Regional Science and Urban Economics 53 (2015) 113–122

Contents lists available at ScienceDirect

Regional Science and Urban Economics

journal homepage: www.elsevier.com/locate/regec

The effect of seismic hazard risk information on property prices: Evidence from a spatial regression discontinuity design

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ARTICLE INFO

Article history:
Received 16 August 2014
Received in revised form 30 April 2015
Accepted 11 May 2015
Available online 19 May 2015

JEL classification:
C21
Q51
Q54

Keywords:
Regression discontinuity design
Seismic hazard risk
Property market
Hedonic price
Quasi-experiment

ABSTRACT

In this paper, we utilize a spatial two-dimensional regression discontinuity (RD) design to study how Tokyo's property market evaluates information on seismic hazard risk. This approach is superior to the conventional one-dimensional RD design as it is able to account for spatially heterogeneous treatment effects and reduce small-sample biases. Our data consists of residential property transactions from the 23-ward area of Tokyo. Our results show that the unit prices of residential properties in low-risk zones were between 13,970–17,380 JPY higher than those in high-risk zones depending on the type of seismic hazard risk. In addition, we find that information on seismic hazard risk does not significantly affect the prices of newly constructed apartments, which are more resistant to earthquake damage than older residences.

1. Introduction

Many studies have evaluated the effects of environmental attributes on property prices. The most common means of accomplishing this analysis is to estimate a hedonic price function by regressing property prices on environmental data as well as other explanatory variables. When a simple linear regression is utilized, the estimated coefficient on the environmental variable represents the marginal economic value of that attribute. However, due to potential endogeneity problems, such a simple regression may not capture the causal relationship between environmental attributes and property prices. For instance, it is reasonable to assume that developers and urban planners would be leery of constructing luxury buildings in unsafe zones as the risks of fire and building collapse from seismic activity would endanger their investments. As such, the standard regression estimation of the benefit of reducing the risk level will be greater than the real, that is, causal value. One potential way to identify such causal effects would be to conduct an experiment with randomization; however, cost and ethical problems would make this an unrealistic approach for a study of the residential market. As such, "quasi"-experimental designs have become increasingly popular in studies seeking to evaluate causal effects in social and economic activities, including environmental valuation studies with hedonic property price analyses (Bin et al., 2009; Chay and Greenstone, 2005; Greenstone and Gallagher, 2008; Greenstone and Gayer, 2009; Hallstrom and Smith, 2005; Kuminoff et al., 2010; Parmetar and Pope, 2009).[1]

This study uses a quasi-experimental technique to investigate how the property market in Tokyo evaluates seismic hazard risk information. Nakagawa et al. (2007) and Naoi et al. (2009) conducted Japanese case studies that explored the effect of seismic hazard risk on property prices and showed that the probabilities of earthquakes and of earthquake-related hazards have significant negative impacts. An influential paper by Brookshire et al. (1985) explored how the publication of the government's locational assessment of earthquake risk affected

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[1] Using quasi-experimental approaches in hedonic property price analyses is not a new idea. For example, a repeat-sales hedonic model is regarded as a quasi-experimental design technique that can identify the causal relationship between property prices and time-varying explanatory variables by examining the difference between periods. However, there are several drawbacks to repeat-sales hedonic models, including data availability and the restrictive assumption that there are no substantial structural changes between the periods that would alter consumers' or suppliers' taste parameters.

http://dx.doi.org/10.1016/j.regsciurbeco.2015.05.005

property prices in California; they concluded that the risk information was fully cross-sectionally capitalized into the property values after its release,[2] and that price variations could be viewed as the willingness-to-pay (WTP) for reductions in property losses. Beron et al. (1997) showed that the Loma Prieta earthquake decreased the hedonic price of earthquake risk in the San Francisco Bay Area; the authors argue that this decrease most likely stemmed from the residents' initial overestimation of the earthquake hazard.[3] However, these studies did not rigorously examine whether or not their results represented causal relationships between property prices and earthquake risk.

Although there are several quasi-experimental design techniques from which to choose, this study employs a regression discontinuity (RD) design to identify the causal impacts of seismic damage risk levels on property prices. Under relatively weak conditions to those imposed by other quasi-experimental techniques, such as the instrumental variables method or the matching method, the causal implications from RD design can be deemed as credible as those from a randomized experiment (at the points of discontinuity) (Imbens and Lemieux, 2008; Lee, 2005; Lee and Lemieux, 2010).

In our empirical analysis, we apply the RD design to data on individual apartment transactions within Tokyo's 23 wards from 2008 to 2012. The treatment variable is binary and takes the value of one if the property is located within a high-risk zone and zero if it is not. Each location's seismic hazard risk level is obtained from data published by the Tokyo Metropolitan Government. In order to estimate the treatment effect, we utilize the two-dimensional spatial RD (2DRD) design technique developed by Imbens and Zajonc (2011). Although Grout et al. (2011) used the standard one-dimensional RD design with the distance from the property to the nearest boundary point to estimate the price effect, the 2DRD design has two main advantages over the one-dimensional design: first, it allows us to account for neighborhood heterogeneity by identifying location-specific treatment effects.[4] Second, by combining a nonparametric local regression with the 2DRD design, we can automatically control for both observable and unobservable location specific effects without introducing additional variables, which will reduce estimation biases.

Our work makes a number of major contributions to the literature on the economic valuation of natural hazard risk: first, we present empirical evidence that the impacts of seismic hazard risk information on residential property prices are locationally heterogeneous and that, on average, the unit prices of residential apartment properties in low-risk zones are between 13,970 and 17,380 JPY higher than those in high-risk zones depending on the type of seismic hazard risk. It should be noted that the “true” risk level is likely to be continuously, rather than discretely, distributed as it is determined by geographical and physical conditions, that is, the differences in the magnitude of the true risk levels should be zero on the boundary of high and low risk zones. In other words, if the residents cared only about the true risk level and not about the risk information reported by the government, we would not observe significant treatment effects. Our empirical results suggest that this is not the case, that is, the provision of (ordinal) risk information does, in fact, affect the market's behavior. Second, we observe that information on seismic hazard risk does not significantly affect the prices of newly constructed apartments, which is reasonable as these newer properties were built under more stringent building code regulations. Finally, by using the estimation results from the 2DRD analysis and applying the expected utility theory presented in Brookshire et al. (1985), we show that the residents of Tokyo's 23 wards act as though the probability of large earthquake is significantly higher than that which is officially reported. In addition, we show that the difference between the estimated prices of properties in safe and unsafe zones is conservative and reasonable if one views it as the WTP for risk reduction, as compared to those obtained by Sato et al. (2009) who utilized the contingent valuation method.

The rest of the paper is organized as follows: In Section 2, we describe the 2DRD design technique. Section 3 presents the data used in our empirical study. Section 4 details the results of the standard regression-based hedonic analysis. In Section 5, we present the results of the 2DRD analysis and numerically demonstrate that the 2DRD design is more appropriate than the standard one-dimensional RD design when there are significant location specific effects. Section 6 contains our concluding remarks.

2. Two-dimensional regression discontinuity design

Recently, the RD design has become increasingly popular in applied economics literature. Most of the applications are based on the one-dimensional RD design, where the dimension of the forcing variable that determines the treatment status is one. However, as the forcing variable in our study, location, is two-dimensional (i.e., longitude and latitude), we may not use this approach and instead turn to the relatively new practice of including multiple forcing variables (Imbens and Zajonc, 2011; Papay et al., 2011; Wong et al., 2012). Specifically, we utilize Imbens and Zajonc's (2011) 2DRD design as it allows us to account for neighborhood heterogeneity and locational specific effects.

Let Y be an outcome variable, such as the residential property price; X be the set of exogenous variables that affect Y; and D be the binary risk variable that equals one if the property is located in a risky zone and zero if it is not. Conventionally, the impact of D on Y is estimated by regressing Y on (D, X) to construct a hedonic price function. If D is exogenous, then such regression approach can be used to estimate the average benefit of a reduction in the risk level. However, as stated in the introduction, the exogeneity of D often does not hold. Also, it is often difficult for the researcher to determine an appropriate functional form for the regression. The RD design allows us to overcome these obstacles.

Let $r \in \mathbf{R}^2$ be the location of the property, which we treat as the forcing variable that determines whether $D = 1$ or 0. Additionally, let us suppose that we have a sample of size n, $\{(Y_i, D_i, X_i, r_i)\}_{i=1}^{n}$. Based on the Rubin causal model, we define the causal effects as follows:

$$Y_i = \begin{cases} Y_i(0) & \text{if } D_i = 0 \\ Y_i(1) & \text{if } D_i = 1 \end{cases},$$

where $Y_i(0)$ is the potential outcome when $D_i = 0$, and $Y_i(1)$ is the potential outcome when $D_i = 1$. As such, we can interpret $Y_i(0) - Y_i(1)$ as the causal effect of reducing the risk level on property i's price. However, it should be noted that we cannot directly compute $Y_i(0) - Y_i(1)$ because when $D_i = 0$ ($D_i = 1$), we cannot observe $Y_i(1)$ ($Y_i(0)$). The 2DRD approach circumvents this problem by conditioning r to a point on the boundary where the value of D changes.

Let $R \subset \mathbf{R}^2$ be the sampling region, which we partition into two sub-regions, R_0 and R_1, such that $\mathbf{R_0} \equiv \{r \in R : D(r) = 0\}$ and $\mathbf{R_1} \equiv \{r \in R : D(r) = 1\}$. The “assignment boundary” is defined as $\mathbf{R_{01}} \equiv \overline{R_0} \cap \overline{R_1}$, where the bar denotes the closure. Consequently, the average effect of reducing risk on Y at a given boundary point, $c \in R_{01}$, and that on the entire boundary may be defined as

$$\tau_c(c) \equiv \mathrm{E}[Y(0) - Y(1) | r = c] \text{ and } \tau \equiv \mathrm{E}[Y(0) - Y(1) | r \in R_{01}],$$

respectively. We will not only calculate the average effect over X, but it is also of interest to explore whether the benefit of risk reduction varies among properties with different X values. In order to do so, we

[2] Following Hidano (2002) and Kanemoto (1988), we use the term “cross-sectional capitalization” to indicate that the cross-sectional, inter-regional variations in the provision of a local public good is capitalized into the regions' property prices.

[3] Studies that investigate the property market's responses to risk information on large-scale natural disasters include Bin et al. (2008) and Bin and Landry (2013) on floods, and Bin and Polasky (2004) and Hallstrom and Smith (2005) on hurricanes.

[4] Grout et al. (2011) estimated regionally heterogeneous treatment effects by partitioning the sample region into several sub-regions with the standard one-dimensional RD approach. This approach is similar, in principle, to our 2DRD approach.