Do Radioactive Spills from the Fukushima Disaster Have any Influence on Seafood Market in Japan?

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Title: Do Radioactive Spills from the Fukushima Disaster Have Any Influence on the Japanese Seafood Market?
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Abstract
We investigated whether the spill of radioactive materials from the Fukushima nuclear plant into the Pacific Ocean had a negative impact on demand for cod and pollock in wholesale markets in Japan. A structural break test detected several break points in the market, including the Fukushima disaster, and successfully eliminated the impact of the other disturbing shocks identified in our analysis. A system of demand equations model which has taken into account the structural breaks indicated that the radioactive spills had a significantly negative impact on demand for cod. Our results suggested that the amount of radiation detected in cod products negatively affected Japanese demand for cod and positively affected demand for pollock, while it did not affect its price. We also found that consumers' current concerns about radioactive spills positively affect cod and pollock markets. We concluded that radioactive spills harm the markets, but the impact is almost negligible.

JFL Classification: C32. Q13. Q22. Q53

Keywords: Radioactive Spill; Structural Break Test; Japanese Seafood Market; Demand Analysis

Introduction

The Great East Japan Earthquake, magnitude 9.0, hit the eastern part of Japan on March 11, 2011, and generated powerful tsunamis that devastated communities along the coast. The death toll including missing persons reached 18,535 and 398,898 houses were destroyed (National Police Agency, 2013). In addition, the earthquake brought disaster to one of nuclear power plants located in Fukushima. The 15-meter-high tsunami destroyed the plant's cooling systems, causing nuclear meltdowns and releases of radioactive materials. The incident was categorized as Level 7 on the International Nuclear Event Scale (INES), making it the second largest nuclear disaster in history after Chernobyl in 1986. Although Tokyo Electric Power Corporation (TEPCO) has been trying to stabilize the reactors, problems continue. In August 2013, TEPCO reported that 300 tons of contaminated water had leaked from a storage tank into the ocean, and radioactive spills turned to be a major concern once again (TABUCHI, 2013). Since then, repetitive radioactive spills has occurred once in a while (Fackler, 2014, Schlanger, 2014). Radioactively contaminated water flowing into the Pacific Ocean poses a threat to fisheries.

The purpose of this study is to estimate economic losses on seafood demands caused by radioactive contamination, and by public concerns about contamination. Since higher levels of radioactivity have been detected in seafood products in Japan after the Fukushima Disaster (Ministry of Health Labor and Wealth, 2013). We targeted Japan's cod (*Gadus macrocephalus*) and pollock (*Theragra chalcogramma*) since these demersal species have more risk than other species (Livingston, 2004). Japanese cod has tested positive for radiation contamination a number of times since the Fukushima Disaster not only in Fukushima area, but also many other areas (Yomiuri Shinbun, 2012). One of fishery authorities in a devastated area is concerned about decreasing sales of seafood products due to the Fukushima Disaster (Iwate Prefecture, 2013). Figure 1 illustrates the declines in price for fresh cod and pollock products after March 2011. This trend may be caused by decrease in cod demand due to radioactive spill and the corresponding excess supply. Accordingly we investigated the impacts of the radioactive spill on both price and quantity in those markets.

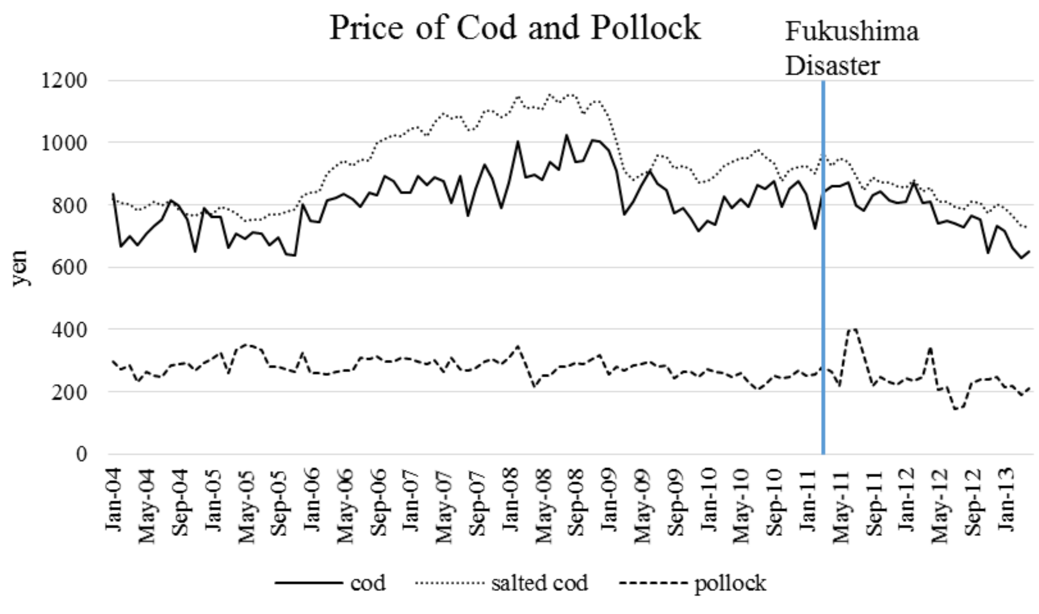

Figure 1. Prices of Cod, Salted Cod, and Pollock

We excluded Fukushima from the analysis in this study because the situation in Fukushima is different from the other prefectures, and still most of fisheries are closed there. Their economic loss will reveal after fishing operation resumed. Despite limiting scope of the analysis to non-radiated area, there has been a concern, especially for cod, about their exposure to radiation. In addition to cod, we also targeted pollock to consider effect of the other related market. In the following sections, we first describe background of the target species and their situation after the Fukushima Disaster, develop economic model, present the data, explain our econometric method, and interpret the empirical results.

Background

Cod and pollock are both important species because of the worldwide popularity. In Japan cod is consumed as fillets and one of ingredients for hot pot in winter. Forms of consumption for pollock is not limited to fillets, but also used for salted roe, fish meals, surimi and the others. Both cod and pollock both inhabit the northern part of Japan as shown in Figure 2. Pacific region occupies more than 70% of their domestic production (Ministry of Agriculture Forestry and Fisheries, 2010). Cod stock is categorized into three populations: North Pacific, Hokkaido and the Sea of Japan. Since each population stays within its range, radioactively contaminated cod is limited to be caught in the North Pacific population. As the matter of fact, almost all of Cesium 134 and 137 detected in cod were caught in the North Pacific population range (Fisheries Agency, 2013b).

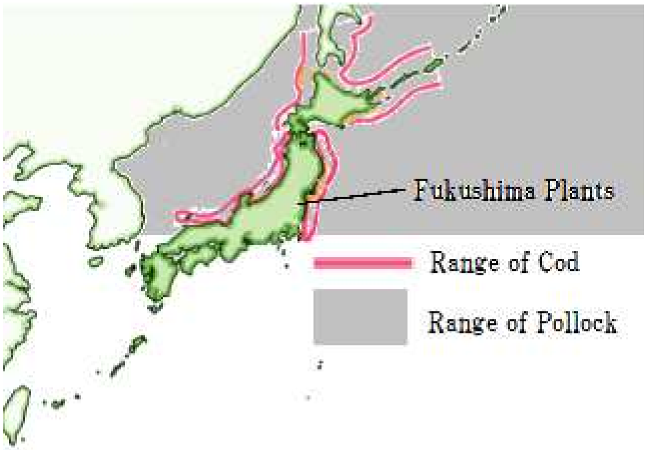

Figure 2 Range of Cod and Pollock Habitats (Edited based on Mori et al. 2012, Chimura et al. 2012, Narimatsu et al. 2012 and Goto et al. 2012)

Japanese authorities have disclosed radiation monitoring results to the public. The Fisheries Agency has tested Cesium concentration in multiple types of seafood from a variety of areas and has frequently updated those information on their websites (Fisheries Agency, 2013b). Figure 3 shows the concentration of radioactive Cesium 134 and 137 in cod products since March 2011.[1] In April 2012, responding to the nuclear incidents, the Japanese government tightened the allowable level of radiation from 500 Becquerel (Bq) per kilogram (kg) to 100 Bq per kg without any loose ends. This made the level of Cesium concentration in some cods in 2012 higher than the national limit, which was far below the level set by the Codex Alimentarius international food standard (Food and Agriculture Organization of the United Nations, 2013, Public Relations Office, 2012).

For those seafood with excessive amount of radioactivity, restriction of distribution is set by the Act on Special Measures for Nuclear Emergency Response. When detected radioactive level exceeds 100 Bq, the relevant local government, Section 20-2 of the Act bans its shipment to the market until weekly test results in the prefectural fishing ground return to the level within limits and remain there for at least one Japanese government claims that seafood in the market including cod is safe to consume (Public Relations Office, 2012). month (Fisheries Agency, 2013a). However, when it comes to a risk to human

[1] The Fukushima and Iwaki areas are excluded from these test results because fishing has been regulated there and none of the areas' seafood products has been distributed in the market since the Fukushima Disaster

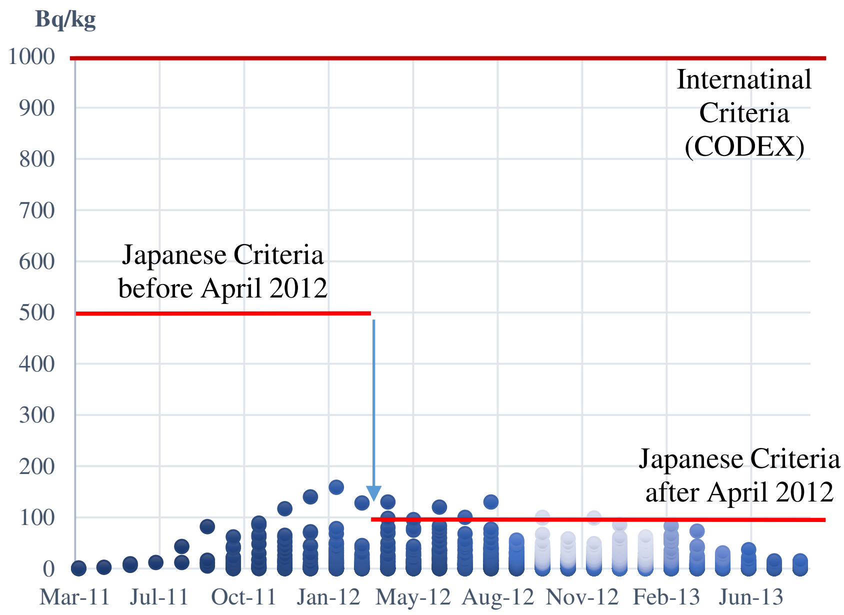

Figure 3. Scatter Plot of Radioactive Ceciums Detected in Cod Products After March 2011

health, 100 Bq is well below the level that affects human health (Ministry of Health Labor and Wealth, 2013).[2] Hence, the

While contamination itself along with the regulation has a negative impact on seafood production, consumers' concerns about radiation must also be paid attention as an important factor consisting the demand. Even when the contamination is slight within the international/Japanese standard, Japanese consumers are so keen to avoid any exposure that they devaluate such seafood. In response, Japanese retailers such as Aeon have begun to establish even stricter limits on radiation (AEON, 2012) that prevents wholesalers from selling radiated products that meet both the Japanese and the international standard. Therefore, some producers even have a possibility to suffer from radioactive contamination within allowable levels.

Public concerns are also of interest to this study. A quick survey shows a substantial number of people in Japan in 2013 did not know that the government was monitoring levels of radioactivity in seafood products nor was suspending shipment of the highly radioactively contaminated seafood to market (Suisan Keizai Daily News 2013). In addition, negative information tends to have a stronger influence on consumers than positive information even when the negative information comes from untrustworthy sources (Fox, et al., 2002). We assume many consumers fear radioactive contamination without accurate knowledge of the actions the government and industry have taken. Accordingly we aim to analyze how much seafood demand is affected by the public concerns.

Model Specification

We employed a system of demand equations derived from utility maximization problem (Mas-Colell, et al., 1995). In order to measure the impact of radiation on both price and quantity, we utilized both quantity and price dependent demands for analysis (DeVoretz and Salvanes, 1993). Price dependent demand model has often been employed for demand analyses of seafood because catches are assumed to

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[2] 100 Bq is calculated and converted from a limit of 1 milli-Sievelt (mSv) per year exposure defined by FAO guidelines (Ministry of Health Labor and Wealth. 2013. *Present situation and counter measurement for radioactive materials in foods (Japanese).* Tokyo.). 100 mSv per year is regarded as the point at which exposure begins to increase the risk of cancer in humans. The maximum exposure allowed for radiological technologists is 50 mSv per year (---. 2013. *Present situation and counter measurement for radioactive materials in foods (Japanese).* Tokyo.).

be stock-dependent (Anderson, 1980, Barten and Bettendorf, 1989, Chambers and McConnell, 1983, DeVoretz and Salvanes, 1993). In the meanwhile, quantity dependent model is also applied for farmed fish especially when market is expected to be under perfect competition (Bjørndal, et al., 1994). Our data come from the world largest wholesale market, which is expected perfect competition. Wild cod and pollock are both dependent upon stock, but can be assumed be independent of stock because fishing efforts have been almost constant in 2000s (Chimura and Funamoto, 2012, Mori, et al., 2012). We assumed stock effect is considered in the model and developed price and quantity dependent model below. The model of log transformation is given by,

$$\begin{cases} q_t^i = \sum_{l=1}^{L}\left(\beta_{11}^i q_{t-l}^i\right) + \sum_{i=1}^{I}\left(\beta_{12}^i p_t^i\right) + \beta_{13}^i y_t^i + \sum_{z=1}\left(\beta_{14}^i x_{z,t}^i\right) + \varepsilon_{1,t}^i \\ p_t^i = \sum_{l=1}^{L}\left(\beta_{21}^i p_{t-l}^i\right) + \sum_{i=1}^{I}\left(\beta_{22}^i q_t^i\right) + \beta_{23}^i y_t^i + \sum_{z=1}\left(\beta_{24}^i x_{z,t}^i\right) + \varepsilon_{2,t}^i \end{cases} \quad (1)$$

where q_t stands for supply of species i, p_t for real prices, and y_t for real disposable income per capita. x_t denotes a combination of dummy variables for zs; z_1 is levels of radioactivity detected in cod and z_2 (in pollock); z_3 is the number of closing cod fisheries due to excessive radioactivity; z_4 is the number of news about harmful rumor; z_5 is public concern about radioactive contamination of cod fisheries; and z_6 is public concern about closing of cod fisheries. The type of fish (cod, salted cod, and pollock) is represented by i. L is the optimal lag length for product i where i =[1,3]. Betas denote the respective coefficients of the variables, and ε's represent white-noise error terms. β_{12} and β_{14} indicate price and income elasticities, and β_4 is a coefficient for the radioactivity dummy variables.

Data

We used monthly data on supplies of fresh cod, salted cod, and pollock products at Tsukiji market, the largest central wholesale market in Japan (Q_t^{Cod}, Q_t^{Slt}, and Q_t^{Pol}), average nominal prices of those products (P_t^{Cod}, P_t^{Slt}, and P_t^{Pol}), disposable income (I_t), the core consumer price index (Θ_t), radioactivity levels detected in cod and pollock products (x_{1t} and x_{2t}), and degree of public concern about radioactive spills (x_{4t}, x_{5t}, x_{6t}). Supplies and prices were obtained from the online database of the Tokyo metropolitan city government, and information on disposable income and the consumer price index was provided by the Ministry of Internal Affair and Communications.[3] Data on radiation levels detected were obtained from Japan's Fisheries Agency, but the data covered irregular time series of at least once a week since 2011. We generated monthly data from those time series.

As for radioactivity level detected cod and pollock, we introduced two dummies: closure dummy and radioactivity dummy. Closure dummy was the number of fisheries closed due to excessive radioactivity.[4] Radioactivity dummy was represented by a variable for the levels of radioactivity detected in cod and pollock in a month. As for public concerns, we used indicators such as the volume of news reports about harmful rumor, public concerns about regulation of cod fisheries, and contamination of cod, based on the Google Trends. Google Trends encodes a variable in an index value between 0 and 100 setting the maximum of the variable as 100.

The data sample covers January 2004 through July 2013 and contains 115 observations. To analyze the data, we seasonally adjusted data that included supplies (q_t), real prices per kg (p_t), and real disposable income per capita (y_t).[5] In our model, q_t is equal to $\ln(Q_t)$, p_t is equal to $\ln(P_t/\Theta_t)$, and y_t is equal to $\ln[I_t/(\Theta_t))]$. We applied the consumer price index to obtain real prices and incomes based on January 2004. Summary statistics are shown in Table 1.

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[3] Prices and quantities were obtained from www.shijou-tokei.metro.tokyo.jp/index.html. The results of radiation testing were obtained from www.jfa.maff.go.jp/j/housyanou/kekka.html and www.google.co.jp/trends. Disposable income and the consumer price index were obtained from www.e-stat.go.jp.

[4] No pollock fisheries were closed during the study period so we did not create a closure dummy for pollock.

[5] Seasonal adjustment was implemented using the X-11 method in *eViews*.

Table 1. Summary Statistics of Variables

Variable	number of obs	Mean	Std. Dev.	Min	Max	skewness	kurtosis
log of supply for cod	115	12.2	0.16	11.8	12.7	0.02	3.47
log of supply for salted cod	115	11.6	0.14	11.2	11.9	-0.42	3.02
log of supply for pollock	115	11.5	0.33	10.4	12.3	-0.75	5.06
log of price for cod	115	6.7	0.11	6.35	6.90	-0.38	2.72
log of price for salted cod	115	6.8	0.13	6.54	7.04	0.12	1.96
log of price for pollock	115	5.6	0.16	4.97	6.00	-0.60	5.11
disposable income	115	12.98	0.02	12.92	13.04	0.26	2.77

Unit Roots and Structural Breaks

Since time series analyses would be skewed by nonstationarity and structural breaks, we tested both unit roots and structural breaks (Bai and Perron, 1998, Enders, 2004). Some of the time series in Figure 1 analyze a nonstationary process and contain structural breaks. We first tested stationarity using augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The unit root tests showed that some of the series were nonstationary and others were stationary (see Table 2).[6] However, unlike frozen seafood, fresh seafood cannot be stored more than a few days. Hence, the series of fresh seafood are disturbed by structural breaks. The literature using frozen seafood tested cointegration and the law of one price (LOP) with nonstationary data (Asche, et al., 2004, Norman-López, et al., 2013). The other literature using fresh seafood analyzed demand with stationary data (Bjørndal, et al., 1994, Cheng and Capps, 1988, Herrmann and Lin, 1988). However, when a structural break occurs, the data is likely to be affected and become nonstationary against nature of fresh seafood (Wakamatsu, 2014). If we can eradicate the influence of structural breaks, we can analyze demand at price level.

Table 2. Augmented Dickey-Fuller and Phillips-Perron Unit Root Tests

	Augmented Dickey-Fuller test				Phillips-Perron test		
	Lags	t (level)	t (1st diff)	Critical value at 5%	z(t) (level)	z(t) (1st diff)	Critical value at 5%
ln q of cod	2	-3.077	-8.163 ***	-3.448	-5.394 ***	-16.354 ***	-3.448
ln q of salted cod	1	-2.677	-9.362 ***	-3.448	-3.333	-14.034 ***	-3.448
ln q of pollck	1	-5.353 ***	-8.074 ***	-3.448	-5.854 ***	-12.06 ***	-3.448
ln p of cod	3	-1.269	-7.529 ***	-3.448	-3.308	-17.541 ***	-3.448
ln p of salted cod	1	-1.071	-7.286 ***	-3.448	-1.044	-10.562 ***	-3.448
ln p of pollck	1	-5.426 ***	-9.665 ***	-3.448	-6.25 ***	-13.681 ***	-3.448
ln y	3	-3.486 **	-9.206 ***	-3.448	-10.059 ***	-27.475 ***	-3.448

*** indicate 1% level of statistiacal sinigificance.

** indicate 5% level of statistical significance.

Structural changes tend to make a process jump up or down a level, causing the series to act like a nonstationary process. When the time series data are grouped by structural breaks, a nonstationary process is converted to a stationary one (Bai and Perron, 2003, Bai and Perron, 1998, Perron, 2006). Thus an apparently nonstationary process sometimes is in actuality a stationary process with structural breaks (Ben Sita, et al., 2012, Perron, 2006). Thus, we implemented structural break tests to deal with bias derived from structural changes. To determine the dates of the breaks, we adopted the structural break test

[6] Since the first differences of the variables rejected all of the null hypotheses, the nonstationary processes are integrated of order one.

by Bai and Perron (2003) and ran the test using the *strucchange* package in R as coded by Zeileis et al. (2003).

Figure 4 clearly demonstrates results of break tests and the occurrence of several structural breakpoints over time. Each series looks like stationary between breaks. We found that the detected breaks were mostly triggered by changes in fish stocks. If we do not take into account the structural breaks, the series would be detected as nonstationary data, which oftentimes skews the analysis. Detailed information on the timing of the breakpoints and corresponding events at the breakpoints are shown in Table 3, and we determined the model selection based on the Akaike information criterion in Table 4 and its detailed statistics such as coefficient and standard errors are available upon request.

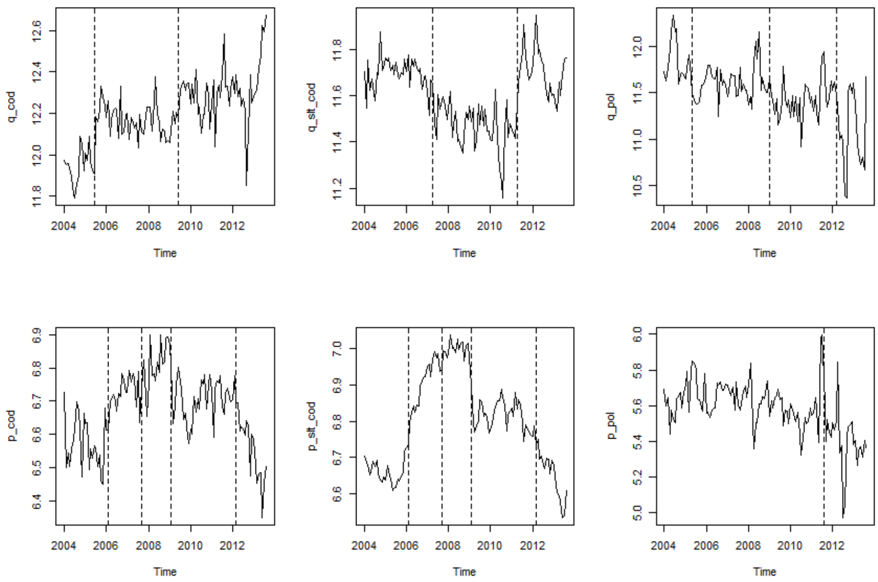

Figure 4. Supply and Price of Each Product with Break Points

Table 3. Timings of Break Points

Variable	Bai and Perron test Break 1	Break 2	Break 3	Break 4
Supply of cod q_t^{cod}	2005 (6) stock ⇑	2009 (6) stock ⇑		
Supply of salted cod q_t^{salt}	2007 (4) ?	2011 (4) Earthquake		
Supply of pollock q_t^{pol}	2005 (5) stock ⇑	2009 (1) Lehman S.	2012 (3) Criteria change	
Price of cod p_t^{cod}	2006 (2) stock ⇑	2007 (9) stock ⇑	2009 (2) Lehman S.	2012 (3) Criteria change
Price of salted cod p_t^{salt}	2006 (2) stock ⇑	2007 (9) stock ⇑	2009 (2) Lehman S.	2012 (3) Criteria change
Price of pollock p_t^{pol}	2011 (8) Earthquake			
Disposable income y_t	2005 (5) Int. rate	2009 (1) Lehman S.		

Note: The values in parentheses denote the number of months that the break occurred.

According to Table 3, overall trends for cod and salted cod are similar, but not for pollock. This disparity is possibly caused by the fact that the pollock products are not only a substitute of cod, but also are ingredients of a variety of products including surimi, roe, fish meal, and others. The all breaks in cod supply are caused by increase in its stock after 2004 and 2009. The breaks of supply in cod and salted cod do not match because salted cod can be stored while fresh cod needs to be consumed shortly. A break for salted cod in 2007 is apparently triggered by no event, but the second period of salted cod price series seems to begin at the first breakpoint. Breaks for pollock are related to improvement of stock (May 2005), and closure of gill net harvesting as well as Lehman shock (January 2009). The break points in prices for cod and salted cod occur simultaneously. Breaks of price in cod and salted cod in 2006 and 2007 were triggered by jumps in stock levels (Goto, 2008, Narimatsu, et al., 2007). The breaks detected in cod may be caused by complex web of the related products markets of pollock. We found a break associated with the earthquake and Fukushima Disaster in the supply of salted cod in April 2011. There was an additional structural break in the price of cod and supply of pollock in April 2012, about the same time that the Japanese government further restricted the allowable level of radioactivity in seafood from 500 to 100 Bq (Fisheries Agency, 2012).

Table 4. AICs across Break Models

AICs	No Break	1 Break	2 Breaks	3 Breaks	4 Breakds	5 Breaks
supply of cod q_t^{cod}	-80.6	-135.3	**-159.7**	-155.6	-148.3	-134.6
supply of salted cod q_t^{salt}	-112.8	-132.2	**-208.8**	-208.2	-200.6	-191.1
supply of pollock q_t^{pol}	77.5	46.8	37.0	**36.5**	41.3	50.3
price of cod p_t^{cod}	-169.1	-188.1	-244.9	-250.0	**-253.5**	-247.6
price of salted cod p_t^{salt}	-135.0	-167.6	-254.9	-329.7	**-346.8**	-340.5
price of pollock p_t^{pol}	-92.2	**-131.7**	-129.7	-121.9	-113.3	-102.7
disposable income y_t	-528.1	-571.7	**-573.7**	-568.5	-561.6	-551.5

Note that the values in bold are optimal break models in the variables.

To remove the effect of structural breaks, we divided the overall data set into subgroups of data between the breaks and ran unit root tests again. According to the results shown in Table 5, most of the variables turned out to be a stationary process. Some of them remained in nonstationary, but it is also considerable when the jump of structural change occurred over a longer period than a month. At any rate, we regarded that structural breaks make the time series look like nonstationary process, but the actual series are in stationary process. We eliminate the influence of structural breaks to estimate the more accurate parameters by developing a specific model for structural changes in the following section.

Table 5

Unit Root Tests with Multiple Breaks

Variable	Lag	ADF Over-all period	ADF (trend) with Multiple Breaks Period 1	Period 2	Period 3	Period 4	Period 5
q_t^{cod}	2	-3.077	-2.45	-4.877 ***	-1.698		
q_t^{salt}	1	-2.677	-2.541	-4.864 ***	-2.818		
q_t^{pol}	1	-5.353 ***	-2.324	-2.947	-4.135 **	-2.413	
p_t^{cod}	3	-1.269	-2.409	-1.471	-3.063	-3.304	-2.271
p_t^{salt}	1	-1.071	-0.214	-1.299	-0.825	-4.082 **	-2.26
p_t^{pol}	1	-5.426 ***	-3.676 **	-3.503			
y_t	3	-3.486 **	-4.495 ***	-4.457 ***	-7.523 ***		

Note: ***, **, and * indicate a 1%, 5%, and 10% level of statistical significance respectively.

Panel A. ADF Test with Multiple Breaks

Variable	Lag	PP Over-all period	PP (trend) with Multiple Breaks Period 1	Period 2	Period 3	Period 4	Period 5
q_t^{cod}	2	-5.394 ***	-2.313	-6.687 ***	-3.653 **		
q_t^{salt}	1	-3.333	-5.12 ***	-4.89 ***	-2.824		
q_t^{pol}	1	-5.854 ***	-1.884	-4.411 ***	-4.712 ***	-2.152	
p_t^{cod}	3	-3.308	-4.21 **	-3.707 **	-4.955 ***	-4.327 ***	-4.044 **
p_t^{salt}	1	-1.044	-0.883	-2.264	-4.961 ***	-3.669 **	-2.323
p_t^{pol}	1	-6.25 ***	-4.929 ***	-3.796 **			
y_t	3	-10.059 ***	-4.495 ***	-6.404 ***	-7.523 ***		

Note: ***, **, and * indicate a 1%, 5%, and 10% level of statistical significance respectively.

Panel B. PP Test with Multiple Breaks

Model with Structural Breaks

We integrated structural-break dummies into the basic model. The equation can be expressed as,

$$\begin{cases} q_t^i = \sum_{bq=1}^{BQ}\{\beta_{10}^i + \sum_{l=1}^{L}(\beta_{11,bq}^i q_{t-1}^i d_{t-1,bq}^i)\} + \sum_i \sum_{bp=1}^{BP}(\beta_{12,bp}^i p_t^i d_{t,bp}^i) + \sum_{by=1}^{BY}(\beta_{13,by}^i y_t^i d_{t,by}^i) + \sum_{z=1}(\beta_{14}^i x_{z,t}^i) + \varepsilon_{1t}^i \\ p_t^i = \sum_{bp=1}^{BP}\{\beta_{20}^i + \sum_{l=1}^{L}(\beta_{21,bp}^i p_{t-1}^i d_{t-1,bp}^i)\} + \sum_i \sum_{bq=1}^{BQ}(\beta_{12,bq}^i q_t^i d_{t,bq}^i) + \sum_{by=1}^{BY}(\beta_{23,by}^i y_t^i d_{t,by}^i) + \sum_{z=1}(\beta_{24}^i x_{z,t}^i) + \varepsilon_{2t}^i \end{cases} \quad (2)$$

where *bq* (supply), *bp* (price), and *by* (disposable income) denote the order of the breaks from the first break and the last break for each variable. $d^i_{t,bq}$, $d^i_{t,bp}$, and $d^i_{t,by}$ are corresponding dummy variables for each break period following Ben Sita, et al. (2012). For example, there are four breaks detected for the price of cod: February 2006, September 2007, February 2009, and March 2012. In this case, we included five dummy variables for $d^i_{t,bp}$; $d^i_{t,1}$ is 1 when $t \leq$ 2006:2 and 0 otherwise and then $d^i_{t,2}$ is 1 when 2006:2 < $t \leq$ 2007:9 and 0 otherwise, $d^i_{t,3}$ is 1 when 2007:9 < $t \leq$ 2009:2 and 0 otherwise, $d^i_{t,4}$ is 1 when 2009:2 < t $\leq$ 2012:3 and 0 otherwise, and $d^i_{t,5}$ is 1 when t > 2012:3 and 0 otherwise.

Empirical Results

Our segregation of the data by structural breaks successfully provide us with accurate results. The results of estimation found some significant impacts of radioactivity variables. We first show the model with dummy for both radioactivity and the number of fisheries closed in Table 6.

Table 6. Results of Estimates

Model 1 (Quantity and Price Dependent Equations with Sum of Radioactivity + Closure Dummy)							
	Equations of Quantity				Equations of Price		
VARIABLES	Cod	Sltd Cod	Pollock	VARIABLES	Cod	Sltd Cod	Pollock
Own Variables				Own Variables			
Lagged Q (Period 1)	0.112*	0.274***	0.450***	Q (Period 1)	-0.517***	-0.00524	-0.196*
	(0.0651)	(0.0671)	(0.0747)		(0.0477)	(0.0286)	(0.106)
Lagged Q (Period 2)	0.129**	0.270***	0.451***	Q (Period 2)	-0.510***	-0.00373	-0.172*
	(0.0637)	(0.0680)	(0.0745)		(0.0469)	(0.0287)	(0.0879)
Lagged Q (Period 3)	0.134**	0.281***	0.427***	Q (Period 3)	-0.510***	-0.00500	0.245***
	(0.0630)	(0.0666)	(0.0742)		(0.0466)	(0.0283)	(0.0622)
Lagged Q (Period 4)			0.385***	Q (Period 4)			0.251***
			(0.0790)				(0.0651)
P (Period 1)	-1.062***	-0.661***	0.384***	Lagged P (Period 1)	0.149***	0.605***	0.0516
	(0.130)	(0.197)	(0.146)		(0.0567)	(0.0556)	(0.0911)
P (Period 2)	-1.037***	-0.647***	0.381**	Lagged P (Period 2)	0.171***	0.618***	0.0105
	(0.130)	(0.192)	(0.148)		(0.0552)	(0.0539)	(0.0924)
P (Period 3)	-1.024***	-0.651***		Lagged P (Period 3)	0.184***	0.620***	
	(0.130)	(0.192)			(0.0545)	(0.0536)	
P (Period 4)	-1.031***	-0.669***		Lagged P (Period 4)	0.183***	0.621***	
	(0.131)	(0.194)			(0.0557)	(0.0548)	
P (Period 5)	-1.027***	-0.657***		Lagged P (Period 5)	0.173***	0.614***	
	(0.130)	(0.197)			(0.0571)	(0.0560)	
Cross Price				Cross Quantity			
P (Cod)		0.252**	-1.018***	Q (Cod)		-0.0952***	-0.202**
		(0.128)	(0.343)			(0.0259)	(0.0967)
P (Salted Cod)	-0.101		0.931***	Q (Salted Cod)	0.193***		0.440***
	(0.181)		(0.341)		(0.0429)		(0.0873)
P (Pollock)	0.177***	0.311***		Q (Pollock)	-0.00426	-0.00641	
	(0.0568)	(0.0557)			(0.0215)	(0.0127)	
Income				Income			
Period 1 (Jan04-May05)	-0.307	-0.628*	-1.590	Period 1 (Jan04-May05)	-0.245	-0.189	0.827
	(0.408)	(0.379)	(1.002)		(0.255)	(0.136)	(0.532)
Period 2 (May05-Jan09)	-0.310	-0.630*	-1.610	Period 2 (May05-Jan09)	-0.244	-0.188	0.811
	(0.408)	(0.380)	(1.003)		(0.256)	(0.137)	(0.515)
Period 3 (Feb09-JuLagged 3)	-0.311	-0.628*	-1.594	Period 3 (Feb09-JuLagged 3)	-0.246	-0.193	0.443
	(0.408)	(0.380)	(1.003)		(0.256)	(0.137)	(0.533)
Radiation				Radiation			
Sum of radioactivity (cod)	-0.0660**	-0.0761***	0.241***	Sum of radioactivity (cod)	-0.00266	0.0161	-0.0167
	(0.0303)	(0.0282)	(0.0641)		(0.0222)	(0.0124)	(0.0383)
Sum of radioactivity (pollock)	0.978**	1.199***	0.486	Sum of radioactivity (pollock)	-0.0295	-0.0540	-0.0207
	(0.401)	(0.416)	(1.277)		(0.267)	(0.154)	(0.688)
Actural Closure (Cod)	-0.0508	0.0211		Actural Closure (Cod)	-0.0560**	-0.0235	
	(0.0394)	(0.0368)			(0.0274)	(0.0150)	
Public Concern				Public Concern			
Constant	21.29***	17.65***	25.53*	Constant	12.75***	6.370***	-5.820
	(5.524)	(5.154)	(13.09)		(3.384)	(1.845)	(7.026)
Observations	114	114	114	Observations	114	114	114
R-squared	0.757	0.756	0.673	R-squared	0.811	0.962	0.601

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The other models are also shown in Appendix (Table B). In Table 6, the results of quantity dependent model show that the levels of detected Cesiums in cod negatively affects cod's demand while radioactivity detected in pollock does not affect pollock itself, but positively affects cod's demand. As described in the introduction, fresh cod normally cannot be regarded as a substitute for fresh pollock; however, it was so after the unusual event of radioactive contamination. Although cod is three times more expensive than pollock, they substitute cod for pollock as the amount of radiation detected increases. According to the results, one Bq in cod and salted cod both decreases the demands by 0.0011 kg, but in the meantime, one Bq in cod increases the demand pollock by 0.0013 kg. Similarly one Bq in pollock increases the demands of cod and salted cod by 0.0027 kg and 0.0033 kg respectively. In the price equation, one actual closure affects cod price, and reduces by 1.75 yen (the averaged is 790 yen/kg). Despite significance of the estimates, the actual impacts on seafood markets are small and negligible.

Table 7. Impacts of Radioactive Spill on Demand and Price of Cod and Pollock

	News for Harmful Rumor (Model 2)		"Cod" and "Reg" (Model 3)		"Cod"&"Contamination" (Model 4)	
	Quantity	Price	Quantity	Price	Quantity	Price
Cod	0.00129 *	0.000512	0.00089 *	9.81e-05	-0.00020	2.43e-05
Salted Cod	0.000989	0.000286	0.00116 **	0.000157	6.26e-07	0.000188
Pollock	-0.000770	0.000657	-0.00189	-0.00199 ***	0.00101	0.00123 ***

The effects of public concern about radiation on demand and price are exhibited in Table 7. Model 2 explains the effect of news reports on harmful rumors, Model 3 demonstrates consumer interest in search terms related to closure of fisheries, and Model 4 describes terms related to cod contamination.[7] Public concerns about cod exposed to radiation had a "positive" effect on demand of cod. The number of news reports for harmful rumors and concern about closures of cod fisheries positively influence on demand cod.

Table 8

Own- and Cross-Price and Imcome Elasticities

	Own-Price Elasticities					Cross-Price Elasticities			Income Elasticities		
Variable	Period 1	Period 2	Period 3	Period 4	Period 5	Cod	Salted Cod	Pollock	Period 1	Period 2	Period 3
Cod	-1.06	-1.04	-1.02	-1.03	-1.03		0.25	-1.02	-0.31	-0.63	-1.59
Salted Cod	-0.66	-0.65	-0.65	-0.67	-0.66	-0.10		0.93	-0.31	-0.63	-1.61
Pollock	0.38	0.38				0.18	0.31		-0.31	-0.63	-1.59

Note: Elasticities are shown when the estimates are statistically significant at a 5% level or more. Light-colored numbers are significant at 10% or less.

Table 8 presents own/cross-price and income elasticities of quantity dependent model for each commodity across the break periods. Price elasticities for cod products did not change across the periods, indicating that the market structure did not change even after the market went through external shocks such as the earthquake and nuclear disaster and fluctuation of stock levels. The own price elasticities of pollock products had positive signs, which indicates Giffen goods and is unlikely in reality or exist in a particular environment (Jansen and De Haan, 2003). Price dependent model, on the other hand, well explained the results because all signs in the pre-Lehman Shock periods show negative, but the post periods show positive in Table 6. Responding the financial shock, prices of fresh cod and salted cod dropped more than pollock did. This disparity created substitution effect, and shifted consumption from pollock to cod consumption to some degree (Fig. 1). It also induced income effects and exceeded substitution effect of pollock, and thus made pollock act like Giffen goods. Yet, considering that pollock in the first two periods did not show Giffen behavior, this phenomenon might be temporary. Most of income elasticities turn out to be not significant at

[7] Google Trends encodes each variable in an index value between 0 and 100 basing the maximum number as 100.

5% level and not so elastic, which means these species are relatively necessary goods for Japanese consumers and are constantly consumed. The cross-price elasticities imply that fresh cod and pollock are complement goods for salted cod, but fresh cod has a higher degree of complementarity than pollock.

Conclusion

This study found that level of radioactivity negatively influences on the markets for both cod and pollock, but the influence is negligibly small. After Fukushima Disaster, Fisheries Agency of Japan encouraged stakeholders not to boycott seafood from the North Pacific Ocean (Suisan Keizai Shinbun, 2012). Our result is evidence to support that the damage of radiation on seafood demand was successfully minimized by all the efforts that stakeholders made. There is additional reason of this minimized impact; Tsukiji is the largest seafood market in Japan where seafood not only come from Fukushima, but also from locations all over Japan. We identified significant negative impacts on demand for cod rather than its price. Just in case of safety, only the limited seafood that passed the world strictest criteria is distributed in markets. Nevertheless, according to the results, radioactivity at safe level affects seafood demand.

We also found that consumers' active concern about radioactive contamination improves consumer preference. Our result that Googling "radioactive contamination of cod" positively affect its demand seems to contradict normal conjecture. However, this is presumably caused by alarmist reaction that consumers tend to overreact to negative reports about the risk and to judge the situation without sufficient knowledge (Viscusi, 1997). Furuta et al. (1998) demonstrated that fear of radiation comes primarily from lack of appropriate information and that education can relieve public concerns. Similarly, this study found, when consumers are actively exposed to accurate information by online searching, public anxiety is abated. Given that exposure to accurate information is the key to resilience from Fukushima Disaster, further study is necessary for policy makers to clarify effectiveness of a counter-radioactive-contamination campaign.

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Appendix

Table A. Statistics of Multiple Break Tests

Coefficients (Std.Errs.)	Period 1	Period 2	Period 3	Period 4	Period 5
supply of cod q_t^{cod}	11.94	12.17	12.31		
	(0.02)	(0.01)	(0.02)		
supply of salted cod q_t^{salt}	11.70	11.47	11.71		
	(0.01)	(0.01)	(0.02)		
supply of pollock q_t^{pol}	11.83	11.61	11.43	11.08	
	(0.06)	(0.03)	(0.03)	(0.10)	
price of cod p_t^{cod}	6.58	6.73	6.81	6.70	6.55
	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)
price of salted cod p_t^{salt}	6.66	6.91	6.99	6.81	6.65
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
price of pollock p_t^{pol}	5.63	5.40			
	(0.01)	(0.03)			
disposable income y_t	13.00	12.98	12.96		
	(0.003)	(0.003)	(0.002)		

Table B. Results of Model Estimations wit

	Model 2 (News on Harmful Rumor)					
	Eq. of Quantity			Eq. of Price		
VARIABLES	Cod	Sltd Cod	Pollock	Cod	Sltd Cod	Pollock
Own Variables						
Q (Period 1)	0.211***	0.332***	0.463***	-0.473***	-0.00590	-0.171
	(0.0642)	(0.0666)	(0.0796)	(0.0459)	(0.0286)	(0.106)
Q (Period 2)	0.229***	0.329***	0.464***	-0.467***	-0.00423	-0.155*
	(0.0627)	(0.0674)	(0.0793)	(0.0452)	(0.0287)	(0.0882)
Q (Period 3)	0.232***	0.339***	0.444***	-0.468***	-0.00575	0.241***
	(0.0620)	(0.0658)	(0.0790)	(0.0449)	(0.0281)	(0.0526)
Q (Period 4)			0.425***			0.246***
			(0.0823)			(0.0542)
P (Period 1)	-0.965***	-0.771***	0.486***	0.140**	0.594***	0.0524
	(0.135)	(0.200)	(0.156)	(0.0588)	(0.0568)	(0.0891)
P (Period 2)	-0.940***	-0.755***	0.510***	0.163***	0.608***	0.0109
	(0.135)	(0.195)	(0.160)	(0.0572)	(0.0551)	(0.0916)
P (Period 3)	-0.926***	-0.758***		0.175***	0.610***	
	(0.135)	(0.195)		(0.0564)	(0.0548)	
P (Period 4)	-0.934***	-0.778***		0.173***	0.610***	
	(0.135)	(0.198)		(0.0576)	(0.0560)	
P (Period 5)	-0.950***	-0.780***		0.153***	0.603***	
	(0.135)	(0.199)		(0.0589)	(0.0569)	
Cros Price (or Quantity)						
Cod		0.314**	-0.896**		-0.0930***	-0.192**
		(0.130)	(0.364)		(0.0242)	(0.0906)
Salted Cod	-0.163		0.978***	0.172***		0.405***
	(0.190)		(0.363)	(0.0419)		(0.0871)
Pollock	0.150**	0.238***		0.00385	0.00692	
	(0.0587)	(0.0548)		(0.0184)	(0.0106)	
Income						
Period 1 (Jan04-May05)	0.0539	-0.321	-1.598	-0.181	-0.133	0.919*
	(0.438)	(0.396)	(1.091)	(0.264)	(0.140)	(0.542)
Period 2 (May05-Jan09)	0.0512	-0.323	-1.621	-0.180	-0.131	0.911*
	(0.439)	(0.396)	(1.093)	(0.264)	(0.140)	(0.526)
Period 3 (Feb09-Jul13)	0.0502	-0.321	-1.607	-0.182	-0.136	0.560
	(0.439)	(0.396)	(1.092)	(0.264)	(0.140)	(0.541)
Radiation	News for Harmful Rumor					
Public Concern	0.00129*	0.000989	-0.000770	0.000512	0.000286	0.000657
	(0.000661)	(0.000628)	(0.00167)	(0.000409)	(0.000265)	(0.000830)
Constant	15.31***	13.72**	23.80*	11.61***	5.528***	-7.037
	(5.899)	(5.339)	(14.21)	(3.456)	(1.879)	(7.050)
Observations	114	114	114	114	114	114
R-squared	0.738	0.748	0.628	0.806	0.962	0.605

	Model 3 (Googling "Cod" and "Regualtion")					
	Eq. of Quantity			Eq. of Price		
VARIABLES	Cod	Sltd Cod	Pollock	Cod	Sltd Cod	Pollock
Own Variables						
Q (Period 1)	0.216***	0.321***	0.408***	-0.469***	-0.00974	-0.181*
	(0.0646)	(0.0656)	(0.0860)	(0.0468)	(0.0280)	(0.102)
Q (Period 2)	0.234***	0.318***	0.409***	-0.463***	-0.00831	-0.200**
	(0.0631)	(0.0663)	(0.0861)	(0.0461)	(0.0282)	(0.0854)
Q (Period 3)	0.238***	0.330***	0.386***	-0.464***	-0.00923	0.157***
	(0.0624)	(0.0649)	(0.0858)	(0.0458)	(0.0277)	(0.0546)
Q (Period 4)			0.369***			0.162***
			(0.0883)			(0.0558)
P (Period 1)	-0.919***	-0.729***	0.317*	0.145**	0.608***	0.0240
	(0.134)	(0.196)	(0.163)	(0.0588)	(0.0551)	(0.0867)
P (Period 2)	-0.895***	-0.715***	0.335**	0.169***	0.621***	-0.0205
	(0.134)	(0.192)	(0.166)	(0.0572)	(0.0534)	(0.0893)
P (Period 3)	-0.882***	-0.717***		0.181***	0.623***	
	(0.134)	(0.192)		(0.0564)	(0.0531)	
P (Period 4)	-0.890***	-0.735***		0.179***	0.624***	
	(0.134)	(0.194)		(0.0577)	(0.0543)	
P (Period 5)	-0.907***	-0.741***		0.158***	0.615***	
	(0.135)	(0.196)		(0.0589)	(0.0553)	
Cros Price (or Quantity)						
Cod		0.335***	-0.818**		-0.0913***	-0.120
		(0.128)	(0.364)		(0.0246)	(0.0894)
Salted Cod	-0.153		0.894**	0.186***		0.484***
	(0.189)		(0.363)	(0.0406)		(0.0841)
Pollock	0.204***	0.307***		0.00480	0.0106	
	(0.0607)	(0.0557)		(0.0199)	(0.0113)	
Income						
Period 1 (Jan04-May05)	-0.118	-0.453	-1.398	-0.245	-0.165	0.742
	(0.427)	(0.382)	(1.058)	(0.260)	(0.136)	(0.515)
Period 2 (May05-Jan09)	-0.122	-0.455	-1.420	-0.245	-0.163	0.764
	(0.427)	(0.383)	(1.059)	(0.260)	(0.137)	(0.499)
Period 3 (Feb09-Jul13)	-0.122	-0.453	-1.405	-0.247	-0.168	0.448
	(0.427)	(0.383)	(1.059)	(0.260)	(0.137)	(0.515)
Radiation	"Cod" and "Reg"					
Public Concern	0.000892*	0.00116**	-0.00189	9.81e-05	0.000157	0.00199***
	(0.000502)	(0.000451)	(0.00140)	(0.000319)	(0.000170)	(0.000665)
Constant	16.82***	14.75***	22.83*	12.19***	5.839***	-6.235
	(5.769)	(5.185)	(13.84)	(3.425)	(1.843)	(6.751)
Observations	114	114	114	114	114	114
R-squared	0.740	0.747	0.634	0.806	0.962	0.624

	Model 4 Googleing "Cod" and "Contamination"					
	Eq. of Quantity			Eq. of Price		
VARIABLES	Cod	Sltd Cod	Pollock	Cod	Sltd Cod	Pollock
Own Variables						
Q (Period 1)	0.211***	0.330***	0.461***	-0.470***	-0.00614	-0.178*
	(0.0651)	(0.0688)	(0.0796)	(0.0464)	(0.0281)	(0.104)
Q (Period 2)	0.229***	0.327***	0.463***	-0.464***	-0.00443	-0.165*
	(0.0636)	(0.0697)	(0.0793)	(0.0456)	(0.0283)	(0.0868)
Q (Period 3)	0.233***	0.338***	0.440***	-0.464***	-0.00582	0.215***
	(0.0629)	(0.0680)	(0.0790)	(0.0454)	(0.0278)	(0.0522)
Q (Period 4)			0.420***			0.218***
			(0.0824)			(0.0537)
P (Period 1)	-0.922***	-0.796***	0.396**	0.143**	0.584***	0.0732
	(0.136)	(0.207)	(0.163)	(0.0586)	(0.0565)	(0.0874)
P (Period 2)	-0.897***	-0.781***	0.420**	0.166***	0.598***	0.0379
	(0.136)	(0.202)	(0.165)	(0.0571)	(0.0548)	(0.0900)
P (Period 3)	-0.884***	-0.783***		0.179***	0.600***	
	(0.136)	(0.202)		(0.0563)	(0.0545)	
P (Period 4)	-0.892***	-0.802***		0.177***	0.600***	
	(0.137)	(0.204)		(0.0575)	(0.0558)	
P (Period 5)	-0.908***	-0.806***		0.156***	0.593***	
	(0.137)	(0.206)		(0.0587)	(0.0567)	
Cros Price (or Quantity)						
Cod		0.348***	-0.897**		-0.0910***	-0.167*
		(0.134)	(0.363)		(0.0243)	(0.0894)
Salted Cod	-0.197		0.956***	0.185***		0.363***
	(0.192)		(0.362)	(0.0410)		(0.0863)
Pollock	0.175***	0.241***		0.00204	0.00575	
	(0.0632)	(0.0593)		(0.0187)	(0.0106)	
Income						
Period 1 (Jan04-May05)	-0.165	-0.456	-1.282	-0.242	-0.142	0.978*
	(0.442)	(0.400)	(1.082)	(0.262)	(0.138)	(0.525)
Period 2 (May05-Jan09)	-0.169	-0.457	-1.304	-0.241	-0.140	0.972*
	(0.443)	(0.401)	(1.083)	(0.263)	(0.138)	(0.509)
Period 3 (Feb09-Jul13)	-0.170	-0.455	-1.290	-0.243	-0.146	0.635
	(0.442)	(0.400)	(1.083)	(0.263)	(0.138)	(0.526)
Radiation	"Cod" and "Contamination"					
Public Concern	-0.000195	6.26e-07	0.00101	2.43e-05	0.000188	0.00123**
	(0.000501)	(0.000484)	(0.00125)	(0.000286)	(0.000163)	(0.000590)
Constant	17.97***	15.43***	20.37	12.21***	5.714***	-7.650
	(5.933)	(5.388)	(14.06)	(3.449)	(1.855)	(6.866)
Observations	114	114	114	114	114	114
R-squared	0.734	0.743	0.632	0.806	0.962	0.622