***	0.05***	−0.26	−0.09**	0.27*	−0.07***	1-Dec-10

Note: Author's estimates. * indicates significance at α = 0.1, ** significance at α = 0.05 and *** significance at α = 0.001. The last column indicates first the number of the break where the dominant change is noted and next the date.

Table A3. Estimated coefficient of test equation for imports

$$y_t=\mu_0+\mu_1 t+a y_{t-1}+\sum_{i=1}^{k}(\gamma_i \Delta y_{t-i})+\sum_{j=1}^{m}(\varphi_j DU_{j,t})+\sum_{j=1}^{m}(\psi_j DT_{j,t})+u_t$$

Series	$\hat{\mu}_0$	$\hat{\mu}_1$	$\hat{a}$	$\hat{k}$	$\hat{\varphi}_1$	$\hat{\psi}_1$	$\hat{\varphi}_2$	$\hat{\psi}_2$	$\hat{\varphi}_3$	$\hat{\psi}_3$	Time of dominant change
(1)	30.09***	0.4***	−1.22***	13	−0.39***	0	−0.6***	0.01	−0.22	−0.39***	2-Aug-10
(2)	15.72***	0.01	0.23***	13	−0.23***	0.02*	−0.15***	0**	−0.21***	−0.02***	1-May-15
(3)	26.16***	0.04***	−0.32***	13	−0.1***	−0.01	−0.02	0.02***	−0.11**	−0.05***	3-Dec-12
(4)	10.59***	−0.18	0.61***	13	−0.38**	0.18	−0.07	0.02***	0.15***	0	1-Nov-15
(5)	19.1***	0.05	−0.15***	13	0.34**	−0.02	−0.28***	0	−0.03	−0.03***	1-Nov-14
(6)	19.79***	0.17***	−0.31***	13	0.1***	−0.02***	0.06***	0.01***	−0.01	−0.17***	3-May-12
(7)	10.79***	0.01**	0.43***	13	0.06**	0	−0.1***	−0.01**	−0.13***	0	3-Feb-16
(8)	31.35***	0.15***	−0.8***	13	0.27*	−0.14***	−0.11***	−0.01***	−0.1***	0.01***	1-Dec-12
(9)	10.21***	0.01	0.44***	13	−0.01	0	0.07	0.03	−0.12***	−0.04	3-Nov-15
(10)	20.09***	0.06*	−0.07***	13	−0.11**	0.01***	0.34***	−0.07**	0.17***	−0.01	2-Jul-12
(11)	27.98***	−0.55***	−0.14***	13	−0.14***	0	0.45***	0.56***	−0.13***	−0.01**	2-Oct-14
(12)	19.24***	−0.03	0.07***	13	0.21***	0.02	0.19***	0	−0.03	0.01***	1-Jun-12
(13)	29.93***	0.04*	−0.82***	13	−0.12*	0	0.45***	−0.04**	−0.18***	0	2-Jan-15
(14)	20***	0.03*	−0.31***	13	−0.12	−0.04**	−0.34***	0.03***	−0.28***	0.02***	2-Feb-14
(15)	10.69***	−0.01*	0.46***	13	−0.13***	0*	−0.23***	−0.03**	−0.13	0.04***	2-Apr-12
(16)	19.31***	0.02**	0.01***	13	−0.14***	−0.01	−0.05*	0.01***	−0.12***	−0.02***	1-Aug-15
(17)	23.46***	0.03	−0.33***	13	0.3***		0.56***	−0.04	−0.17**	0	2-Sep-14
(18)	13.1***	0	0.29***	13	0.12**	0	0.3***	0.03***	0.1	−0.03***	1-Jul-13
(19)	7.8***	0***	0.59***	13	−0.08**	0.01	0.02	0	0.05	0	1-Jul-14
(20)	17.88***	0.01**	0.08***	13	0.12***	−0.01	−0.08**	0.01***	−0.14***	−0.01	3-Jul-13
(21)	9.19***	0.13***	0.39***	13	−0.08**	0	−0.04	0	−0.36***	−0.13***	3-Nov-14
(22)	15.65***	0.04	0.15***	13	0.15***	0.03	−0.1***	0	0.38***	−0.07	3-Apr-11
(23)	17.13***	−0.11	0.17***	12	0.52***	0.11	−0.18**	0.01	−0.18***	−0.02	1-Jul-14
(24)	15.59***	−0.07*	0.29***	13	−0.27*	−0.04	−0.19*	0.02***	0.37	0.09***	1-Jul-14

Note: Author's estimates. * indicates significance at α = 0.1, ** significance at α = 0.05 and *** significance at α = 0.001. The last column indicates first the number of the break where the dominant change is noted and next the date.