An economic evaluation of nuclear power plant externalities, using the hedonic price approach

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Received August 9, 2013; accepted April 8, 2014

ABSTRACT

This study evaluates the external costs of nuclear power plants in Japan. Using the hedonic price approach, we analyze changes in land price in Fukui Prefecture before and after the Fukushima nuclear accident. The land in question is located far from the Fukushima accident area and was not directly impacted by the accident itself. The results of this study reveal that the area affected by the nuclear power plant's negative externalities expanded following the accident, and that the intensity of the external costs also increased. In addition, the costs and benefits of nuclear power plants are found to be distributed unequally across several regions.

Keywords: Nuclear power plant, External cost, Hedonic price approach, Fukushima nuclear accident

JEL classification: Q51

1 Introduction

The accident that occurred at the Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station in March 2011 resulted in an enormous amount of damage. The full extent of the damage contains elements that have yet to be explained, and an economic assessment of the damage not yet been completed.

However, one thing that has become clear from the Fukushima nuclear accident is that the various assumptions that were in place prior to the accident vis-à-vis assessments of the spatial extent of a damaged area need to be fundamentally re-examined. Before the Fukushima nuclear accident, there was in Japan a widely believed nuclear energy "safety myth," and many believed that damage could be more or less contained to a limited area, should an accident occur. Nonetheless, the Fukushima nuclear accident resulted in a large evacuation zone being established for a 30-km zone around the reactor site, and as of June 2014, the fallout from the accident has still not been fully resolved. In essence, it is now clear that areas that were thought to have been spared were, in fact, damaged as well. This raises several questions, such as whether preferences toward nuclear power stations have changed among local communities located near reactor sites, or how financial assessments have changed in analyses of the costs and benefits of nuclear power. This study aims to clarify these two issues.

By their very nature, nuclear power stations are high-risk, and so they are typically frowned upon. A range of financial incentives is usually offered to local communities to compensate them for accepting such a facility. In other words, the placement of a nuclear reactor simultaneously imparts upon nearby communities both costs and benefits: accepting an unwanted nuclear reactor is a type of cost, and nuclear-power subsidies are a type of benefit. Understanding this relationship requires clarifying the size of the associated costs and benefits and their related causes, but the body of research that attempts to comprehensively analyze the advantages and disadvantages of nuclear power stations has been rather limited. In particular, it can be assumed at the very least that among communities located near other reactor sites in Japan, the Fukushima nuclear accident has shifted outlooks regarding nuclear power plants; to the best of our knowledge, however, no research has sought to assess such perceptual changes.

Based on the aforementioned awareness of nuclear power perceptions and the aforementioned research objectives, this study uses a hedonic price approach to evaluate the external costs imparted on a community by a nearby nuclear power plant. A study area was chosen for the evaluation by creating a zone within a 40-km radius of each of four nuclear reactor plants in Fukui Prefecture; these include the Takahama, Ohi, Mihama, and Tsuruga Nuclear Power Stations, and they are collectively located between 480 and 530 km from the Fukushima accident area. The spatial distances to which various externalities extend from a reactor site were clarified, and the extents of related external costs were measured. Fourteen reactors are located within Fukui Prefecture, which is the highest number of reactors for any single prefecture in Japan; it comes as no surprise, then, that Fukui Prefecture accounts for an extremely high proportion of Japan's nuclear energy capacity. As Japan deliberates how to manage the major challenges it faces as the country's energy policy undergoes a significant transformation, it is vital when looking at various energy options to evaluate not only individual consumer costs, but also social costs that stem from various external costs.

This paper is organized as follows. Section 2 explains the costs and benefits of nuclear power plants, and the relevant combinations of attributes. Section 3 provides a review of the pertinent literature. Section 4 describes the study area and data used in analysis, and provides summary statistics. Section 5 outlines the analytical model and presents estimation results. Section 6 interprets the estimation results, and provides discussion after calculating the external costs of nuclear power plants. Section 7 ends the paper by providing final conclusions.

2 Costs and benefits of nuclear power plants

An attempt to look at the various costs and benefits of a nuclear power plant requires, first, an examination of who pays for, and who benefits from, the various costs and benefits in question.

First, let us look at the benefits derived from nuclear station placement. The most obvious benefit of establishing a nuclear power station is the station's ability to generate electric power. The electricity generated at a nuclear power station is sent to households and enterprises, where it is put to use supporting daily life and various industrial activities. Furthermore, a nuclear power plant results in much lower volumes of carbon dioxide emissions than fossil fuel-fired power plants during power generation, resulting in widespread social benefits. Furthermore, a nuclear power plant contributes to employment; this is a benefit especially in a country like Japan, which faces a stagnant economy and an increasing unemployment rate. The benefits of employment accrue not only during plant construction, but also during normal operation and maintenance. While employment at nuclear power stations has spillover effects throughout the market, the beneficiaries of this benefit are primarily limited to those who live near the nuclear reactor site.

Furthermore, improvements in the budgets of communities where reactors are located can also be considered types of benefits. Various financial incentives are provided to prefectures and towns that host reactor sites, such as grants paid under the Three Power Source Development Laws (*Dengen-sanpoh*: three legal acts that provide a mixture of financial incentives to facilitate the locating of power generation units). Research by Miyoshi (2011) shows that four towns within Fukui Prefecture (Tsuruga, Mihama, Ohi, and Takahama) with nuclear reactors have comparatively stable and healthy finances, and are not affected by the financial troubles that other towns lacking nuclear power stations commonly face. However, it should be pointed out that such financial incentives do not offer any sort of permanent stability, since nuclear power plants depreciate over time, and so annual revenues from fixed-asset taxes will fall from year to year, and grants will be limited to the specific decommissioning timeframe of any particular reactor.

Furthermore, one must not overlook the fact that local communities that host reactor sites receive not only financial benefits from the public sector, but also enormous financial contributions from power utilities. For example, the Kansai Electric Power Company made payments to Fukui Prefecture of JPY5 billion for electrification work along the JR Obama line, and close to JPY3 billion for a power transmission and direct current power project along the JR Hokuriku line that connects Tsuruga and Nagahama. While the exact purpose of these payments is unclear, and it cannot be said for certain these were rewards were made in exchange for hosting nuclear power stations, it is clear that the residents of Fukui Prefecture did receive some sizeable financial benefits from power companies.

Next, the costs incurred by a community in hosting a nuclear power plant should be assessed. The most obvious cost is the risk associated with radioactive pollution during normal plant operation and from nuclear accidents. Comparatively, the area under this risk will be significantly smaller and more localized than the widespread region that will receive the benefit of the plant's power generation. Only local constituencies that host nuclear power plants and the immediate community around a reactor site are subject to the risk of radioactive contamination. While the area affected by radioactive contamination partially overlaps with some of the area that receives the benefit of power supplies, there is essentially a considerable gap between the two regions. As demonstrated by Kajita (1979), the benefit of a nuclear power plant fades with distance from the reactor site and is widely distributed, whereas the risk is concentrated within a limited area. In other words, the example of a nuclear power plant reveals that prior to the Fukushima nuclear accident, power utility companies were clear beneficiaries of nuclear power in the benefit-receiving region, and further from a reactor site, and the Ministry of Economy, Trade and Industry could collectively and institutionally represent the rarefied benefits of nuclear power. In contrast, it is easier for risk to be ignored and to accumulate steadily in the region subject to nuclear risk, since the residents are less likely to organize and aim for opportunities to voice their interests as effectively as those in benefit-receiving regions.

Consequently, it is very important to evaluate and clarify the scope of the externalities imparted on local communities around a reactor site, since such areas have fewer opportunities to voice their interests, and in such areas, risks are more likely to be left unaccounted for.

3 Previous research

3.1 Measurement methods for nonmarket assets

Many diverse approaches have been developed for assessing the benefits of nonmarket assets, which are not traded openly in a normal market environment; these assets include the externalities of nuclear power plants. As per research conducted by Hidano (1997), methods for evaluating nonmarket benefits can be categorized in terms of the data used, which typically fall into those representing human awareness, human action, or market activity.

A typical approach that focuses on awareness is the contingent valuation method, which uses surveys to obtain willingness-to-pay and willingness-to-accept values directly from survey participants; it is useful for assessing far-reaching perceptions of environmental quality and social infrastructure. However, one challenge inherent in the contingent valuation method is that different types of bias can skew the survey results.

A typical approach that focuses on human action is the travel cost method, which measures the benefits that stem from actual individual activity that makes use of environmental assets (e.g., recreational travel). One advantage of this method is the ability to measure benefits at the individual level. However, a challenge inherent in the travel cost method is that useable data that correctly reflect and capture subject activity tend to be rather limited, and this poses difficulties for modeling the benefits to study subjects.

Finally, a typical approach that focuses on market activity is the hedonic price approach. The hedonic price approach is typically used to explain real estate prices (i.e., the explained variable), using variables that represent environmental quality and social infrastructure; by estimating the effect on land prices, hedonic functions can be used to explain the benefits of the various variables. Although the hedonic price approach does not allow for as wide an analysis as the contingent valuation method, and requires the assumption that the real estate market is in a state of full competition, this method is a convenient way of evaluating the overall benefits of variables that indirectly have boosting effects in a market environment. Additionally, with this method, real estate price functions can be accurately estimated with relative ease, making it highly practical. Finally, the method is superior to other methods in terms of objectivity and the continuity of the data used.

Naturally, when measuring the benefits of nonmarket assets, an evaluation method capable of assessing the target subject should be chosen based on the aforementioned characteristics. The hedonic price approach is appropriate for this research, because the costs and benefits of nuclear power plants are reflected in land prices through capitalization, as demonstrated in earlier sections. The hedonic price approach was also chosen due to the availability of reliable land-price data, and the method was used to evaluate both the costs and benefits of nuclear power plants.

3.2 Previous research using the hedonic method

Rosen (1974) established a theoretical economic basis for using the hedonic price approach. Ever since, many examples of economic assessments using hedonic methodologies have been developed, to assess projects that exhibit both positive and negative externalities.

Research from Sawamura and Ishikawa (2011) covering a 25-year period (1985–2010) used the hedonic price approach to assess 30 unpopular public facilities, both domestically and abroad. Indeed, hedonic methodologies have been used to evaluate a wide range of unpopular facilities, such as chemical treatment plants, incineration plants, and lead-smelting plants.

However, there have been only a few hedonic assessments of nuclear power stations: those of Nelson (1981) and Gamble and Downing (1982) on the Three Mile Island nuclear accident, and more recently, that by Yamane et al. (2011a, 2011b). However, other examples could not be found for the case of Japan.

Nelson (1981) assessed land prices in an area 20 miles (approximately 32 km) around Three Mile Island, both before and after the nuclear accident there. Nelson found no significantly statistical change in land prices before and after the accident, and discusses those findings. Gamble and Downing (1982) also found no statistically significant changes in land prices before and after the Three Mile Island accident.

Yamane et al. (2011a) examined land prices in Aomori Prefecture between 1976 and 2004, and found that land prices fell during periods of heightened concern among local communities vis-à-vis radiation contamination risks when plans were announced to build nuclear facilities within the prefecture. Yamane et al. (2011b) surveyed rents in 2003 and 2008 within a 20-km radius of each reactor in Japan, and found that public welfare increased at greater distances from a nuclear reactor. However, from our perspective, this study is marked by several problems.

The first is that the effects of the Fukushima nuclear accident are not represented at all, because all the data used were collected prior to that accident. The second is that the land price function used does not fit the data well: with the freedom adjusted, it shows a coefficient of determination of only 0.61. Hence, the level to which regional factors are reflected in the findings is suspect. (This will be reviewed further in Section 5.1.) Additionally, no research examples could be found that evaluate how nuclear power plant externalities change over distance, or regional differences in terms of externalities.

4 Study region and data

4.1 Description of study region

The 40-km zone around each of four nuclear power stations in Fukui Prefecture was chosen as a study region, for a total of four study regions. Prior to the Fukushima nuclear accident, the four stations annually produced around 76,000,000,000 kWh of electricity.[1] As of February 2013, however, all reactors were offline, except units 3 and 4 at the Ohi Nuclear Power Station. Figure 1 shows the location of these nuclear power stations in Fukui Prefecture, and Table 1 provides the details of each reactor.

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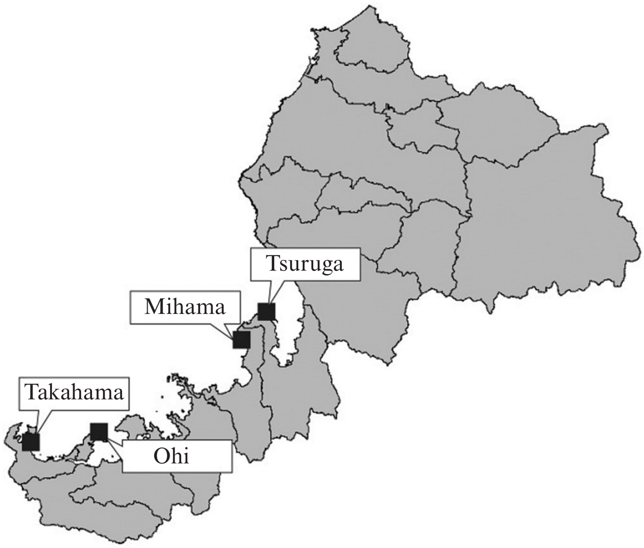
[1] Despite some variation by year, according to the 2010 Fukui Prefecture Statistical Ledger (2012), annual power production volumes equal 76,000,000,000 kWh.

Figure 1. Locations of four nuclear power stations in Fukui Prefecture.



Source: Created by author.

4.2 Data descriptions

For data with regard to the study region, prefectural land price data were selected, with land prices indicated for residential areas. For data reflecting the period prior to the Fukushima accident, public land price data from January 1, 2011, as well as prefectural survey data from July 1, 2010, were used. For data reflecting the period after the Fukushima accident, public land price data from January 1, 2012, as well as prefectural survey data from July 1, 2012, were used. Although the legal bases of prefectural land price data and public land price data differ, both datasets are theoretically identical, in that both sets of land prices have been appraised as normal land prices by a real estate appraiser. Therefore, we consider both datasets identical. Second, the following data types were collected for each zone in the study region.

Geographic information system (GIS) data were created from land price data, prefectural survey data, and location and other data that had been drawn from the "National Land Numerical Information" dataset provided by the Ministry of Land, Infrastructure, Transport and Tourism. However, this dataset did not contain information for the "Distance to road in front" variable. Consequently, information from the "Land General Information System" dataset from the Ministry of Land, Infrastructure, Transport and Tourism was also included. Furthermore, GIS data from the "National Land Numerical Information" dataset were downloaded, and the

Table 1. Details of four nuclear power stations in Fukui Prefecture.

Name of plant	Hosting constituency	Operator[a]	Rated output; first year of operation
Takahama Nuclear Power Station	Takahama Town	Kansai Electric Power Company, Inc.	Unit 1 (826 MW, 1974) Unit 2 (826 MW, 1975) Unit 3 (870 MW, 1985) Unit 4 (870 MW, 1985)
Ohi Nuclear Power Station	Ohi Town	Kansai Electric Power Company, Inc.	Unit 1 (1,175 MW, 1979) Unit 2 (1,175 MW, 1979) Unit 3 (1,180 MW, 1991) Unit 4 (1,180 MW, 1995)
Mihama Nuclear Power Station	Mihama Town	Kansai Electric Power Company, Inc.	Unit 1 (340 MW, 1970) Unit 2 (500 MW, 1972) Unit 3 (826 MW, 1976)
Tsuruga Nuclear Power Station	Tsuruga City	Japan Atomic Power Company, Inc.[b]	Unit 1 (357 MW, 1970) Unit 2 (1,160 MW, 1987)

[a] Power suppliers in Japan operate regional monopolies that each serve a single coverage area; there are 10 regional utilities throughout the country. The Kansai Electric Power Company primarily serves the Kinki Region of Japan, and among the 10 utilities, its power-generation mix contains the highest percentage of power coming from nuclear.
[b] The Japan Atomic Power Company is owned by nine of the 10 power utilities (Okinawa Electric Power Company being the exception). The company's main mission is to build and operate nuclear plants, and produce power. The Tsuruga Nuclear Power Plant provides electricity for Chubu Electric, Hokuriku Electric, and Kansai Electric.
Source: Created by author using data from the home pages of the Kansai Electric Power Company (http://www.kepco.co.jp/) and the Japan Atomic Power Company (http://www.japc.co.jp/index.html).

"Distance from reactor" variable was measured using GIS software.[2] Data were also downloaded from the "National Land Numerical Information" dataset, to obtain further information on the quality of life and the social infrastructure of each zone in the study region. Regional information variables such as "Population density" and "Proportion elderly" were obtained as GIS data from the dataset "Japan in Figures: 2005 National Survey data (small region) from the Ministry of Internal Affairs and Communications." More recent national survey data from 2010 were not used, because this dataset does not have appropriate labor force information, and it was deemed insufficient for the analysis. Finally, GIS data were used to extract regional weather information from the "National Land Numerical Information" dataset.

[2] i.e., MANDARA (ver.9.36).

The following is a list of data items gathered for analysis, with summary statistics outlined in Tables 2 and 3.[3]

Table 2. Summary statistics: pre-Fukushima accident dataset.

	Minimum	**Maximum**	**Average**	**Standard deviation**
Rent (JPY/m^2)	122.500	4825.000	1779.623	1090.058
Parcel area (m^2)	69.000	1069.000	294.162	171.878
Width of road in front (m)	2.000	28.000	6.371	3.109
Sewer availability (yes, 1; no, 0)	0.000	1.000	0.908	0.289
Distance from reactor (km)	2.357057	40.982	27.768	10.710
Existence of train station (yes, 1; no, 0)	0.000	1.000	0.423	0.495
Distance from port (km)	0.761	39.397	18.140	9.431
Distance from hospital (km)	0.025	5.709	0.789	0.984
Distance from post office (km)	0.008	3.866	0.716	0.646
Distance from city (km)	0.423	32.416	9.067	7.978
Distance from highway (km)	0.650	27.830	7.737	6.544
Population (people)	0.000	3269.000	713.592	602.669
Population density (people/km^2)	0.000	12595.460	2757.378	2711.406

(*Continued*)

[3] Analysis was performed using R (ver. 2.12.0).

Table 2. Continued.

	Minimum	Maximum	Average	Standard deviation
Proportion elderly (%)	0.000	0.576	0.242	0.092
Proportion high income (%)	0.000	0.288	0.151	0.048
Deepest snow cover (cm)	0.000	123.000	36.915	13.430
Air temperature (0.1°C)	120.000	153.000	141.721	5.805

Note: In cases where data were not available at the municipal level for "Population," "Population density," "Proportion elderly," and "Proportion high income," these variables were assigned the minimum value of zero.
Source: Created by author using data from Section 4.2.

4.2.1 Information on land prices and on land price surveys

1. Rent: Price calculated by multiplying 5% interest on the land prices found in the land price data and the prefectural survey data (JPY/m^2)
2. Parcel area: Area of each survey point (m^2)
3. Distance to road in front: Distance to the road in front of each survey point (m)
4. Sewer availability: Categorization based on existence of sewer system (yes, 1; no, 0)

4.2.2 Power generation information

1. Distance from reactor: Distance from each survey point to the nearest nuclear power station (km)

Table 3. Summary statistics: post-Fukushima accident dataset.

	Minimum	Maximum	Average	Standard deviation
Rent (JPY/m^2)	123.500	5,150.000	1,875.000	1,158.951
Parcel area (m^2)	69.000	1,069.000	297.772	173.994
Width of road in front (m)	2.000	28.000	6.242	2.985
Sewer availability (yes, 1; no, 0)	0.000	1.000	0.910	0.286
Distance from reactor (km)	2.357	40.982	27.832	10.759
Existence of train station (yes, 1; no, 0)	0.000	1.000	0.422	0.495
Distance from port (km)	1.087	60.647	25.968	14.576
Distance from hospital (km)	0.026	5.709	0.788	0.980
Distance from post office (km)	0.026	3.866	0.725	0.649
Distance from city (km)	0.360	32.416	9.377	7.983
Distance from highway (km)	0.650	27.830	7.826	6.565
Population (people)	36.000	3,269.000	716.063	603.929
Population density (people/km^2)	7.889	12,595.460	2,741.284	2,719.225
Proportion elderly (%)	0.021	0.576	0.244	0.091
Proportion high income (%)	0.035	0.288	0.151	0.047
Deepest snow cover (cm)	0.000	123.000	36.817	13.188
Air temperature (0.1°C)	120.000	153.000	141.675	5.823

Source: Created by author using data from Section 4.2.

4.2.3 Information on life convenience and social infrastructure

1. Existence of train station: Existence of a train station within 1,500 m of each survey point (yes, 1; no, 0)
2. Distance from port: Distance to the nearest port from each survey point (km)[4]
3. Distance from hospital: Distance to the nearest hospital or clinic from each survey point (km)
4. Distance from post office: Distance to the nearest post office from each survey point (km)
5. Distance from city: Distance to the nearest city with a population over 50,000 people from each survey point (km)
6. Distance from highway: Distance to the nearest highway interchange from each survey point (km)

4.2.4 Information on status of region

1. Population: Town population at survey point (people)
2. Population density: Population density of the population at survey point (people/km^2)
3. Proportion elderly: Proportion of population over 65 years of age at survey point (%)
4. Proportion high income: Percentage of those reporting employment in "specialized or technical fields" or "management," among those employed in the towns at each survey point (%)[5]
5. Deepest snow cover: Deepest annual snow cover along a 1-km mesh at each survey point (cm)
6. Air temperature: Annual average air temperature along a 1-km mesh at each survey point (0.1°C)

5 Analysis using the hedonic price approach

5.1 Model selection

Research, such as the current study, that applies the hedonic price approach to small 1–2-km areas that cover several prefectures faces some challenges. One

[4]Ports for this study include specific main ports, main ports, and regional ports, as defined by the national law on ports.

[5]Such occupations are thought to correlate with higher incomes.

such challenge comes in determining the distance to the nearest train station, an explanatory variable used in many hedonic assessments. This variable can be extremely useful in analyzing small regions, but this is not necessarily so when the study region covers over 40 km; this is because an area 500 m from a station within a large city differs drastically from an area 500 m from an unmanned station in a very rural area. To address such issues, other variables are required to explain differences among regions. In the current study, the variables within the "regional status" category were used to explain regional differences. Such regional variables were not used by Yamane et al. (2011b), and this could possibly explain the low coefficient of determination (0.61) they observed.

The effects of adjacent urban areas were also not considered in the current study. The distance from cities with populations exceeding 150,000 was used as an explanatory variable, but there are few cities used in the assessment with populations exceeding 100,000. Even for the four nuclear power stations in Fukui Prefecture, the two nearest large towns (Tsuruga and Maizuru) are located about 15 km from the reactor sites, and neither has a population of even 100,000. Ignoring the presence of smaller built-up areas could lead to the conclusion that land prices increase at greater distances from nuclear power stations, but most nuclear power stations are located in rural areas, and land prices naturally increase as one drawer nearer to an urban area (and further from the plant). Consequently, this research uses cities with populations exceeding 50,000 as an explanatory variable in the regional status information, in order to perform more accurate analysis.

In hedonic assessments, there are no *a priori* restrictions when deriving formulae to explain land prices; in practical applications, there is some room to choose formulae based on the best fit of the estimation, as well as the theoretical propriety of the estimated parameters. Using this approach, the following formulae were selected for this research. Then, the coefficient is estimated by ordinary least squares. The following model is most applicable to the formula.

$$\begin{aligned}\ln(RENT) = {} & \alpha_0 + \alpha_1 \ln(AREA) + \alpha_2 \ln(ROAD) + \alpha_3 SEWER + \alpha_4 \ln(PLANT) \\ & + \alpha_5 DSTAT + \alpha_6 PORT + \alpha_7 HOS + \alpha_8 POST + \alpha_9 CITY \\ & + \alpha_{10} HWAY + \alpha_{11} POP + \alpha_{12} DENS + \alpha_{13} ELD + \alpha_{14} RICH \\ & + \alpha_{15} SNOW + \alpha_{16} TEMP + \varepsilon\end{aligned}$$

RENT: Rent; a_i: parameter; *AREA*: Parcel area; *ROAD*: Width of road in front; *SEWER*: Existence of sewer system or not; *PLANT*: Distance from reactor; *DSTAT*: Existence of station; *PORT*: Distance from port; *HOS*: Distance from hospital; *POST*: Distance from post office; *CITY*: Distance from city; *HWAY*: Distance from highway; *POP*: Population; *DENS*: Population density; *ELD*: Proportion elderly; *RICH*: Proportion high income; *SNOW*: Deepest snow cover; *TEMP*: Air temperature; ε: Error coefficient.

AREA, *ROAD*, and *SEWER* are variables that explain individual land characteristics; *DSTAT*, *PORT*, *HOS*, *POST*, *CITY*, and *HWAY* explain the convenience of the location. The reasons for entering the regional status information into the model were explained previously in this section. "Existence of train station" was used as a dummy variable. In general, as the distance from a station increases, the region shifts from one that uses railway-based transportation to one that uses either buses or cars; as such, this variable does not have a linear effect on the study results. Additionally, a dummy variable that explains the difference between public land price data and prefectural survey data was incorporated into our model on trial, but it is not significant. Therefore it is dropped.

The positive and negative effects of model coefficients are considered in this section, with the exceptions of *AREA* and *PLANT*, for which no such relationship exists. Land prices typically increase with larger parcel areas, but in reality, most large parcel area locations are all located outside urban areas, and so it is difficult to know if the *AREA* coefficient has a positive or negative effect. Additionally, power plants represented by *PLANT* have been shown to have both positive and negative effects, and so the effects of this variable were also not known.

The variables *ROAD*, *SEWER*, *DSTAT*, *POP*, *DENS*, *RICH*, and *TEMP* were considered to have positive coefficients. When a road in front was over 6 m wide, the convenience of the location was believed to increase on that basis, since it would facilitate a higher degree of urban-like development. Utility increased when a proper sewer system was in place. Convenience was also assumed to increase when a station existed within 1,500 m of a survey point. Higher population densities also suggest that more people are collecting in an active area. Higher rents suggest that people with higher incomes live in that area. Finally, areas with better weather (i.e., higher temperatures) are more likely to be favored over other areas.

The variables *PORT*, *HOS*, *POST*, *HWAY*, *CITY*, *ELD*, and *SNOW* were expected to have negative coefficients. This is due to the positive effect on convenience that comes with having good access to ports, hospitals, post offices, highways, and large cities. Finally, it was generally assumed that heavy snowfall contributed to less convenience.

5.2 Precision and confidence of estimation model

One challenge faced when applying hedonic assessments is the issue of multicollinearity, which significantly reduces the reliability of a model that is based on variables that bear strong correlations with one another. Consequently, analysis in this research was conducted while observing variance inflation factor (VIF) values to determine the presence of multicollinearity. Generally, VIF values that exceed 10 indicate with certainty the presence of multicollinearity.

We conducted an estimation of all the samples, in order to check the applicability of the land price function; the results are shown in Tables 4 and 5. Table 4 shows the results using pre-Fukushima accident data, and Table 5 shows results using post-Fukushima accident data.

As seen in Tables 4 and 5, almost every variable is significant, and the positive and negative characteristics of the coefficients are as explained previously.

Furthermore, a coefficient of determination that exceeded 0.8 was observed after adjusting the degrees of freedom, and this indicates a good fit with the data. The reason for the good fit is that the model includes variables that more accurately reflect regional conditions. Furthermore, the VIF values (which indicate the presence of multicollinearity) were all under 3, indicating that there were no problems with multicollinearity. An F-test to determine the significance of the model garnered good results. In conclusion, test results indicate that the land price formula used possesses a significant level of precision and confidence.

Table 4. Estimates (pre-Fukushima accident data).

Variable	Coefficient	*p*-value	VIF
Constant	4.825***	0.0000207	
ln(*AREA*)	–0.2318***	0.00000159	1.286705
ln(*ROAD*)	0.08422	0.208296	1.141369
SEWER	0.2381**	0.003827	1.171615
ln(*PLANT*)	0.05888	0.242399	1.464497
DSTAT	0.05869	0.219487	1.197116
PORT	–0.0006677	0.713642	1.509537
HOS	–0.09768**	0.002033	2.028857
POST	–0.09768***	0.0000697	1.739114
CITY	–0.009548*	0.017471	2.183508
HWAY	–0.01997***	0.000000493	1.386824
POP	0.0001307**	0.001139	1.236891
DENS	0.00007405***	0.0000000015	2.213604
ELD	–0.9323***	0.000747	1.328420
RICH	1.64**	0.002333	1.322144
SNOW	–0.0074***	0.000174	1.409999
TEMP	0.02537***	0.0000574	2.801688
Sample size Adjusted R-squared	268 0.8027		

Note: VIF: variance inflation factor. ***: Significance level below 0.1%; **: 1% significance; *: 5% significance.

5.3 Analysis using distance data from nuclear power stations

The first objective of this research was to estimate the degree to which various nuclear power plant externalities affect various regions. The study area was broken down according to distance from the nuclear power station, and divided into regions: within 40 km, 35 km, 30 km, 25 km, 20 km, and 15 km from the

Table 5. Estimates (post-Fukushima accident data).

Variable	Coefficient	*p*-value	VIF
Constant	3.644**	0.00117	
ln(*AREA*)	–0.2345***	0.0000016	1.309285
ln(*ROAD*)	0.1234†	0.05788	1.166308
SEWER	0.2327**	0.00450	1.219265
ln(*PLANT*)	0.07863	0.15936	1.827658
DSTAT	0.08484†	0.06766	1.156423
PORT	0.002181	0.54331	2.523277
HOS	–0.07411*	0.01741	2.050775
POST	–0.1952***	0.00000965	1.722295
CITY	–0.1952*	0.03678	2.026361
HWAY	–0.02173***	0.000000228	1.579754
POP	0.0001114**	0.00472	1.225059
DENS	0.00006736***	0.0000000118	2.120269
ELD	–1.174***	0.0000179	1.337500
RICH	1.561**	0.00179	1.261885
SNOW	–0.004937**	0.00998	1.441284
TEMP	0.03204***	0.0000013	3.107639
Sample size	272		
Adjusted R-squared	0.8008		

Note: VIF: variance inflation factor. ***: Significance level below 0.1%; **: 1% significance; *: 5% significance; †: 10% significance.

Table 6. ln(*PLANT*) coefficients and *p*-values.

	Pre-Fukushima nuclear accident		**Post-Fukushima nuclear accident**	
	Coefficient	***p*-value**	**Coefficient**	***p*-value**
Within 40 km	0.05888	0.242399	0.07863	0.15936
Within 35 km	–0.04782	0.497765	–0.002895	0.969531
Within 30 km	0.04448	0.573412	0.1317	0.136544
Within 25 km	0.1151	0.23897	**0.2267***	**0.048594**
Within 20 km	**0.3216****	**0.003603**	**0.3611****	**0.001376**
Within 15 km	**0.4279***	**0.02386**	**0.3771***	**0.012432**

Note 1) **: 1% significance; *: 5% significance.
Note 2) Various zones were determined by rounding down fractions. For example, "within 15 km" includes regions within 15 km plus a fraction (i.e., <16 km). This was done to achieve an ample sample size, and doing so assisted in later calculations of externalities.
Note 3) The "within 15 km" zone featured a small sample size consisting of fewer than 50 observations, and so it could feature strong multicollinearity; it is nonetheless included here as a reference.

reactor site. Analytical results with regard to these various zones are shown in Table 6, which shows ln(*PLANT*) coefficients and *p*-values, with significance levels over 1%, and coefficients and *p*-values over 5% highlighted in bold/grayed text for emphasis. Further discussion of the analytical results is presented in Section 6.

6 Interpretation and discussion of analytical results

6.1 Interpretation of analytical results

The analytical results indicate a good fit with the data, with the coefficients of determination exceeding 0.75 with the freedom adjusted in all cases for all distance zones, in both the pre-Fukushima and post-Fukushima datasets. The signs of the coefficients were as expected, with almost all VIF values exceeding 4, other than that for the within-15 km zone. Consequently, it is believed that the estimation results demonstrate a good level of reliability.

Looking at the ln(*PLANT*) variable, there was a significant relationship between land prices and nuclear power stations in the within-20 km zone before the Fukushima nuclear accident, with a positive coefficient indicating land prices increased at distances from nuclear power stations. This suggests that a nuclear power station imparts a negative externality on this region. In the post-Fukushima data, this relationship extends even further to also include the within-25 km zone, which also showed significant results. Despite the lack of a significant difference, large coefficients were still observed in this dataset, with 12% observed in the within-20 km zone, and 96% observed in the within-25 km zone.

Based on these results, it is clear that areas negatively impacted by nuclear power plant externalities are growing larger, because significant results were observed up to the within-25 km zone. The area negatively impacted is expanding in size; moreover, the large coefficients suggest that the negative externalities from a nuclear power plant are also increasing in intensity. These results suggest that popular opinions of nuclear facilities are trending toward disapproval following the Fukushima accident, as perceptions change regarding the scope and extent of nuclear accidents. This result is consistent with the actual change in the local government's attitude toward the nuclear power plant following the severe Fukushima accident. The local government, which had previously ignored the possibility of a nuclear accident, has started to make evacuation plans in the wake of the Fukushima accident.

It should be pointed out, however, that these results differ significantly from those observed in the case of the Three Mile Island accident: Nelson (1981) and Gamble and Downing (1982) demonstrated that there was no change in nearby land prices before and after the accident. The fact is that while there were no changes in land prices for land in the vicinity of Three Mile Island that had been directly impacted by the accident, changes were observed in Fukui Prefecture, which was not directly affected. Three possible reasons might explain this.

The first is the scale of the accident. The Fukushima nuclear accident was only the second Level 7 nuclear accident in human history, according to the international scale for measuring nuclear accidents; this differentiates it from the Level 5 status given to the Three Mile Island accident. Hence, it is certain that the scales of damage inflicted by these accidents were quite different, and so it may be that the Fukushima accident had a comparatively more lasting impact on risk awareness among the people surveyed in each study.

The second reason is the difference in the movements of labor for each accident. The Three Mile Island accident resulted in a large amount of work near the accident site, which attracted many laborers. This collection of labor increased the demand for housing, which might have offset the negative impacts of the accident itself.

A third reason can be found in differences in compensation laws between Japan and the United States. Nelson (1981) emphasizes how in the United States, high expectations for generous federal and state compensation to accident victims may have contributed to a lack of change in land prices in the vicinity of Three Mile Island. Gamble and Downing (1982) report similar findings. Compensation related to nuclear accidents is quite clear-cut in the United States, on account of the Price–Anderson Nuclear Industries Indemnity Act, which stipulates upper limits to compensation amounts paid by private nuclear operators during a nuclear disaster (approximately USD10 billion), with any remaining compensation to be paid by the federal government. The existence of this legal framework may contribute to a sense of security among local populations, should they be affected by damage from a nuclear accident. In comparison, under Japanese law pertaining to compensation for nuclear accidents, private operators are responsible for unlimited liability.[6] Consequently, there is no guarantee an operator will be protected from compensation claims, should a nuclear accident occur; this was recently observed in the case of Tokyo Electric Power, which was restructured following the Fukushima nuclear accident. This leads to uncertainty regarding whether compensation will be quickly and adequately handled, and these differences in compensation systems could influence or otherwise give rise to differences in attitude between the United States and Japan with regard to nuclear accidents.

6.2 External costs of nuclear power plants

The external costs of nuclear power plants were calculated using estimate values for the within-25 km zone derived from post-Fukushima accident data. External costs are expressed as annual figures, since the aforementioned estimates of land prices from public and survey records were also converted to yearly rent values by applying a 5% interest factor. The following explains the calculation method used to estimate external costs.

Taking the natural log of the rent function,

$$\begin{aligned}\ln(RENT) = \alpha_0 + \alpha_1 \ln(AREA) + \alpha_2 \ln(ROAD) \\ + \alpha_3 SEWER + \alpha_4 \ln(PLANT) + \alpha_5 DSTAT \\ + \alpha_6 PORT + \alpha_7 HOS + \alpha_8 POST + \alpha_9 CITY \\ + \alpha_{10} HWAY + \alpha_{11} POP + \alpha_{13} DENS + \alpha_{13} ELD \\ + \alpha_{14} RICH + \alpha_{15} SNOW + \alpha_{16} TEMP + \varepsilon\end{aligned}$$

in terms of the explanatory variables, the rent at any point i can be described by

$$RENT^i = \exp\{\alpha_5 \ln(PLANT^i) + X^i\}.$$

X^i: sum of all terms to the right outside $a_5\ln(PLANT^i)$

The point at which the effects of a nuclear power plant are zero is point *T*, and the distance from a reactor is *T* (km). Assuming that the conditions

[6] According to Japanese nuclear compensation law, the government is responsible for providing support for accidents that cannot be independently covered by a private operator, but the level of compensation support is not clearly defined.

between points i and t are constant other than the distance from the reactor, rent at point t can be described as

$$RENT^t = \exp\{\alpha_5 \ln(T) + X^i\},$$

with the difference between rent at points i and t given by the equation

$$RENT^i - RENT^t = \exp\left\{\alpha_5 \ln(PLANT^i) + X^i\right\} - \exp\left\{\alpha_5 \ln(T) + X^i\right\}, \quad (1)$$

which describes the external costs of a nuclear power station. The external costs describe the costs as a value per square meter, which can be used to derive the total external cost; this is done by multiplying that value by the surface area of the region affected by the plant. However, the true external costs of a reactor site cannot be measured merely by multiplying higher rent values by some particular area around a reactor site. This is because the land price function presented here was developed while taking into account only residential areas; as such, it is not appropriate to apply it to other, nonresidential areas. Consequently, external costs were assessed by undertaking the following procedures.

Points 26 km from a reactor site where no significant effects were observed were deemed to receive zero effect from a reactor, and thus mark the point where reactor externalities converge to zero.

1. From equation (1), externalities were calculated per square meter from public land price records and land price survey data.
2. Average externalities per square meter for each town block were derived from the external costs of land prices from public and survey data for each town block observed at the nearest distance from a reactor.
3. Data describing average total floor area (m^2) per residence in each town block and total number of housing units were derived from 2005 national survey data (small region).
4. Total external costs were calculated by multiplying the value in (2) by the average total floor area per residence in each town block and the total number of housing units.

This calculation can be described through the following equation:
Total external costs =

$$\sum_i (\textit{average external cost per square meter of ith town block} \\ \times \textit{average total floor area per housing unit in ith town block} \\ \times \textit{total number of housing units in ith town block})$$

This equation derived a total externality cost of JPY4,352,694,450, with an average of JPY33,731. Dividing the total external costs by the annual power output of these four nuclear power stations in Fukui Prefecture yields an external cost of JPY0.06/kWh. The assessment results are listed in Table 7.

These external costs can be incurred even if the nuclear power plant in question were not operating. In Japan, all units were offline—except those at the Ohi and Takahama Nuclear Power Plants—at the time the public land price data used for the post-Fukushima assessments were released (January 1, 2012); only the Ohi Nuclear Power Plant was online when the Prefecture survey data were released (July 1, 2012). Nonetheless, significant effects were still observed vis-à-vis land prices. Similar research by Hite et al. (2001)—who compared various effects of radioactive waste disposal sites that were both still in operation and shut down—also showed downward pressure on real estate prices, even after such a facility ceased operations. There is the possibility a similar tendency may be observed for Japanese nuclear power plants; it may even render such facilities unpopular, if there is the perception that they adversely impact land prices even after being decommissioned. The negative effects may be exacerbated following decommission, and so the JPY0.06/kWh value reckoned in this study may actually be an underestimation of the true cost.[7]

Attempts to interpret such external costs require caution. For example, one could argue that even when reaching levels as high as JPY4.35 billion/year, such external costs could be compensated for by government support initiatives. However, such reasoning is erroneous, because changes in rent prices reflect the extra burden on consumers after subtracting the benefits from the costs of a certain project. Consequently, the external costs estimated in this study reflect total costs after accounting for benefits like extra employment and government subsidies, versus costs like the risk of radioactive contamination. In other words, only the net negative impacts are shown in this study, after cancelling out the positive effects of a nuclear power plant. However, it should also be pointed out that the full set of benefits is not reflected in the externality assessments performed here; electricity in Japan can be consumed at essentially constant prices throughout the entire country, and so nuclear power plants provide the benefit of electricity to regions located far away that do not have a direct spatial relationship with the reactor site.

In conclusion, the current study demonstrated that after comparing the benefits enjoyed by a community around a reactor (e.g., higher employment and government grants) to the costs (e.g., risk of radioactive contamination), the cost side of the equation is drastically more significant, and compensation at

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[7] It should be noted that at the time of this study (February 2013), the possibility of reactor restarts remained, and the results could potentially reflect the existence of public acceptance of reactor restarts. Furthermore, the Tokai Nuclear Power Plant is the only commercial nuclear power plant in Japan to have been decommissioned. As no research could be found that looks at changes in public perception before and after the Tokai decommissioning, strictly speaking, this study could not draw conclusions on whether or not the public views nuclear reactors unfavorably even after decommissioning.

Table 7. Yearly external costs of nuclear power stations.

Total external cost	JPY4.35 billion
Average external cost per household	JPY33,731
External costs per kilowatt hour of nuclear power output	JPY0.06

current levels fall short of covering costs that equal approximately JPY4.35 billion/year. Put another way, the nearly 400,000 people who reside near nuclear reactor sites owned by Kansai Electric Company are forced to bear an extensive extra burden in order for 20 million people to enjoy the benefit of the electric power provided within Kansai Electric Company's supply area.

6.3 Incidence of cost and benefit

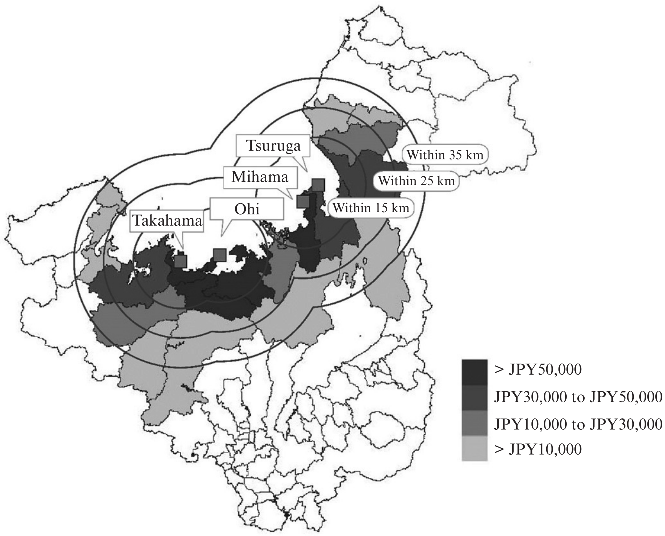
Ideally, the external costs described in Section 6.2 should be borne by electric companies or, by extension, the consumers of the electricity produced. However, under Japan's current electric power regime, customers are not obliged to compensate for external costs resulting from power generation, which are ultimately and unilaterally leveraged against the local communities that reside near nuclear power plants. This transfer of externalities translates into a situation where power customers enjoy the benefits of receiving access to cheap power. The following is an attempt to estimate the financial benefit.[8]

According to the results of the 2012 Survey of Household Finances executed by Japan's Ministry of Internal Affairs and Communications, the average annual power consumption of households with two or more occupants was 5,306 kWh. Second, Kansai Electric Power Company generates 48% of electricity via nuclear power. Therefore, using the following equation, it can be said that those residents who receive power within Kansai Electric's service area are realizing savings of nearly JPY152/year.

External cost per 1 kWh
× annual average power consumption
× proportion of electricity at Kansai Electric
provided by nuclear = JPY152/year

[8]This calculation is based on data for Kansai Electric Company, since nearly all of the power produced by nuclear power plants in Fukui Prefecture is delivered to Kansai Electric Company's service area.

Figure 2. Annual external costs per residence in each city and town.



Source: Created by author.

Table 8. Annual external costs per residence in each city and town.

City/ Town	Ine Town	Sabae City	Takashima City	Kyotanba City	Nagahama City	Miyazu City
External cost	299	415	1,978	2,095	2,467	3,471
City/ Town	Nantan City	Echizen Town	Echizen City	Ayabe City	Wakasa Town	Maizuru City
External cost	5,326	9,648	10,478	13,529	19,075	32,401
City/ Town	Minamiechizen Town	Tsuruga City	Ohi Town	Obama City	Mihama Town	Takahama Town
External cost	33,986	48,037	50,461	54,910	72,880	90,528

Note: Figures adjusted by subtracting JPY152 from the originally calculated cost value to reflect the fact that these citizens also enjoy the benefit of cheap nuclear power.

In contrast, an annual average cost of JPY33,731 is borne by the local communities that reside near nuclear power plants. In summary, despite some regions receiving a benefit of JPY152/year, there also exists a zone within 25 km of each reactor site that is subject to negative externalities. The benefits of a nuclear power plant are thinly spread over a wide area, whereas the costs imparted by a nuclear power station cannot be removed—even with various compensation mechanisms such as job creation or government grants—and these various costs are both very localized and high in intensity.

Figure 2 shows the results of calculating individual household external costs as per Section 6.2 for each city or town, with the results shown on a map containing Fukui, Shiga, and Kyoto Prefectures. Detailed results are listed in Table 8, which show significant variation in costs, even within the same 25-km zone. A difference of over JPY90,000/year was observed between households in Takahama Town, which bears some of the highest costs, and households outside the 25-km zone. This shows a sharp contrast in costs and benefits between various regions, and highlights serious implications in terms of fairness.

7 Concluding remarks

Hedonic analysis was performed to ascertain how local community preferences in Japan have changed toward nuclear power stations, before and after the Fukushima nuclear accident in Fukui Prefecture—a prefecture quite remote from Fukushima and likely to have suffered no directly impact from the Fukushima accident itself. External costs of nuclear power plants were estimated using a uniquely developed function for estimating land prices.

The study results clarified that the area affected by nuclear power plant negative externalities expanded from a zone within 20 km of a reactor site before the Fukushima accident, to a zone within 25 km after. Not only did the area affected become larger, but the intensity of the negative external costs increased by approximately 12% in the within-20 km zone, and by approximately 96% in the within-25 km zone. The results also demonstrated that a nuclear power plant, on average, imparts an annual cost of JPY33,731 for each residence located within 25 km of a reactor site. Finally, the costs and benefits bestowed by nuclear power plants were found to be distributed unevenly across several regions, with the largest difference among regions reaching over JPY90,000/year.

Study results were obtained for Fukui Prefecture, which is located sufficiently far from the Fukushima accident area. Consequently, there is the possibility that the larger distribution and intensity in negative externalities observed in this study could occur in prefectures other than Fukui throughout Japan, and possibly also in other locations throughout the world that host nuclear power plants. However, this study assessed only the effects of nuclear plants located the shortest distance from the survey area, and so the cost results observed in this study may in fact be more intense for areas that have multiple nuclear power facilities located within 25 km.

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Appendix

The appendix lists the detailed results of the analysis described in Section 5.3, "Analysis using distance data from nuclear power stations." The results of analysis within the 40-km range were already reported in Tables 4 and 5.

• Pre-Fukushima nuclear accident, within 35 km of site.

Variable	Coefficient	*p*-value	VIF
Constant	6.547***	0.0000144	
ln(*AREA*)	–0.2627***	0.0000267	1.348029
ln(*ROAD*)	0.07994	0.345664	1.246447
SEWER	0.2083*	0.037430	1.173410
ln(*PLANT*)	–0.04782	0.497765	1.728222
DSTAT	0.03463	0.574481	1.728222
PORT	0.000632†	0.785983	1.495486
HOS	–0.1152**	0.001961	1.939784
POST	–0.186***	0.000715	1.781598
CITY	–0.01118*	0.035224	2.107934
HWAY	–0.01611**	0.002894	1.529932
POP	0.000114*	0.025195	1.295147
DENS	0.00006472***	0.0000762	2.106401
ELD	–1.174**	0.001149	1.376233
RICH	1.379*	0.040569	1.288414
SNOW	–0.009911***	0.000389	2.117812
TEMP	0.01824*	0.020946	3.027951
Sample size	183		
Adjusted R-squared	0.7775		

• **Pre-Fukushima nuclear accident, within 30 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	4.333**	0.005885	
ln(*AREA*)	–0.1916	0.003525	1.373898
ln(*ROAD*)	0.1529**	0.063006†	1.285093
SEWER	0.2496*	0.034809	1.322376
ln(*PLANT*)	0.04448	0.573412	1.860504
DSTAT	0.02817	0.663447	1.294281
PORT	0.0002359	0.929001	1.694446
HOS	–0.1005**	0.004388	1.771229
POST	–0.1547**	0.006390	1.755432
CITY	–0.007073	0.178500	2.386065
HWAY	–0.02044**	0.003958	2.012746
POP	0.0000956†	0.059568	1.360514
DENS	0.00005825***	0.000482	2.241337
ELD	–0.7201†	0.054273	1.390909
RICH	1.281†	0.076281	1.436851
SNOW	–0.01465***	0.000261	2.779801
TEMP	0.0285**	0.001409	3.331456
Sample size	135		
Adjusted R-squared	0.8083		

• **Pre-Fukushima nuclear accident, within 25 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	5.755**	0.00108	
ln(*AREA*)	–0.2225**	0.00182	1.590783
ln(*ROAD*)	0.266**	0.00525	1.323830
SEWER	0.05189	0.68681	1.291599
ln(*PLANT*)	0.1151	0.23897	2.135194
DSTAT	0.1151	0.94402	1.370684
PORT	0.0007445	0.81325	2.126663
HOS	–0.129***	0.00046	1.880932
POST	–0.1992**	0.00646	1.781107
CITY	–0.004718	0.37943	2.530990
HWAY	–0.02344**	0.00489	2.458342
POP	0.0001116†	0.09701	1.689800
DENS	0.0000461*	0.01114	2.802919
ELD	–0.2538	0.58747	1.704094
RICH	–0.2538*	0.03788	1.367079
SNOW	–0.01995***	0.0000283	4.035758
TEMP	0.01928†	0.06086	4.005188
Sample size	99		
Adjusted R-squared	0.84		

• **Pre-Fukushima nuclear accident, within 20 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	5.21**	0.004072	
ln(*AREA*)	–0.2441***	0.000614	1.627956
ln(*ROAD*)	0.2746**	0.002596	1.410329
SEWER	0.1819	0.190405	1.567227
ln(*PLANT*)	0.3216**	0.003603	2.242438
DSTAT	0.08317	0.249074	1.628761
PORT	0.002543	0.434222	2.856283
HOS	–0.1108**	0.002045	2.292198
POST	–0.158*	0.024937	1.979998
CITY	–0.003526	0.459755	2.552801
HWAY	–0.04404***	0.00000757	2.920165
POP	0.0000275	0.678386	1.824259
DENS	0.00001916	0.258143	2.918658
ELD	–0.6278	0.167062	1.687755
RICH	1.946**	0.006695	1.444707
SNOW	–0.02644***	0.0000003	4.541669
TEMP	0.02225*	0.045363	4.275522
Sample size	78		
Adjusted R-squared	0.8894		

• **Pre-Fukushima nuclear accident, within 15 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	5.695†	0.07652	
ln(*AREA*)	–0.1733	0.08661†	1.575986
ln(*ROAD*)	0.3064**	0.00619	1.436983
SEWER	0.0253	0.91415	1.875916
ln(*PLANT*)	0.4279*	0.02386	3.133010
DSTAT	0.102	0.31128	2.243877
PORT	0.005548	0.30797	6.906937
HOS	–0.03723	0.48494	2.220873
POST	–0.1784†	0.07287	3.026858
CITY	–0.0007579	0.88066	2.545624
HWAY	–0.06272***	0.0000377	2.858841
POP	0.00002221	0.77936	1.974528
DENS	0.00001285	0.52154	3.080429
ELD	–0.761	0.22690	1.726648
RICH	1.616*	0.04703	1.356380
SNOW	–0.03142***	0.00000257	3.917482
TEMP	0.01698	0.41413	7.263241
Sample size Adjusted R-squared	53 0.8786		

• **Post-Fukushima nuclear accident, within 35 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	5.458***	0.000239	
ln(*AREA*)	–0.2834***	0.00000742	1.346399
ln(*ROAD*)	0.1423†	0.081269	1.283278
SEWER	0.2*	0.045210	1.236619
ln(*PLANT*)	–0.002895	0.969531	2.021523
DSTAT	0.07217	0.228701	1.196724
PORT	–0.0007177	0.868590	2.225257
HOS	–0.09*	0.014850	2.003072
POST	–0.21***	0.000127	1.778507
CITY	–0.008299†	0.097044	1.983612
HWAY	–0.01872***	0.000964	1.710113
POP	0.00009397†	0.058869	1.265370
DENS	0.00005535***	0.000521	2.076482
ELD	–1.529***	0.000016	1.362971
RICH	–1.529*	0.043493	1.243127
SNOW	–0.006013*	0.014846	1.804516
TEMP	0.02459**	0.002438	3.212046
Sample size	187		
Adjusted R-squared	0.775		

• **Post-Fukushima nuclear accident, within 30 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	2.851	0.061594†	
ln(*AREA*)	–0.2301***	0.000452	1.386819
ln(*ROAD*)	–0.2301*	0.014725	1.349938
SEWER	0.2758*	0.021184	1.453049
ln(*PLANT*)	0.1317	0.136544	2.336567
DSTAT	0.06561	0.298208	1.259621
PORT	0.06561	0.178586	2.133985
HOS	–0.06535†	0.061441	1.825984
POST	–0.2187***	0.00008	1.614270
CITY	–0.003862	0.435287	2.223310
HWAY	–0.02227**	0.002116	2.122418
POP	0.00006043	0.227499	1.344534
DENS	0.00004428**	0.006398	2.179567
ELD	–1.231***	0.000757	1.348687
RICH	0.8478	0.190202	1.366235
SNOW	–0.007944**	0.009206	1.855076
TEMP	–0.007944***	0.0000147	3.113053
Sample size	139		
Adjusted R-squared	0.8055		

• Post-Fukushima nuclear accident, within 25 km of site.			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	4.634**	0.004061	
ln(*AREA*)	–0.2664***	0.0000825	1.501754
ln(*ROAD*)	0.3066***	0.000931	1.355313
SEWER	0.105	0.440062	1.335466
ln(*PLANT*)	0.2267*	0.048594	3.139439
DSTAT	0.02434	0.705690	1.288669
PORT	–0.008223†	0.074918	2.164994
HOS	–0.008223***	0.000634	1.881481
POST	–0.2315**	0.001045	1.746858
CITY	–0.003011	0.564865	2.717500
HWAY	–0.02479**	0.003541	2.769928
POP	0.00005628	0.356128	1.532036
DENS	0.00002635	0.109273	2.542867
ELD	–0.7632†	0.062417	1.534235
RICH	1.514*	0.023595	1.316226
SNOW	–0.01642***	0.00000585	2.468282
TEMP	0.02685**	0.003226	3.299946
Sample size Adjusted R-squared	101 0.8509		

• **Post-Fukushima nuclear accident, within 20 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	3.343*	0.036433	
ln(*AREA*)	–0.2595***	0.000116	1.559283
ln(*ROAD*)	0.2942***	0.000815	1.444017
SEWER	0.1992	0.167509	1.466976
ln(*PLANT*)	0.3611**	0.001376	2.546656
DSTAT	0.05116	0.425561	1.427925
PORT	–0.002439	0.649693	2.672095
HOS	–0.108**	0.001929	2.333400
POST	–0.1908**	0.004360	1.857846
CITY	–0.003197	0.476167	2.441099
HWAY	–0.04514***	0.00000813	3.368354
POP	–0.00004113	0.489357	1.601331
DENS	–0.00004113	0.980876	2.638112
ELD	–1.102**	0.006758	1.574672
RICH	2.215***	0.000796	1.450180
SNOW	–0.02196***	0.00000000793	2.502939
TEMP	0.0351***	0.000378	3.386477
Sample size Adjusted R-squared	78 0.8975		

• **Post-Fukushima nuclear accident, within 15 km of site.**			
Variable	**Coefficient**	***p*-value**	**VIF**
Constant	2.152	0.261436	
ln(*AREA*)	–0.1923*	0.034111	1.556976
ln(*ROAD*)	0.3439***	0.000795	1.403700
SEWER	0.008915	0.970534	1.265949
ln(*PLANT*)	0.3771*	0.012432	2.439588
DSTAT	0.1198	0.128690	1.660322
PORT	0.03632*	0.011566	6.728219
HOS	–0.061	0.205447	2.244615
POST	–0.1435†	0.086365	2.664487
CITY	–0.0133*	0.022497	3.882123
HWAY	–0.08945***	0.00000344	5.375908
POP	–0.00001436	0.842585	1.966141
DENS	–0.00001337	0.462026	3.150998
ELD	–1.474*	0.014611	1.855466
RICH	1.517*	0.035843	1.311448
SNOW	–0.02486***	0.000000963	2.736578
TEMP	0.04353***	0.000421	2.728135
Sample size	53		
Adjusted R-squared	0.9033		

Notes: for the following tables: VIF: variance inflation factor. ***: Significance level below 0.1%; **: 1% significance; *: 5% significance; †: 10% significance.