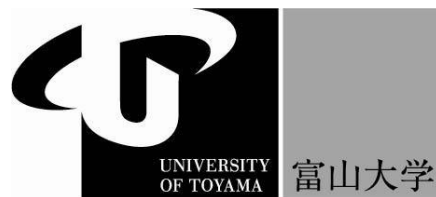


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Risk?: Evidence from the 2011 Disaster in Japan**

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How Do Agricultural Markets Respond to Radiation Risk? Evidence from the 2011 Disaster in Japan*

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Abstract

Since the explosion of the Fukushima Daiichi Nuclear Power Plant in March 2011, public anxiety surrounding the radioactive contamination of food and the environment has become widespread. This article examines how the price of vegetables in the Tokyo Metropolitan Central Wholesale Market was impacted in the wake of the nuclear accident. This study exploits the quasi-experimental condition generated by this accident to test the market price change using monthly panel data on the price of six types of fresh vegetable from each of the 47 prefectures in Japan. Our estimation results show that the price of vegetables grown in Fukushima Prefecture was discounted by 10 - 38 % after the disaster compared to the counter-factual estimates in the absence of a perceived radiation risk. This effect has persisted even after radioactive detection tests showed negative results in subsequent years. Consumer behavior of avoiding purchasing vegetables from Fukushima and instead buying vegetables grown in other areas may explain the price gap.

JEL Code: Q13, Q51, Q53, R11

Key Words: Food Safety; Radiation; Hedonics; Fukushima; Tokyo

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1 Introduction

The Great East Japan Earthquake on March 11, 2011, the tsunami that followed, and the resulting accident at the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Plant (NPP) caused devastating socioeconomic damage to Eastern Japan. Soon after the nuclear power plant accident, public anxiety surrounding the radioactive contamination of food and the environment became widespread.

In this article, the price of six types of fresh vegetables (asparagus, bean sprouts, broccoli, cucumbers, green beans and tomatoes) is used to examine how the actual pricing of agricultural produce in the wholesale market in Tokyo, which is the largest consumption center for agricultural produce from Eastern Japan, was impacted in the wake of the nuclear accident. If urban consumers fear that food produced in or near Fukushima is more likely to contain radioactive materials and thus to be more harmful to their health, they would avoid purchasing those products and instead buy substitutes produced in areas distant from Fukushima. Since 2000, Japanese agricultural regulations have mandated that agricultural produce should be labeled with the site of origin and that this information should be made available to consumers. We use this information to assess the market reaction to radiation risk under the shock of the Fukushima Daiichi NPP accident.

In addition to the practical importance of assessing the impact of this nuclear disaster (the largest in scale) on agricultural markets, the use of agricultural price data makes a novel contribution to the hedonic environmental valuation literature by assessing urbanites' perception of environmental risks. Unlike houses, vegetables are transported from the site of origin and delivered to consumer locations. This mobility allows us to assess urban consumers' risk perception (willingness to accept the risk) toward an environmental hazard originating at a distant location. The large number of transactions in the urban consumption center and the mobility allow their hedonic price functions to follow those of differentiated products (Rosen

1974, Epple 1984). In addition, the perishable nature of fresh vegetables allows our analysis to focus on short-term risk perception, whereas house prices are subject to expectations in response to future environmental changes (Kiel and McClain 1995; Gayer and Viscusi 2002; Tajima 2003).

In this study, we analyze monthly panel data on the mean price (monthly average of auction prices per kilogram) of six types of vegetables traded in the Tokyo Metropolitan Central Wholesale Market from January 2006 to March 2015. Monthly price data are available at the level of 47 Japanese prefectures, allowing us to estimate the marginal effect of the perceived radiation risk on the market price before and after the nuclear accident, exploiting the quasi-experimental condition generated by the nuclear accident. The estimation results show that having been grown in Fukushima Prefecture emerges as a new factor that decreased the value of vegetables traded in the Tokyo wholesale market by 10-38 percent. The proximity of the neighboring prefectures and the Fukushima Daiichi NPP has a relatively small influence on the price of vegetables.

The rest of the article is organized as follows. Section 2 reviews the hedonic studies of environmental hazards and food safety. Section 3 provides the background for this disastrous event. Section 4 presents our theoretical and econometric models and describes the data, and Section 5 summarizes the empirical results. Section 6 concludes and provides policy implications.

2 Literature

This study builds on the intersection of two distinct lines of research that use the hedonic pricing method: (1) studies that examined the impact of proximity to environmentally hazardous sites on local housing prices and (2) studies that measured the effects of health benefits or risks on the price of agricultural products. Recent studies that aimed to measure the impact of the Fukushima nuclear accident are also reviewed with respect to these lines of research.

Urban and environmental economists have long used the hedonic pricing method to estimate the risk perception associated with environmental hazards. The majority of the literature uses local housing transaction data as well as repeated sales data to single out the effects of risks originating from hazardous waste sites (Kohlhase 1991, Kiel 1995, Kiel and McClain 1995, Gayer and Viscusi 2002, Greenstone and Gallagher 2008). Naoi, Seko and Sumita (2009) analyzed rents and owner-provided value for houses in a household panel survey to show that risk perception toward earthquakes experienced upward revision after major earthquakes. Other studies analyzing the impact of spent nuclear waste used their transportation route (rail track) and proximity to assess their impact on local housing prices (Gawande and Jenkins-Smith 2001, Gawande et al. 2013). The basis for using house prices is that these are fixed in specific locations, as is the source of environmental hazards, and a clear relationship can be established between them through their geographical proximity. These relationships are represented in econometric models as a distance or a dummy variable to indicate the likelihood of environmental risk in a particular area.

Recent studies have contributed to the above-mentioned literature by addressing the impacts of the Fukushima nuclear disaster. The immediate impacts of radioactive contamination on appraised land prices (Yamane, Ohgaki and Asano 2013) and market transaction land prices (Kawaguchi and Yukutake 2014) were estimated using a hedonic pricing framework and findings demonstrate that the actual contamination level reduced the land price significantly.

Researchers outside of Japan tested whether the Fukushima nuclear disaster increased the risk perception of consumers toward nuclear power plants. Using a difference-in-difference hedonic approach, Fink and Stratmann (2013) did not find a revision (discount) of house prices in areas located near nuclear power plants in the United States. In contrast, Boes, Nüesch and Wüthrich (2014) find a 2.3% discount in advertised apartment rents near nuclear power plants in Switzerland after the Fukushima accident, and Zhu et al. (2014) find a short-term (one month after the Fukushima disaster) but significant reduction in land transaction

price within 40km from active nuclear plants in China.

Food and agricultural economists have applied the hedonic pricing method to estimate the effects of various characteristics of vegetables, such as size, color, ripeness, and taste, on their retail price (Huang and Lin 2007). This technique has also been used to estimate the loss of value associated with potential health risks or the price premium associated with avoided pesticide risks for organic foods (Estes and Smith 1996, Thompson and Kidwell 1998, Maguire, Owens et al. 2004, Lin, Smith et al. 2008), the reduced price of genetically modified organisms (Loureiro and Hine 2004), and the price reduction for milk produced from cloned cows (Brooks and Lusk 2010). Asche and Guillen (2012) addressed the negative effects of certain sites of origin on the market prices of frozen fish (Spanish hake) and attributed these to general environmental concerns of consumers that could not be ascribed to a particular hazard source. Most of this literature uses individual purchases at retail stores as the unit of analysis based on field surveys or the use of scanner data. These trade variables are complemented by identifiers of the purchaser's characteristics (typically age, gender, income, education and household attributes, such as if they live with young children) to analyze the role of these attributes in purchasing decisions. Our empirical method is based on the literature described above. However, the use of monthly prefecture-level data on wholesale price and quantity requires a unique approach, such as the use of a panel estimation model, to address the aggregated nature of our data.

In the wake of the Fukushima accident, a significant number of Japanese scholars addressed the impacts of radioactive food risks or the public anxiety associated with these risks. Ujiie (2013) analyzed consecutive questionnaire surveys that were conducted every four months after the earthquake to estimate consumers' willingness to accept (WTA) or buy produce (spinach and milk) from Fukushima and Ibaraki Prefectures¹. He then estimated the contribution of "health risk due to radioactive contamination" and the "origin of the food." The

¹Ibaraki Prefecture is adjacent to Fukushima Prefecture to the south.

results suggested that consumers' aversion to agricultural food due to fear of contamination remained strong two years after the nuclear accident. The level of aversion was higher for the respondents living in Western Japan (Osaka) compared with Eastern Japan (Tokyo). In addition, Ujiie (2014) suggested that the demand for food produced in "distant" areas was rising among major retailers.

Other researchers addressed these issues using stated-preference economic studies, such as choice experiments (Kuriyama 2012), conjoint surveys, and other forms of consumer survey. Most studies obtained consistent results that suggested prevalent lower willingness to pay for fresh food produced in the disaster-affected areas in the wake of the nuclear disaster. Yoshino (2013) examined actual market price data to estimate the losses due to price reduction after the nuclear incident. He estimated the typical yearly price gaps in the years prior to the nuclear accident and compared the result with the actual price difference after the accident. Although this approach is suitable for estimating the aggregate welfare loss, it does not allow us to compare the change in consumer behavior before and after the crisis. Kikuchi (2013) compares the price of vegetables produced in Fukushima Prefecture in the Tokyo Wholesale Market to the average prices over four years prior to the nuclear accident. He finds that most vegetables produced in Fukushima lost both their value and their share in the Tokyo market after the nuclear accident, and this trend worsened in the second year compared to the first.

3 Background

3.1 The Great East Japan Earthquake

On the afternoon of March 11, 2011, the largest-magnitude earthquake ever recorded in Japan struck the eastern part of the country (known as the Tohoku area). Its effects were particularly strong in the region adjacent to the Pacific Ocean. The epicenter of the earthquake was only 70 km away from Sendai city, the largest city in the Tohoku area (see Figure 1), and magnitude of 9.0 meant it was the world's fifth largest earthquake in the last 100 years.

////////// *Insert Figure 1 around here* //////////

It was not the earthquake itself but the resulting tsunami that caused the majority of the damage. Although rescue teams were dispatched from 29 countries and international organizations, the number of casualties totaled more than 15,000. The tsunami exacerbated the damage by striking the Fukushima Daiichi Nuclear Power Plant. Losing electricity to support all means of cooling, the nuclear reactors in the plant, none in operation but all containing spent nuclear fuel, exploded (phreatic explosion), and a large amount of radioactive material was released into the air.² Figure 2 depicts the change in the aerial radiation dose in four cities including Fukushima city, which is 65 km away from the nuclear plant, and farther locations shown in Figure 1. A significant increase of radiation dose occurred immediately after the phreatic explosion but declined sharply within the next few days.³

////////// *Insert Figure 2 around here* //////////

Because the wind direction was mainly to the South, Ibaraki Prefecture, which is adjacent to the south of Fukushima, was exposed to a higher risk of radioactive material fall-out. The dose level of Ibaraki Prefecture only recently returned to normal, whereas Tokyo returned its normal level within several months. Hokkaido and most of Western Japan were not affected in terms of their aerial radiation dose. Soon after the earthquake, it became common to see information on aerial radiation doses at the prefectural level in the media on a daily basis. Repeated exposure to this type of information might have created a new perception of risk for Japanese consumers.

3.2 Food Safety Measures and Consumers' Risk Perception

To address public anxiety, the Japanese Ministry of Health, Labor and Welfare (MHLW) adopted provisional regulations on the level of radioactive substances in foods on March 17,

²This incident was recorded as level 7 in the International Nuclear Event Scale (INES) determined by IAEA. It is the second level 7 event in history. The first level 7 event was the Chernobyl disaster.

³The data for Fukushima in Figure 2 have many gaps due to the loss of electricity. After the emergency electric supply was exhausted, the data record was no longer available.

2011. These regulations designate the maximum permissible dose of radioactive substances for each food category; the value for radioactive cesium in general food products was set at 500 Becquerel/kg or less. A smaller dose of 100 Becquerel/kg was applied in a revised regulation enacted in April 2012, approximately one year after the earthquake (Hosono et al. 2013).

To avoid distributing foods that were contaminated above the maximum permissible level of radioactive cesium, local government authorities, producers, consumer organizations, and retailers conducted intensive radiation inspections of foods produced in Eastern Japan. Foods contaminated above the permissible level were banned from market distribution, and the restriction was often extended to the community or prefectural level. The incidents of reported high-level contamination in fresh vegetables were concentrated in the first few weeks after the accident and from certain prefectures in and near Fukushima. On March 21, 2011, the Japanese government restricted distribution of spinach produced in Fukushima, Tochigi, Ibaraki, and Gunma Prefectures and two days later the restriction was extended to other leafy vegetables and flower-head brassicas (e.g., broccoli and cauliflowers) from Fukushima and two cities in Chiba Prefecture.⁴

Table 1 summarizes the results of the food tests. Regardless of the upward revision of the maximum permissible dose in April 2012, the percentage of positive results was the highest in the first year (April 2011 to March 2012). In more than 99.9% of all foods tested in recent years, any remaining radioactive cesium has been below the detectable level.

////////// Insert Table 1 around here //////////

As defined by the regulation and active radioactive detector testing, the food products distributed in the market are considered safe. However, after more than three years since the

⁴The entire list of distribution restrictions since the 2011 disaster for each prefecture is available from Ministry of Labor, Health and Welfare in English and is updated on a regular basis. See http://www.mhlw.go.jp/english/topics/2011eq/d1/food_instruction_August25_2015.pdf (Accessed on September 8, 2015)

nuclear accident, a number of reports suggest that the market demand for foods produced in or near Fukushima continues to be reduced due to fear of food contamination. A consumer monitor survey by the Japanese Food Safety Commission (2013) found that as of August 2013, more than half of their 353 monitors remained worried about food contaminated with radioactive materials; 29.5 percent were “very worried” (the highest choice in the 5-point Likert scale), and 38.0 percent were “worried” (second highest). Among those who reported to be “very worried,” 37.5 percent responded to another question that they were “avoiding eating/purchasing food that is suspected to be contaminated even though it is below the permissible level.” In response to such consumer reactions, in April 2013, a national television news program reported that food distributors assume that end-users avoid food products from Fukushima Prefecture; they cited experts stating that the initial disorder in releasing food safety information and the revision of the regulations discouraged consumers from trusting authorities, such as the Japanese government and the scientific community (Japan Broadcast Company, 2013).

The disparity between the safety standard imposed by the government and consumers’ perception may be explained by the difference in the foundation of the risk perception. The national safety standard is designated based on clinically and/or experimentally proven health risks. In this case, the threshold exposure level is 50 m Sievert/year, which is considered to be associated with the development of thyroid cancer (Michino 2012).

For general consumers, the risk is less clear. They may form risk perceptions based on their exposure to general information on radiation risks (e.g., former detector test results, aerial radiation doses), and the media may even be biased toward fear. Consumers also fear latent risks that are currently unknown. A good example of a latent risk of exposure to radioactive fallout can be drawn from a study on the subclinical legacy of Chernobyl (Almond et al. 2009). The authors compared the academic performance of Swedish students who were exposed to the radioactive fallout from the Chernobyl accidents in utero to those in adjacent

cohorts or those from areas that had less fallout exposure. Prenatal exposure to relatively high (but clinically considered harmless) radioactive doses led to lower test scores and lower rates of qualifying for high school education.

3.3 Labeling Mandate for the Site of Origin of Agricultural Produce

In response to the new risk of food contamination with radioactive substances, Japanese consumers have developed a habit of checking the site of origin when they buy agricultural produce (Food Safety Commission 2013). Labeling the site of origin for agricultural products – at the prefecture level if it is domestically produced and at the national level if imported – was mandated in 2000 in the Japanese Agricultural Standards (JAS), which are specified under the Law Concerning Standardization and Proper Quality Labeling of Agricultural and Forestry Products (Law No.175 in 1950). The site-origin labeling mandate was initially intended to give consumers references to pesticide standards, which vary among countries and regions, as well as to respond to “buy local” movements.⁵

4 The Model

4.1 Theoretical Framework

To establish the market condition to which each consumer is subjected, we should consider that the real risk is unknown to a purchaser for the following two reasons. First, the purchaser is not able to definitively know whether the particular product (i.e., the bag of cucumbers in front of him/her) is contaminated with radioactive substances because the radioactive detector test is conducted on a sampling basis. Second, although the government informs consumers of the maximum permissible dose of radioactive substances, consumers do not know exactly which level of intake would harm their health, how, and to what degree. In

⁵Should a retailer intentionally label some agricultural produce with a different site of origin (to sell it), the retailer would be charged with a violation of the JAS law and Unfair Competition Prevention Act (Act No. 47 of May 19, 1993). There are penalties for these violations, but it is rather difficult to monitor and enforce these rulings. In fact, most charges arise from reporting by employees (whistleblowers). Thus, we do not discuss this issue further and simply assume that the site of origin is properly labeled in the following analysis.

short, consumers face market decisions with highly limited information; at a retail store, the information available to the shopper is typically price, appearance (through which the shopper assesses the quantity and quality of the produce), and the growing site (labeled at the prefectural level).

Let us assume that the market price of a type of vegetable i produced in prefecture s at time t is determined as

$$p_{ist} = f(r_{ist}, X_{ist}), \quad (1)$$

where r_{ist} is the perceived risk of intake of radioactive substances embodied in vegetable i produced in s at time t , and X_{ist} is the vector of factors that may affect the market price of the vegetable other than the perceived risk of a radioactive substance.

The price gradient with respect to the perceived risk of a radioactive substance is the parameter of focus in this study. Similar to pesticide risk, perceived radiation risk is expected to discourage consumers from buying affected produce. This consumer response toward food risk can be expressed as

$$\frac{\partial p}{\partial r} < 0 \quad (2)$$

Before the Fukushima nuclear accident in March 2011, the risks associated with radioactive substances were not widely perceived in the domestic food market in Japan. In the wake of the accident, they were suddenly perceived as an immediate risk and were associated with the Fukushima Nuclear Plant location. Consumers responded to the risk by avoiding foods produced in and/or near Fukushima.

4.2 Empirical Framework

The notable issue is how to analyze the effect of the perceived radiation risk due to the accident at Fukushima Nuclear Plant on the price of vegetables. Given the lack of data on

the levels of radioactive contaminants in each vegetable in the wholesale market, we use two treatment variables discussed in detail in the Data section to denote the perceived risk, which appears as r in (1) and (2).

Using monthly-panel market price data for each type of vegetable i grown in prefecture s at time t (year-month), we use the following regression model to identify the impacts of perceived radiation risk on vegetable prices in each fiscal year after the Fukushima disaster.

$$\log(p_{ist}) = \alpha_i + X_{st}\beta_i + \sum_{j=2011}^{2014} \gamma_{ij}T_sD_j + \delta_{is} + \mu_{it} + \epsilon_{ist}, \quad (3)$$

where p_{ist} denotes the monthly average of the market trade price in Japanese yen per kilogram, and X_{st} denotes the vector of factors that may affect the market price of vegetable i produced in s at t other than the perceived risk of a radioactive substance. T_s denotes a treatment variable that proxies the perceived radiation risk. D_j is a dummy variable that equals 1 when the month falls between April of year j and March of year $(j + 1)$, where j corresponds to periods that follow the disaster: 2011, 2012, 2013, and 2014. This variable is a year-dummy that considers both the timing in relation to the occurrence of the nuclear accident shown in (2) and Japanese fiscal years that begin in April. δ_{is} and μ_{it} are fixed-effect coefficients estimated on dummy variables that denote each of 47 prefectures and 111 year-month periods. ϵ_{ist} is the residual. We take the log of prices to address the nonlinear relationship between the price and the treatment.

The inclusion of prefectural fixed effects allows us to assume that some geographical characteristics (such as transport cost to Tokyo) did not change over time. To control for exogenous market conditions that might affect the overall market price level, we also include fixed effects for each period t (year-month).

By estimating a panel OLS regression with this specification under the conditional independence assumption, one could interpret the value of γ_{ij} as the price differential with respect

to the perceived risk, because from (3) we can derive

$$\frac{\partial E[\log(p_{ist})|j = 2011, 2012, 2013, 2014]}{\partial T_s} = \gamma_{ij}. \quad (4)$$

Although one could estimate the coefficients on the interacted terms for each period t , the merit of the current form is its simplicity and more stable estimation; an intuitive interpretation of γ_{ij} would be an “annual mean of price discount” in the presence of perceived radiation risk. The expected sign of the coefficients is

$$\gamma_{ij} < 0|_{j=2011,2012,2013,2014} \quad (5)$$

This form of regression also allows us to include placebo tests by estimating the following regression and seeing if ϕ_{ij} estimated for the years before the nuclear accident are not statistically different from zero.

$$\log(p_{ist}) = \alpha_i + X_{ist}\beta_i + \sum_{j=2009}^{2010} \phi_{ij}T_sD_j + \sum_{j=2011}^{2014} \gamma_{ij}T_sD_j + \delta_{is} + \mu_{it} + \epsilon_{ist}, \quad (6)$$

Because information on individual purchases and purchasers is not available in our monthly wholesale market data, our empirical strategy aims to capture a general trend across different purchasers.⁶

4.3 Data

Our empirical analyses focus on fresh vegetables sold in the Tokyo Metropolitan Central Wholesale Market.⁷ Fresh vegetables are perishable and thus shipped and sold in a few days

⁶Our price variable is the monthly average of the auction prices determined by wholesalers and buyers (middle wholesalers and/or distributors) from the wholesale market. We assume that the buyers’ bid price is based on their short-term expectations of their retail sales.

⁷Since the “Central Wholesale Market Law” was enacted in March 1923, each prefecture has established publicly owned wholesale markets at which fresh foods are collected and distributed, prices are set through fair auctions between sellers and buyers, transaction accounts are settled, and information is provided on market trades. The Tokyo Metropolitan Government established 11 Central Wholesale Markets in various locations within its boundary to ensure fresh food for consumers (the population exceeds 13 million people); this is the largest among all Japanese prefectures. The Tokyo Metropolitan Government administers the construction of markets, maintains and manages the facilities, provides directions and supervises the handling of produce according to the Wholesale Market Law and Ordinances. Nine markets trade vegetables, and the data we use were the total values obtained from these nine markets (<http://www.shijou.metro.tokyo.jp/english/>).

after being harvested,⁸ allowing us to focus on the market's short-term risk perception. In addition, domestic produce still accounts for a major part of Japanese vegetable consumption (76% self-sufficiency ratio, based on calories), although the country is known for a small self-sufficiency ratio of only 39%⁹ for all foodstuffs (17% for meat and 37% for fruits, respectively).¹⁰

The Tokyo Metropolitan Central Wholesale Market is the largest wholesale market in Japan. According to the Production Agriculture Income Statistics from MAFF, the total revenue in all wholesale markets together in Japan is 2.2 trillion JPY in 2010 and that of the Tokyo wholesale market is about 432.8 billion JPY (19.1%). Although it is not adjacent to Tokyo, vegetables from Fukushima at the Tokyo wholesale market had a certain amount of presence before the earthquake. It was ranked 10th in terms of market share (2.6% in 2010).

The data used for our empirical analysis were obtained from the Market Trade Information Website of the Tokyo Wholesale Market.¹¹ This dataset contains variables on price (monthly mean for each site-of-origin prefecture in JPY) and quantity (monthly total in kilograms for each prefecture) during the period from January 2006 to March 2015. Our dependent variable is the price (monthly average in JPY/kg), and for estimation, we take the natural logarithm of the value.

For the following analyses, we choose six vegetables for which a significant share at the Tokyo Wholesale Market was grown in Fukushima (over 5%) before the earthquake (five-year average of the 2006-2010 period): asparagus (17%); bean sprouts (61%); broccoli (5%); cucumbers (14%); green beans (27%); and tomatoes (6%).

Ideally, we should have the level of radioactive contamination in each prefecture at each

⁸Among storable agricultural produce or produce that takes a longer time to grow (i.e., rice, wheat, tea, dried mushrooms), the actual growing period may vary among items sold at the market at the same time.

⁹This number is based on calories. See the website of the Ministry of Agriculture, Forestry and Fishery (MAFF) for more details (http://www.maff.go.jp/j/zyukyu/zikyu_ritu/pdf/26ritu.pdf).

¹⁰According to MAFF, seafood has relatively high self-sufficiency ratio (67%). However, it is difficult to discern where the seafood comes from in that the origin is determined by the seaport at which the seafood is landed (and not where it is caught), we exclude them from our analysis.

¹¹<http://www.shijou-tokei.metro.tokyo.jp/index.html>

time, but as we described in the introduction, it is hard to obtain a single variable for each prefecture that represents the level of contamination. To capture the possible risk of the radioactive contamination of vegetables in each prefecture, we apply two treatment indices: The first is a *Fukushima* dummy variable that takes 1 for Fukushima Prefecture and 0 for the other 46 prefectures. The second is a continuous variable that denotes the proximity of the production site of each vegetable to the Fukushima Daiichi NPP. This reflects that the risk of radioactive material is perceived to be larger when the production site is closer to the damaged nuclear plant. In particular, we define this variable as

$$proximity = \log \left[\frac{1}{distance} \right], \quad (7)$$

where the *distance* from each prefecture's capital city to the Fukushima Daiichi NPP is measured in kilometers.

The data for the monthly average price of vegetables are aggregated at the prefecture level, and there are no data that can be used to capture the average quality of vegetables in each prefecture. Instead, we use average temperature in degrees Celsius and its squared term as the proxy variables for the quality of each vegetable. The quality of vegetables will increase at the appropriate temperature, and extremely high or low temperatures will adversely affect it. In addition, the set of prefectural dummy and year-month dummy variables are also used as explanatory variables.

////////// Insert Table 2 around here //////////

Table 2 presents the summary statistics. The 9 years and three months (111 months) of data for the 47 prefectures should yield 5,217 observations for each type of vegetable. However, because the number of prefectures that send certain vegetables to the Tokyo wholesale market are limited and fluctuate seasonally, the actual number of observations ranges from 1,270 to 3,716.

5 Results

Table 3 shows the regression results for six vegetables in the form of (6), using the Fukushima dummy as the treatment variable. For all five types of vegetable except for tomatoes, the coefficients for the interaction of the “years after the nuclear accident” and “Fukushima”, namely γ_{ij} , are negative and statistically significant at a 99.9% significance level. In contrast, ϕ_{ij} , the interactions between “years before the accident” and “Fukushima”, are mostly statistically insignificant or positive, except for asparagus in 2010 and tomatoes in 2009.

////////// Insert Table 3 around here //////////

The coefficients and their standard errors are plotted in Figure 3 for each vegetable to see their change over time. The lines above and below the dots show the 95% confidence interval. In fiscal years 2009 and 2010, the coefficients rarely deviate from zero with statistical significance, while in 2011, all five vegetables except for tomatoes take values smaller than zero with a 95% significance level. This trend persisted for following three years.

////////// Insert Figure 3 around here //////////

With the semi-log functional form, we can interpret the value of γ as the “percentage change in the price of a vegetable in the presence of perceived risk (in this case, if it is produced in Fukushima) compared to the counterfactual case in the absence of risk during the same period.” Thus, in the 2011 fiscal year, the price change rate of asparagus from Fukushima was -18% ($=\exp[-0.196] - 1$). The same interpretations give the price change due to the risk for bean sprouts to be -38% ($=\exp[-0.48] - 1$); broccoli -25% ($=\exp[-0.29] - 1$); cucumbers -12% ($=\exp[-0.13] - 1$); and green beans -10% ($=\exp[-0.10] - 1$).

Another important finding is that the impacts on the price of these five vegetables remained significant in the three years that followed. The coefficients on the interaction terms

remained negative and significant until 2014. For cucumbers and green beans, the magnitude of the coefficient became larger in fiscal year 2012 compared to 2011.

Bean sprouts are notable for the large magnitude of their price discount as well as the standard errors. In contrast to other vegetables that are grown outside or in greenhouses with natural daylight, bean sprouts are not supposed to be exposed to sunlight (similar to alfalfa sprouts) and are grown inside, thus their production is not conditioned by weather or season. This irrelevance to weather also explains easier inter-regional substitution, which might have led to the decreased demand for the Fukushima-grown bean sprouts, resulting in the sharp drop in price after the disaster.

With tomatoes, we observe a positive price change of 19% ($= \exp[0.176] - 1$). The change is likely to be attributed to the market shortage of tomatoes in periods that followed the earthquake; because prefectures in Northeastern Japan supplies the large share in the Tokyo market during the summer season, but the earthquake, tsunami, and nuclear disaster reduced the quantity supplied from these prefectures, and the increased supply from other regions could not fully meet market demand.¹²

////////// Insert Table 4 around here //////////

Table 4 contains the estimation results using *Proximity* as a continuous treatment variable. In this estimation, the coefficients of the Treatment-Year interaction terms can be interpreted as the price elasticity with respect to proximity (inverse of distance) between the growing site and Fukushima Daiichi Nuclear Plant. For years after the nuclear disaster, the coefficients of the interaction terms for bean sprouts, broccoli, and green beans are mostly negative, but those with statistical significance at a 95% confidence level were limited to bean sprouts in FY2013 and broccoli in FY2011 and 2012. A coefficient of -0.416 for bean sprouts

¹²Kikuchi (2013) shows that the average price of all domestic tomatoes in August 2011 was 28.2% higher than the four-year average price in the same month in 2007, 2008, 2009 and 2010. For the same period, tomatoes produced in Fukushima experienced a 15.0% price increase.

in FY2013 means that the price elasticity with respect to the distance to the Fukushima Daiichi NPP is 0.42; when the distance increases by 1%, the price increases by 0.42%.

Our estimates above enable us to conclude that there is legitimate evidence of a price decline for Fukushima grown vegetables due to the nuclear disaster. There are several reasons why the market discriminates against the vegetables produced in Fukushima Prefecture. First, consumers developed new shopping behaviors to check the origin of agricultural produce in the wake of the nuclear accident and did not revise these behaviors afterwards. Whereas cesium detection cases were widely reported and left consumers with strong anxiety shortly after the disaster, current test results suggesting that this produce is safe rarely make news headlines. As a result, only consumers who are eager to collect information on radiation risks are informed with updated safety information, while other consumers are making decisions based on outdated risk perceptions.

The estimation results show that the proximity of the production area and the Fukushima Daiichi NPP has a relatively small influence on the price of vegetables. As noted in Section 3, the major portion of radioactive material fell in Fukushima and in other prefectures located to the south of Fukushima prefecture. Thus the level of radioactive contamination is not simply proportional to the distance from the NPP, and this may be one reason for the weak relation between proximity to the NPP and the price of vegetables.

6 Conclusion

For all of the vegetables we examined, the effects of the nuclear accident on the price of agricultural products grown in Fukushima Prefecture except for tomatoes were large and statistically significant, and these effects persisted for at least four years after the accident. This result is striking given that cesium contamination was rarely detected and was never above the maximum permissible level after the second year. Our estimation results also show that the impacts of the proximity of Fukushima's neighboring prefectures and the Fukushima

Daiichi NPP are much smaller both in magnitude and statistical significance.

To address issues associated with the lowered market price, food safety information must be communicated to the consumer with a strong emphasis on revising their risk perception. As noted in the overview of this article, some consumers still tend to avoid purchasing food from Fukushima regardless of its contamination level. Removing the source of their anxiety through appropriate risk communication measures is critical to fresh foods from Fukushima Prefecture regaining their market competitiveness in major consumption areas.

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A Figures

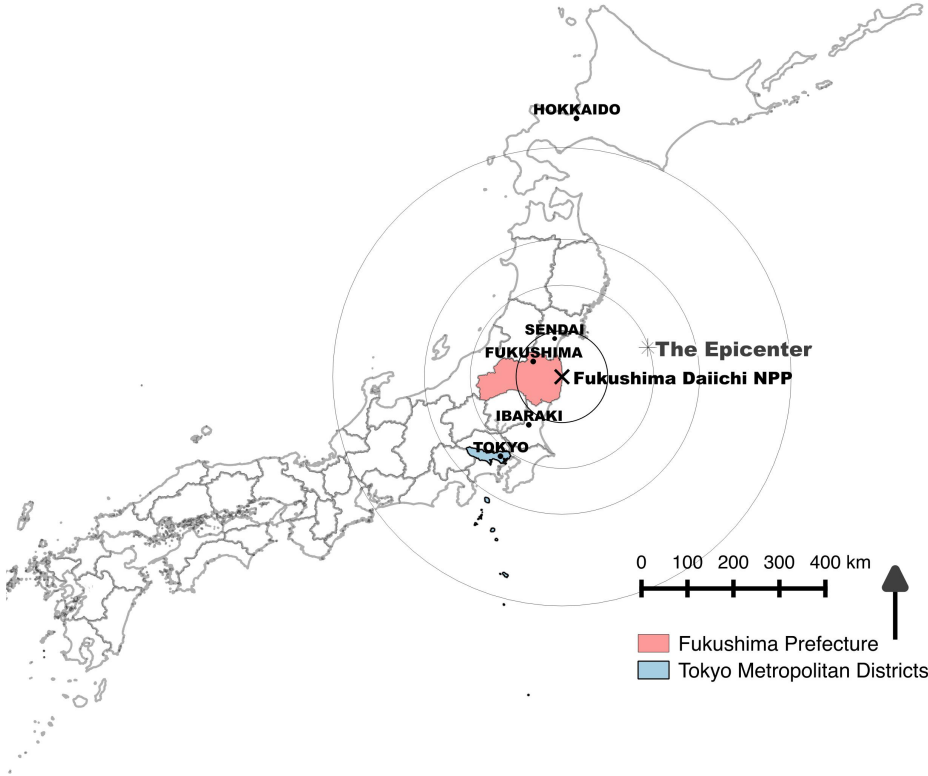


Figure 1: Locations of Key Geographical References

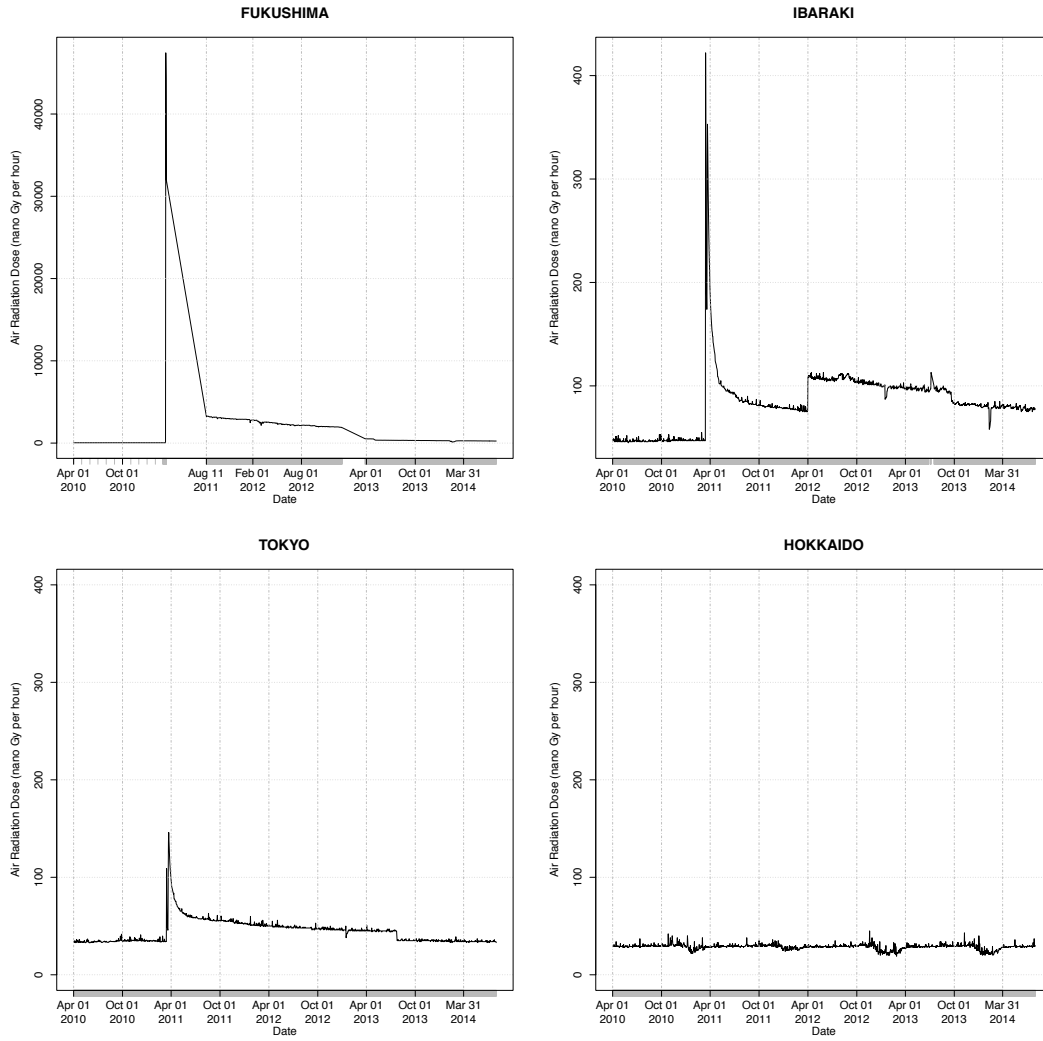


Figure 2: Change in Air Radiation Doses in Four Prefectures

Source: Japan Chemical Analysis Center and the Nuclear Regulation Authority (<http://www.kankyo-hoshano.go.jp/en/index.html>)

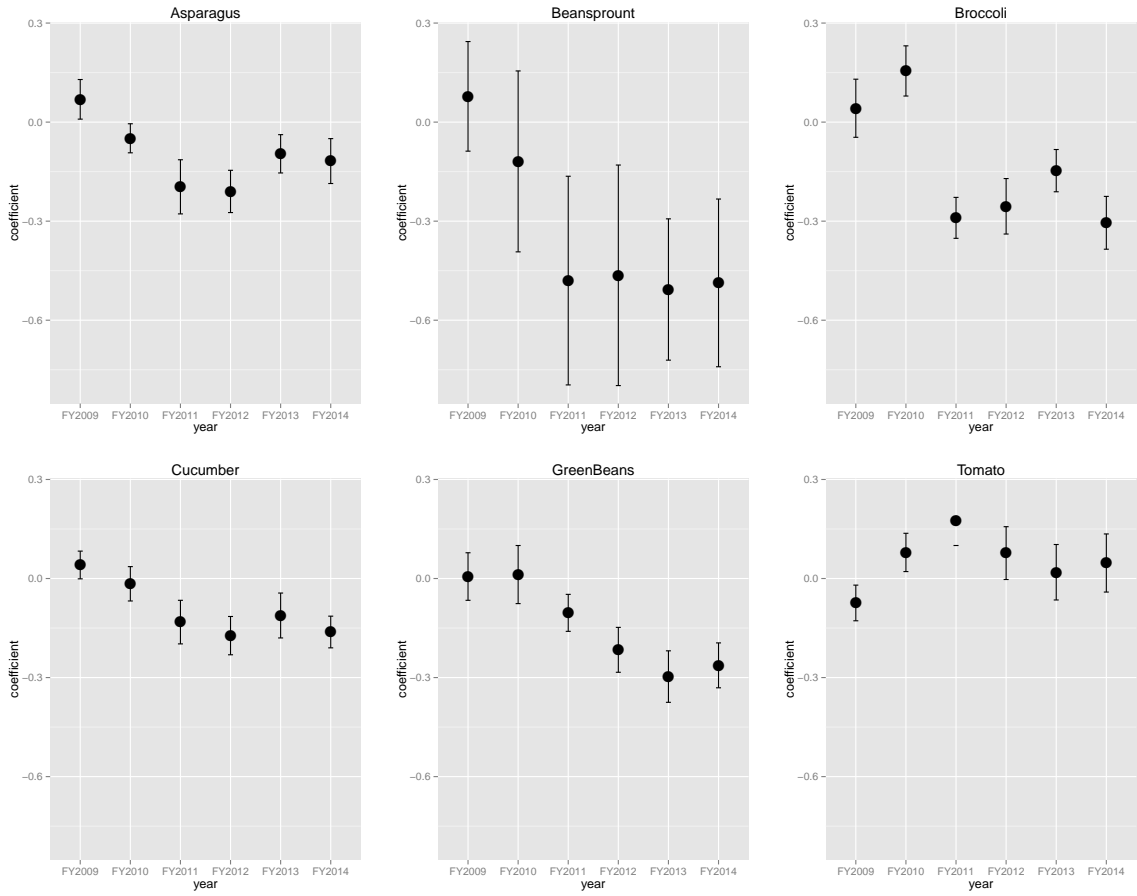


Figure 3: Changes in Estimated Coefficients (FY2009-FY2014)

B Tables

Table 1: Transition in Cesium Test Results

| | Number of Food Cesium Tests Conducted | Number of Tests in which the Dose Exceeded the Safety Standard | Rate of Tests Dose over Safety Standard |
|-----------------|---|--|---|
| APR2011-MAR2012 | 137,037 | 1,204 | 0.879% |
| APR2012-MAR2013 | 278,275 | 2,372 | 0.852% |
| APR2013-MAR2014 | 333,969 | 1,017 | 0.305% |

Source: Ujiie (2014), based on the Ministry of Health and Welfare's publication

Table 2: Summary Statistics

| Variable | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
|---------------------------|-----------|-----------|--------------|-----------|----------|-----------|
| | Asparagus | | Bean sprouts | | Broccoli | |
| Price | 1197.07 | 467.76 | 180.43 | 209.40 | 376.12 | 465.55 |
| Average temperature | 15.34 | 8.64 | 14.53 | 8.32 | 13.48 | 7.33 |
| Distance to Fukushima NPP | 483.59 | 380.80 | 242.11 | 137.02 | 480.57 | 338.97 |
| Fukushima dummy | 0.05 | 0.21 | 0.09 | 0.28 | 0.04 | 0.19 |
| No. of Obs. | 2,094 | | 1,270 | | 2,411 | |
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. |
| | Cucumbers | | Green Beans | | Tomatoes | |
| Price | 338.84 | 147.39 | 814.56 | 88.10 | 506.11 | 285.68 |
| Average temperature | 15.77 | 7.96 | 17.19 | 7.42 | 15.30 | 8.16 |
| Distance to Fukushima NPP | 510.08 | 403.60 | 558.97 | 468.02 | 532.31 | 371.58 |
| Fukushima dummy | 0.04 | 0.19 | 0.04 | 0.19 | 0.03 | 0.17 |
| No. of Obs. | 2,863 | | 2,120 | | 3,716 | |

Table 3: Estimation Results (Treatment Variable: *Fukushima* as Binary)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|----------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| | Asparagus | Bean sprouts | Broccoli | Cucumbers | Green beans | Tomatoes |
| Average Temperature | -0.013 (0.016) | -0.001 (0.016) | -0.019 (0.024) | -0.021 (0.023) | 0.038 (0.027) | -0.030** (0.015) |
| Average Temperature (squared) | -0.000 (0.000) | 0.000 (0.001) | -0.002*** (0.000) | 0.000 (0.000) | -0.001** (0.001) | 0.000 (0.000) |
| Fukushima*FY09 | 0.069** (0.030) | 0.078 (0.083) | 0.042 (0.044) | 0.041* (0.021) | 0.006 (0.036) | -0.074*** (0.027) |
| Fukushima*FY10 | -0.049** (0.022) | -0.119 (0.137) | 0.155*** (0.038) | -0.016 (0.026) | 0.012 (0.044) | 0.079*** (0.029) |
| Fukushima*FY11 | -0.196*** (0.041) | -0.480*** (0.158) | -0.290*** (0.031) | -0.132*** (0.033) | -0.104*** (0.028) | 0.176*** (0.038) |
| Fukushima*FY12 | -0.210*** (0.032) | -0.464*** (0.167) | -0.255*** (0.042) | -0.173*** (0.029) | -0.216*** (0.034) | 0.077* (0.040) |
| Fukushima*FY13 | -0.096*** (0.029) | -0.507*** (0.107) | -0.147*** (0.032) | -0.112*** (0.034) | -0.297*** (0.039) | 0.019 (0.042) |
| Fukushima*FY14 | -0.118*** (0.034) | -0.487*** (0.127) | -0.305*** (0.040) | -0.162*** (0.024) | -0.263*** (0.034) | 0.047 (0.044) |
| Constant | 7.322*** (0.119) | 4.755*** (0.076) | 6.191*** (0.117) | 6.261*** (0.105) | 6.673*** (0.158) | 6.050*** (0.067) |
| Year-Month FE | Y | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y | Y |
| N | 2094 | 1270 | 2411 | 2863 | 2120 | 3716 |
| adj. R^2 | 0.384 | 0.087 | 0.270 | 0.425 | 0.283 | 0.264 |

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Estimation Results (Treatment Variable: *Proximity* is Continuous)

| | (1) | (2) | (3) | (4) | (5) | (6) |
|----------------------------------|---------------------|----------------------|----------------------|---------------------|---------------------|---------------------|
| | Asparagus | Bean sprouts | Broccoli | Cucumbers | Green beans | Tomatoes |
| Average Temperature | -0.015 (0.016) | -0.001 (0.016) | -0.019 (0.025) | -0.021 (0.023) | 0.038 (0.026) | -0.032** (0.015) |
| Average Temperature (squared) | -0.000 (0.000) | 0.000 (0.001) | -0.002*** (0.000) | 0.000 (0.000) | -0.002** (0.001) | 0.000 (0.000) |
| Proximity*FY09 | 0.007 (0.024) | -0.050 (0.109) | -0.032 (0.039) | -0.005 (0.022) | -0.034 (0.030) | 0.011 (0.028) |
| Proximity*FY10 | -0.013 (0.025) | -0.357 (0.264) | -0.021 (0.038) | 0.023 (0.024) | 0.071* (0.038) | 0.047* (0.026) |
| Proximity*FY11 | 0.065 (0.048) | -0.453* (0.267) | -0.091** (0.037) | -0.017 (0.054) | 0.000 (0.025) | 0.043 (0.034) |
| Proximity*FY12 | 0.044 (0.043) | -0.454 (0.296) | -0.092*** (0.030) | -0.030 (0.030) | 0.002 (0.039) | 0.015 (0.032) |
| Proximity*FY13 | 0.048 (0.034) | -0.416*** (0.132) | -0.019 (0.032) | 0.011 (0.039) | 0.019 (0.048) | 0.058 (0.038) |
| Proximity*FY14 | 0.061 (0.041) | -0.193 (0.142) | -0.052 (0.034) | -0.009 (0.027) | 0.011 (0.041) | 0.030 (0.039) |
| Constant | 7.341*** (0.121) | 4.744*** (0.076) | 6.195*** (0.116) | 6.263*** (0.105) | 6.678*** (0.157) | 6.056*** (0.067) |
| Year-Month FE | Y | Y | Y | Y | Y | Y |
| Prefecture FE | Y | Y | Y | Y | Y | Y |
| <i>N</i> | 2094 | 1270 | 2411 | 2863 | 2120 | 3716 |
| adj. <i>R</i> ² | 0.386 | 0.121 | 0.269 | 0.425 | 0.283 | 0.265 |

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$