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Fear of nuclear power? Evidence from Fukushima nuclear accident and land markets in China

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ABSTRACT

This paper examines whether the 2011 Fukushima Nuclear Accident (FNA) changed the Chinese public's attitude toward nuclear energy by studying transactions in land markets near nuclear power plants in China. Using a data set that matched the details of all nuclear reactors in China with information on land transactions around them before and after the FNA, we find that the accident had dynamic effects on land markets in China. Land prices within 40 km of nuclear power plants dropped by about 18% one month after the nuclear accident. However, the impact of FNA decreased over the longer term, eventually becoming statistically insignificant. Also, the impacts of the disaster varied with plant characteristics such as operating status, construction year, and size.

1. Introduction

This paper provides empirical evidence of the effect of the 2011 Fukushima Nuclear Accident (FNA) on Chinese land markets located close to nuclear power plants. The FNA was triggered by an earthquake off the coast of Japan that registered 9.0 on the Moment magnitude scale. The earthquake and the ensuing tsunami resulted in massive economic losses and environmental damage.[1] Over 100,000 residents who lived within 20 km of the nuclear power plant were forced to evacuate one day after the accident. The Japanese Science Ministry reported that long-lived radioactive cesium had contaminated over 30,000 km^2 of Japanese land (World Nuclear Association, 2014). Additionally, a large amount of contaminated water accumulated on the site, and managing the contaminated water is a difficult and risky endeavour.

Along with its direct physical impact on the surrounding area, the FNA also had profound impacts on the nuclear industry worldwide. Many countries, including Germany, Italy, Switzerland, Belgium, and France, almost immediately re-evaluated their nuclear power programs, with China announcing that it would temporarily stop approving new nuclear plants.[2] Fifteen years after the April 1986

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[1] The total economic losses were estimated to be around 700 billion US dollars.

[2] Furthermore, the German Parliament passed the "Thirteenth Amendment to the Atomic Energy Act" on 30th June 2011 to phase the operation of seven oldest nuclear power plants in August 2011, and the phasing-out of the remaining nine nuclear power plants will be concluded by 2022.

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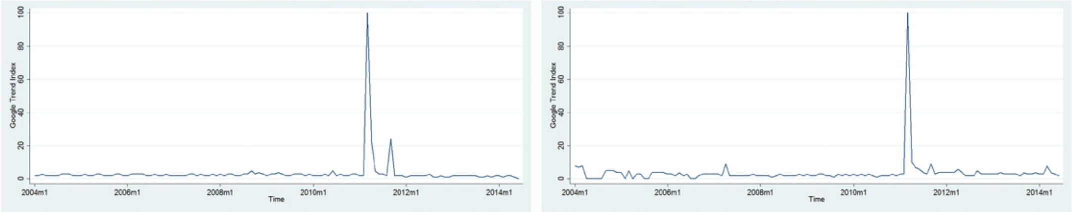
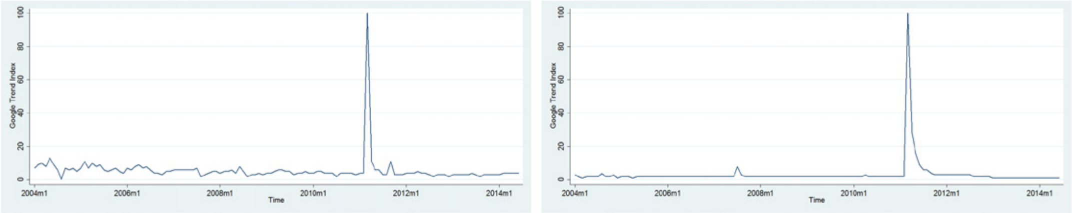
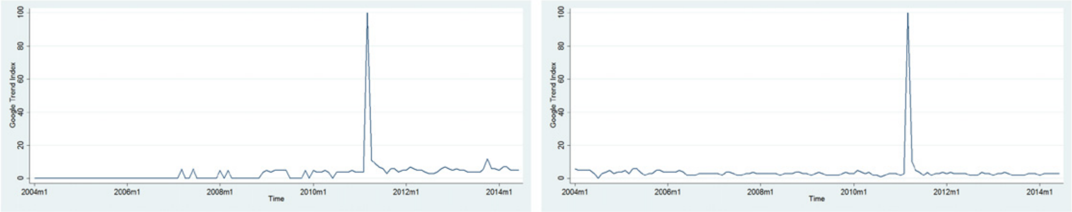


(a) China (b) France



(c) Germany (d) Japan



(e) U.K. (f) U.S.

Fig. 1. Google trends in different countries. Note: Data are downloaded from http://www.google.com/trends/, after searching the keyword "nuclear power plant" translated in respective languages. The statistics represent the trends of searching frequencies over time. Note that the indices are normalized to 100 at their highest points of different countries.

Chernobyl accident in Ukraine, FNA reignited global concern over the safety of nuclear power plants and led to a significant decline in the development of the nuclear energy industry worldwide.[3]

Social media played an important role in transmitting information about the direct consequences of the disaster. To provide a flavour of the public's reaction to this large-scale nuclear accident, Fig. 1 presents the frequency of Google searches involving the keywords "Nuclear Power Plant" across six countries.[4] In each country, search frequencies soared to their peak levels in the days immediately after the FNA, but then declined sharply over the following one to two months. The trend of Google searches appears very similar across the six countries. Although the search frequency trend suggests intensive but short-lived public interest, the real effects of the FNA on the public acceptance of nuclear power are still unclear. On one hand, if people overreacted only temporarily as predicted by prospect theory, then the FNA will not have a persistent effect on risk perception. On the other hand, it is possible that risk assessment is permanently heightened as a result of the increased awareness of nuclear safety concerns in the post–FNA era.

The property market provides a unique lens to examine public perceptions of environmental hazards. Using data from various sources, a growing body of literature has sought to track the impact of environmental disamenities on property values using revealed preference models.[5] An implicit assumption of early studies is that the risk associated with environmental disamenities is constant over time. However, this assumption is not sensible in our case, because the FNA led to the public updating their assessment of the risks of nuclear energy, which consequently affected their marginal willingness to pay for property located near nuclear plants. China was selected for our study on the price effects of changes in perceptions of nuclear safety-related risk because it has a fast-growing number of nuclear power plants. However, it was not itself directly impacted by the FNA, as it experienced neither earthquake-related destruction, nor radiation contamination.

Using a comprehensive micro-level dataset of urban land transactions that took place between July 2010 and December 2011, our empirical results suggest that, first, land prices in a 40 km radius around nuclear plants in China dropped by about 18% one month after FNA, which can be translated into about 2.2 billion RMB (347 million US dollars) loss in land transaction revenue for the local governments. However, we did not find significant negative effects further than that distance. This geographic cutoff is similar to the extended distance of contamination in Japan. Second, the effects are transitory, as the impact of FNA on land prices near nuclear plants decreased in the months following the disaster and became statistically insignificant. Third, the effects are heterogeneous across nearby plants. That is, the estimated short-run effects are stronger

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[3] The FNA has triggered some large-scale anti-nuclear protests worldwide, such as in Japan and some European countries, as well as a recent protest in Taiwan in April 2014.

[4] Google Trends is a statistical compilation of the search frequencies of keywords used in Google's search engine over time. The data can be downloaded from http://www.google.com/trends/.

[5] For example, there are papers on Superfund cleanups of hazardous waste sites and housing market (Gayer et al., 2000, Greenstone and Gallagher, 2008), nuclear waste transportation rail and housing market (Gawande et al., 2013), air pollution and housing prices (Chay and Greenstone, 2005), toxic plants and housing prices (Currie et al., 2013), and water quality and land prices (Leggett and Bockstael, 2000).

for land parcels near operational plants and those under construction. Additionally, older plants and those with a larger capacity impacted nearby land prices more profoundly, demonstrating the rational variance of price with the level of perceived risk.

This paper contributes to the literature in three ways. First, it sheds light on evaluating the dynamic economic impact of the FNA in China. Much attention has been paid in the literature to the health and economic consequences of the FNA in Japan. However, the impact of the FNA has been felt worldwide, with ongoing concerns about nuclear safety in countries around the world (Davis, 2012), making it no less important to estimate the costs of increasing public nuclear risk perception outside of Japan.[6]

Our paper is related to two recent works by Bauer et al. (2013) and Boes et al. (2015), which study the impacts of FNA on Germany's housing markets and Switzerland's rental markets near nuclear power plants. Both studies find that the housing prices near nuclear power plants have decreased after FNA. However, due to the social media censorship in China, the spreading of information, which can consequently influence the updated risk perception, may result in different impacts on real estate markets in China than in other countries. Indeed, we find that compared to the evidence from Switzerland and Germany, the reaction of land markets in China is much stronger in terms of magnitude and affected distance. However, it only lasts for one month, which is substantially shorter than the estimates found in those two countries. We believe that the empirical findings of this paper will highlight important economic implications of the development of the nuclear industry and energy policy in China.

Second, this paper is related to a growing body of literature which investigates the economic impacts of various hazardous facilities (Currie et al., 2013, Gawande et al., 2013, Gayer et al., 2000, Greenstone and Gallagher, 2008). Many studies in this area tend to look at the value of housing in proximity to hazardous sites over a long term period, assuming that people get complete information. Muller and Mendelsohn (2009) consider the role of regulation policy and calculate the welfare gain of switching pollutant trading program for 3130 electric generating units in the US. While such studies tend to disregard the FNA-like shocks that dramatically influence risk perception, the current paper aims specifically to evaluate the effects of such shocks on public risk assessment and on price. Our study thus adds to the discussion on how an exogenous shock that impacts the perceived risk arising from proximity to hazardous sites influences the marginal value of property in the area. Since the FNA did not have a direct impact on China's environment, we believe that the findings we present represents the pure price effect of the updated perceived risk associated with hazard facilities.

Third, this paper also adds to the literature on the economic impact of unexpected events. As outlined previously, as well as having direct economic consequences (Barone and Mocetti, 2014), natural disasters also influence people's risk perception. Theories of experimental psychology predict that people and markets will overrespond to unpredictable events by giving more recent information more weight (Kahneman and Tversky, 1979). These theories are supported by numerous empirical studies that track stock prices following such unpredicted events (Bondt and Thaler, 1985, Brooks et al., 2003, Ederington and Lee, 1993). Nevertheless, it is worth noting that such an overreaction to changed risk perception is not universal, and that patterns of risk perception make it such that this effect does not hold in all markets (Viscusi, 1990). In the case of the real estate market, it is still unclear if it can respond as fast as the stock markets. Many recent empirical studies have investigated the reaction of property prices to different unexpected events, and found mixed results.[7] Our paper therefore contributes to the literature by showing how a disaster can change risk perceptions internationally.

The paper proceeds as follows. Section 2 provides some background information on the FNA, development of the nuclear energy industry in China before and after FNA, and urban land markets. In Section 3, we describe the land transaction data used in the study, and provide information on the locations of all nuclear reactors in China. We also describe how the two different data sets were matched for econometric analysis. Section 4 introduces the difference-in-differences identification strategy. The results of our empirical analysis are presented in Section 5. Finally, Section 6 concludes the paper.

2. Background

2.1. FNA and nuclear industry development in China

Nuclear energy has attracted international attention ever since the first commercial nuclear power plant was built in the USA in 1954. Nuclear energy is a potentially clean and efficient source of energy that does not produce greenhouse gases, and currently provides about 20% of the world's energy. The investment in a nuclear power plant can have significant economic effects on local communities and empirical studies have shown that the establishment of a nuclear energy facility generally stimulates per capita income and employment (Ando, 2015). However, unlike other large-scale power generation projects, the major issue associated with nuclear power is the unpredictability of the health and environmental risks posed to neighbouring communities. The public concern over nuclear hazards has historically been provoked by a number of significant nuclear plant accidents. Of these, only two have measured up to level 7 (the highest level) on the International Nuclear Event Scale (INES). These were the April 1986 Chernobyl accident in Ukraine, and the March 2011 Fukushima accident (FNA) in Japan.

The FNA caused massive damage to the Japanese economy and raised many environmental and public health concerns. The first explosion of the No.1 reactor occurred on March 11, 2011 and was followed immediately by the evacuation of people living within a 20 km radius of the power plant. The subsequent explosions on March 15 of the No. 2 and No. 4 reactors raised the overall level of concern and the evacuation zone was extended up to a 30 km radius. The melting of the reactor on the same date raised concerns over the spread of radiation to a wider area through wind and rain. The graphs in Appendix A illustrate the ground level dose rate and the rate of deposit of radioactive substances (mainly cesium-134 and cesium-137) that were being leaked by the reactor one month after the accident. The graphs show that the most affected areas were in the northwest parts of the plant. While the radiation dose for people living within 40 km of Fukushima is greater than $2\mu Sv$ per hour (equivalent to about 7884 millirems per year), the average exposure to natural radiation among people in non-contaminated zones is only 300 millirems per year (at sea level). Even the US federal limit for occupational radiation exposure for individuals involved in work in nuclear zones (5000 millirems per year) is far surpassed in the area surrounding the plant. What's more, the two main radionuclides, cesium-137 and cesium-134, have 30-year half-life and 2-year

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[6] Huang et al. (2013) found that the public acceptance of nuclear power in China decreased significantly after the Japan disaster. However, the economic value of this increased risk perception has not been studied.

[7] Beron et al. (1997) find evidence that real estate markets initially overreacted to the 1989 Loma Prieta earthquake in the US. Similarly, Deng et al.'s (2015) assessment of the housing price impacts of the 2008 Wenchuan earthquake in Sichuan, China, shows disparities between changes in the housing prices of lower and higher floors. Studies have found that other extreme events, such as Hurricane Floyd (Bin and Polasky, 2004) and 9/11 attack (Abadie and Dermisi, 2008), have significantly affected house prices. However, Wong (2008) found no evidence of excessive price reactions to the 2003 Severe Acute Respiratory Syndrome (SARS) epidemic in Hong Kong.

half-life respectively, which means that the contamination of the affected areas will persist for an extendedperiod (World Nuclear Association, 2014).

China first made the commitment to develop nuclear-power plants in 1970. While the first commercial nuclear plant began operation at Daya Bay only in February 1994, the nuclear industry subsequently moved into a rapid phase of development. Soaring demands for energy coupled with serious concerns over pollution led to the establishment of huge incentives to build new nuclear power plants. This policy, together with the substantially lower costs of constructing a nuclear power plant in China relative to other countries, means that China's nuclear generating capacity is the fastest growing in the world (Davis, 2012). The construction of eight additional nuclear power plants was announced in the Tenth Economic Five-Year Plan (2001–2005), and the numbers have risen consistently in the years since. Prior to the FNA, the government aimed to increase China's nuclear power generation capacity to 70–80 GWe by 2020, 200 GWe by 2030, and 400–500 GWe by 2050.

During the phase of rapid development of the nuclear industry between 1970 and 2005, China mainly adopted the nuclear technology from France, Canada and Russia (Zhou, 2011), with particular focus on using the French element in the local development. However, in 2004, the central government decided to use the Westinghouse AP1000, a Generation-III technology, rather than the indigenous technology pushed by the China National Nuclear Corporation (CNNC), to be the main nuclear reactor technology in the near future. The latest technology acquisition is therefore mainly from the US via Westinghouse (owned by Toshiba) and French. The safety level of a nuclear power plant is associated with many aspects including the generation of the reactor technology, training of nuclear power workforce, and the safety culture at the operation level. It is expected that along with the newly planned AP1000 reactor and the investment in nuclear power workforce training, the risk of nuclear accident will be substantially reduced in the future. In fact, as China has endeavoured to achieve world's best standards in nuclear safety, the International Atomic Energy Agency (IAEA) concludes high confidence on China's nuclear safety regulation system (World Nuclear Association, 2014).[8]

The FNA received immediate and extensive coverage in Chinese media such as newspapers, television, internet and state radio (He et al., 2014, Thomson, 2011, Wang et al., 2014). The Chinese public became more aware of the advantages and limitations of nuclear power plants. They also pressed the authorities to release more information about the operation, construction and future development of China's nuclear power (Thomson, 2011). In response to the FNA and the subsequent rising concern of the general public over the safety of nuclear power, the State Council announced its decision to temporarily suspend the approval of new nuclear power plants. The authorities also decided to conduct a comprehensive safety check of all nuclear power plants, which were all found to be safe after the inspection (He et al., 2014, Wang et al., 2014). The national policy toward nuclear energy changed from "positive development" in 2004 to "steady development with safety" between 2011 and 2012. Nevertheless, the suspension of the approval of new nuclear power plants was short-lived and new construction projects received official approval from October 2012.

2.2. Urban land markets in China

The 1982 Constitution of China delineates that land is publicly owned and private ownership is legitimately prohibited in China. Initially, administrative orders were mainly used for urban land redistribution. However, the 1988 Amendments of the Constitution and the Amendments of the Land Administration Law (LAL) separated land use rights from ownership and allowed it to be transferred through fixed-term leasehold. In particular, the city governments are the only legitimate sellers in the primary urban land markets. After some reforms in the early 2000s, the procedure of urban land market transactions has been standardized. At the beginning of each year, a local land planning committee decides on leasehold details, including the total amount of leaseholds, land use regulations, the sequences of sales, and reserve price of each individual parcel. Subsequently, the land parcels are sold by the land bureau via a selected transaction method, such as negotiated sales, English auctions, two-stage auctions, and sealed bids (Cai et al., 2013, Qin et al., 2016).[9]

Among these transaction methods, negotiated sales differ from the others in terms of transaction transparency: transaction prices are negotiated between potential buyers and local land bureau. Negotiated sales were widely used in the 1990s and the early 2000s. However, since the reform in 2002 officially banned the negotiated sales of for-profit use land after 2004, the proportion of negotiated sales has decreased substantially over time (Qin et al., 2016). The English auction, two-stage auction, and sealed bid can be labelled as different land auction forms. In practice, auctions with detailed land characteristics are announced about 20 days in advance, a cash deposit is required to be made for each auction participant. It is noteworthy that different from the conventional English auction where potential bidders enter simultaneously, the two-stage auction has a first stage of approximately 10 days during which the auction details are listed, bidders are required to express interest in entering the auction with their minimum prices publicized. If there are at least two bidders willing to offer prices above the reserve price set by the government, then the transaction turns into an English auction in the second stage (Cai et al., 2013).

3. Data

This study adopts a comprehensive data set that combines information from several sources. It includes information on the geographic location of all nuclear plants in China, the land parcels that surround them, details of individual nuclear reactors, and the land transactions that took place during the period being studied. In the following sections, we describe the key features of this combined data set.

3.1. Data on nuclear power plants in China

Data on nuclear power plants in China was obtained from the World Nuclear Association (WNA), an international organization with members from various nuclear-related industries.[10] WNA is a reliable source of both detailed and regularly updated information on every commercial nuclear power reactor in China. Information obtained from the WNA included the name of the various nuclear power plants, their location, capacity, model of the reactors used, the company that controls the project, as well as the construction and operation dates for each plant. As one nuclear power plant usually contains multiple reactors constructed at different times, newer reactors had to be manually matched with their plants by cross-referencing their project names. By referencing the construction dates and the dates of operation, we were able to infer the operating status of each nuclear power reactor. Using the time of the FNA

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[8] Website: http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx.

[9] As the urban land market transactions have been standardized, the quantity of land parcels sold is barely affected by the FNA, which was pre-determined at the beginning of each year.

[10] Website: http://www.world-nuclear.org/.

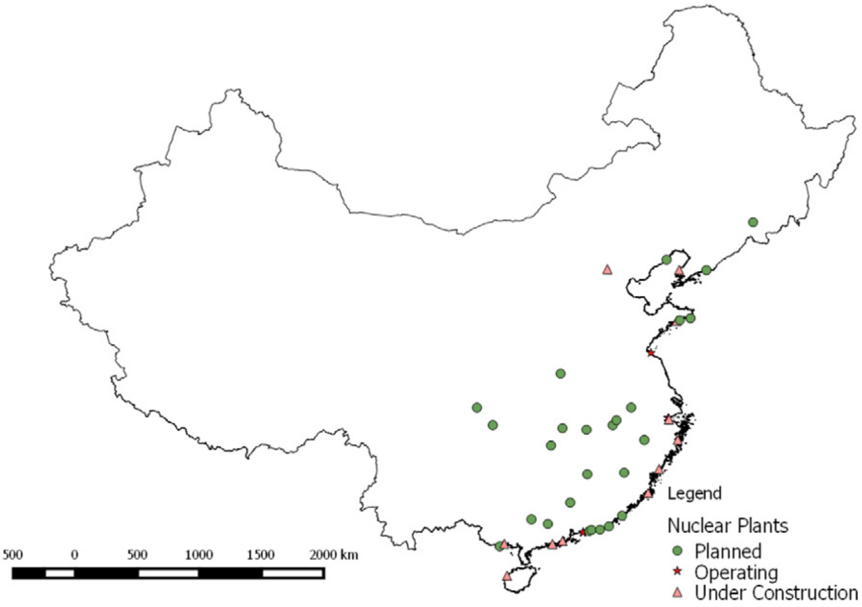

Fig. 2. Geographic distribution of nuclear power plants in mainland China in 2011. Note: Reactor data are collected from World Nuclear Association and then merged at the plant level. The addresses of plant sites are confirmed by matching with the information on the official websites of local governments, and converted to geographic coordinates using the Google Geocoding Services.

(2011) as our frame of reference, we categorized the plants into three major groups: operational, under construction, and in planning. If a nuclear plant had at least one operating reactor, it was categorized as being operational. Plants were defined as being "under construction" if at least one new reactor was being constructed, and no other reactors were operational.

In March 2011, 15 commercial nuclear reactors were operating in China across seven nuclear plants. The plants generated a total of 13,990 MWe of electricity. Additionally, 48 nuclear reactors with a combined capacity of up to 52,502 MWe capacity were being constructed at that time. A further 125 reactors capable of generating at least 164,960 MWe of electricity were in the planning phase of development. After grouping the reactors into different plants by their project names, Fig. 2 presents the location of all 45 nuclear plants, each of which either were already hosting or were going to host one or more reactors. Most of these 45 plants were sited in southern China because of the uneven distribution of the population, the demand for energy and the availability of natural resources. Except for the "Chinese Experimental Fast Reactor" which is located close to the capital, Beijing, all other plants were located in coastal regions. Although nuclear power plants are more complex to build inland than on the coast, new inland plants are being planned in increasing numbers and it is estimated that they will soon account for 38% of all Chinese nuclear plants.

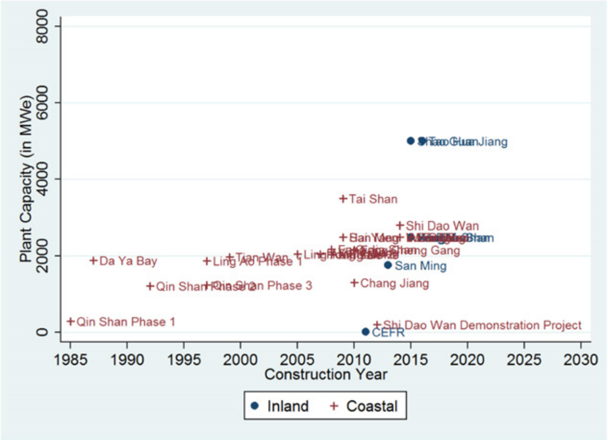

Fig. 3. Capacity and construction time of nuclear power plants in China. Note: The label of each scatter point is the name of the nuclear power plant. The construction year is defined as the year when the first reactor unit of the power plant starts to be constructed. For the planned new plants, the proposed construction time is used.

Fig. 3 shows another significant feature of the new plants, specifically their ever-increasing electricity generating capacity. The first commercial nuclear plant built in China was the Qinshan Phase 1 with one reactor and a capacity of 298 MWe. Subsequent plants far surpassed Qinshan in their generational capabilities. Prior to the FNA, the biggest plant in operation, the Lingao Phase 2, had two M310-CPR-1000 reactors with a combined generating capacity of 2052 MWe. The average capacity of plants currently operating across China is 1507 MWe, with the plants currently being constructed having average capacity of 2047 MWe. The plants in the planning phase have even greater generational power (average 3549 MWe). In addition, the average planned capacity of single inland plant is much larger than the coastal plant, mainly due to the newer and more advanced adopted technology of power generation.

3.2. Data on land transactions

Our micro-level land transaction data are originally from the Ministry of Land and Resources of China, where the result of each urban land transaction can be reviewed by the public.[11] There were 305,599 transactions recorded in China from July 2010 to December 2011. Therefore, our data set only covers the primary market in which local governments are the exclusive sellers, and no resale information is provided.

This database includes many important land characteristics that can be used in a conventional hedonic estimation framework, such as land price, area, address, land class, transaction method, the buyers' identity, and proposed uses for the land. We geocoded the precise

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[11] The information of land transactions is posted on http://www.landchina.com.

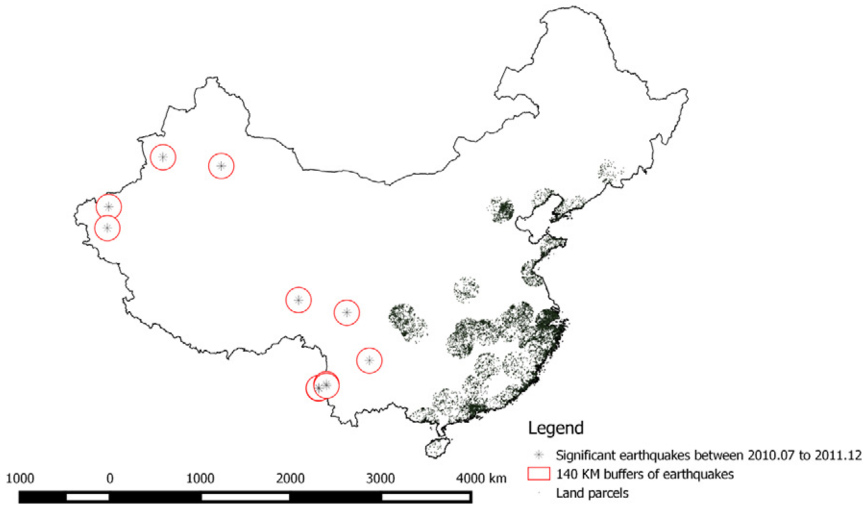

Fig. 4. Geography distribution of selected land parcels and significant earthquakes in mainland China. Note: The addresses of land parcels are geocoded by using Google Geocode Service to obtain the accurate geographic coordinates. Each point represents a land parcel. The land parcels of 140km of nuclear power plants are selected. Data of 11 earthquakes recorded during July 2010 to December 2011 are collected from NOAA.

coordinates of each land parcel using their listed addresses, and then matched these coordinates to nearby nuclear plants.

We concentrated our analysis on areas within a 140 km radius of the power plants, and the treatment groups (0–40 km) and control groups (100–140 km) were constructed to identify the causal effects of FNA on land prices. Within the 140 km buffer zone around plant sites, we then matched each land parcel with the nearest nuclear power plants and calculated the distance between them. Fig. 4 shows the geographic distribution of the land transaction pool. Since most of the power plants are in southern China, a substantial proportion of the land sales are in the same region.

We also checked for the possible direct impacts of significant natural disasters on the land markets around nuclear plants. Earthquakes are known to be the biggest threat to nuclear plants. If nuclear plants are affected by domestic earthquakes, it would be difficult to distinguish between the indirect impacts of FNA and the direct impacts of domestic disasters on land markets. To verify whether our selected land transactions were affected by nearby earthquakes, we collected information on significant earthquakes in China between July 2010 and December 2012 from the U.S. National Oceanic and Atmospheric Administration (NOAA).

Fig. 4 lists the 11 significant earthquakes that occurred in the period under study. However, all of them took place in the far west of China, outside of the 140-km buffer zones we selected around the nuclear plants. The most significant one among the 11 earthquakes was the Kaishi earthquake in Xinjiang Province on August 11, 2011, which had a magnitude of Mw 5.7 but caused no deaths. Since all domestic earthquakes in that period were far from our research region and were not associated with any nuclear risk, we can assume that land transactions near nuclear power plants were more likely to be affected by FNA rather than domestic earthquakes.

3.3. Other supplementary data

Land prices may also affected by other environmental amenities. For example, geographic factors, such as the distance to the shoreline or inland water, may influence access to overseas or domestic markets, and may have an impact on land value. We calculate the nearest distance from each land parcel to the shoreline and inland water bodies, such as lakes and rivers. These two variables are controlled for, as additional geographical characteristics of the land.

We also attempt to control for the level of development of the neighbourhood in each land parcel. Since obtaining official data at the community/town level in China is difficult in China, following Henderson et al. (2012), we use a different measure of economic activity: the level of night light observed from space. We matched the land parcels with the night light images obtained from NOAA in the 2010 and 2011 waves. Each satellite-year data set is a high-resolution raster image representing the average amount of light observed from satellites, and every pixel represents approximately 1 km^2. The pixel values range from 0 to 63, where higher values reflect a higher level of lighting, and hence, more intense economic activity.[12] We calculated the average pixel value (i.e. the average level of lighting) of a 5 km zone around each land parcel to capture the level of economic activity in each neighbourhood during the transaction year. Fig. 5 is an example of the geographic information and light measures used for the land parcels.

3.4. Summary statistics

Table 1 shows the summary statistics of our sample.[13] Overall, 79,688 land transactions occurred between July 2010 and December 2011. The average unit land price was about 11.2 million Yuan per hectare. The relatively large standard deviation in land prices indicates that land values vary significantly in our sample. This may due to disparities in the level of development and urbanization in China. About 43% of observations are newly-developed land parcels transferred from the rural sector, suggesting that almost half of our sample is likely to be located at the urban fringes. This makes sense because, besides geological and seismological issues, another important consideration for selecting nuclear power sites is that the plants should be in low population density zones to avoid any potential adverse impacts on public health.

The urban land in China is transferred through fixed-term leasehold from the local government. The maximum length of usage is 70 years and the mean value is about 57 in our data. Additionally,

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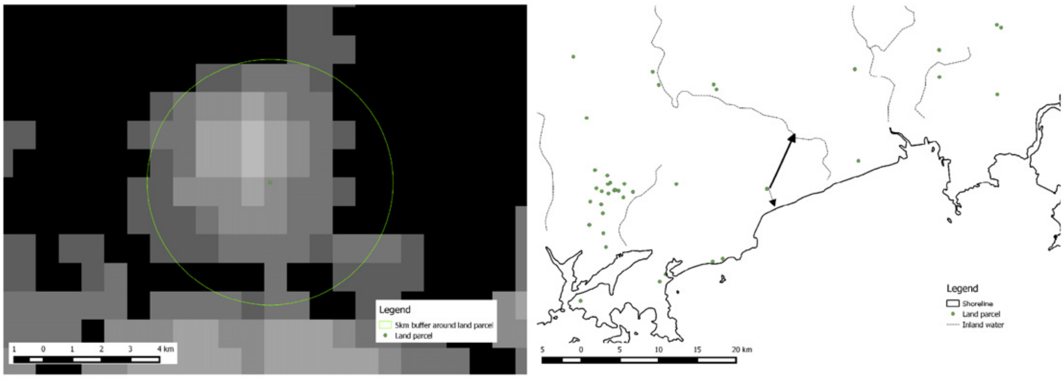
[12] More detailed description of this satellite data can be found in Henderson et al. (2012).

[13] For simplicity, we only present the statistics of some most important variables in this table, because there are a long list of category dummies for some variables. For instance, there are 18 classes for the variable “land class”. We will generate and control for the dummies of these variable in our regression analysis.



(a) Light at night data (b) Distance to shoreline and inland water

Fig. 5. Examples of other geographical controls.

the summary statistics on land classes are also of interest. Land class is a fundamental factor for determining government-reserved land prices in China, and is defined by the location of land. For example, first-class land sites are typically in the most developed areas of megacities such as Beijing and Shanghai. In our data, only about 26% of the land was in the first and second land classes.

Table 2 displays the summary statistics by distance band and by the operational status of the nearest nuclear power plant. The average price of land parcels within 20 km radium of nuclear power plants is significantly lower than those located in other distance bands. The levels of economic activities measured by average light at night are also lower in areas closer to nuclear power plants. The characteristics of land parcels also differ by the operational status of the nearest nuclear power plant. Land parcels near planned plants are much less expensive than those located near operational ones or those under construction. Consistent with our expectation, areas near planned nuclear power plants have lower level of economic activity.

4. Estimation strategy

In this section, we propose a difference-in-differences (DID) estimation model to examine the effects of increased risk perception of nuclear power safety. Land within the 100–140 km zone around each nuclear power plant is selected as the control group. Based on the assessment reports of FNA, radioactive contamination affected an area about 60 km around the Fukushima Dai-ichi nuclear plant. Furthermore, two recent studies: Bauer et al. (2013) and Boes et al. (2015), which investigate the impacts of FNA on the real estate markets in German and Switzerland, find that the impacts are restricted to areas within 5 km and 20 km radius, respectively. Therefore, choosing a zone 100–140 km away from nuclear power plant sites is rather conservative.

As it is expected that the treatment effects of FNA on land prices tend to be spatially heterogeneous. That is, the public's perception of the risk of nuclear accidents and the expected disutility of disaster exposure decreases with distance from the plants. Therefore, if any, the treatment effects of FNA on land prices are expected to decline with distance. To examine this, we use the regression method to search for effects at different distance bands from the nuclear plants. Specifically, we divide the 100 km buffer zones around the nuclear power plant sites into five rings, and estimate the effects of FNA on land prices using each individual band as a treatment group until the estimated effects of FNA on land prices taper off. Hence the cut-off distance of the significant effects and insignificant effects implies the maximum geographic extension of the impact of FNA.

To begin, the basic estimation model is specified as the following standard difference-in-differences (DID) framework:

$$\ln(P_{ict}) = A_c + B_t + \alpha X_{ict} + \beta \times I_{post-FNA} \times I_{treatment} + \epsilon_{ict} \quad (1)$$

Table 1
Descriptive statistics (N = 79,688).

Variable	Description	Mean	SD
Price	Unit price of land parcel (in 10,000 Yuan per hectare)	1117.233	3214.578
Logprice	Log of unit price	5.746	1.791
FAR	Floor area ratio	1.430	1.223
Landsize	Land area (in hectare)	2.641	8.751
New	Land transferred from rural to urban use (1 yes and 0 otherwise)	0.434	0.496
Firstclass	First-class land (1 yes and 0 otherwise)	0.140	0.347
Secondclass	Second-class land (1 yes and 0 otherwise)	0.120	0.325
Years	Years of usage	57.341	13.924
Light	Average light at night of 5 km radius	33.762	19.589
km_to_shore	Distance to shoreline (in km)	274.271	329.574
km_to_water	Distance to inland water (in km)	2.795	3.874
Distance (0–20 km)	Distance to nearest NPP is less than 20 km	0.029	0.167
Distance (20–40 km)	Distance to nearest NPP is between 20 km and 40 km	0.098	0.298
Distance (40–60 km)	Distance to nearest NPP is between 40 km and 60 km	0.143	0.350
Distance (60–80 km)	Distance to nearest NPP is between 60 km and 80 km	0.173	0.379
Distance (80–100 km)	Distance to nearest NPP is between 80 km and 100 km	0.228	0.420
Distance (100–140 km)	Distance to nearest NPP is between 100 km and 140 km	0.329	0.470
Operating	The status of nearest NPP is operating	0.147	0.355
Constructing	The status of nearest NPP is constructing	0.270	0.444
Planning	The status of nearest NPP is planning	0.582	0.493

Table 2
Descriptive statistics by groups.

	By distance bands						By nearest plant's operating status		
Variables	0–20 km	20–40 km	40–60 km	60–80 km	80–100 km	100–140 km	Operating	Constructing	Planning
Price	733.2	1000.2	932.4	1079.3	1342.1	1130.2	1337.5	1486.9	889.8
	(1757.9)	(2596.3)	(2527.6)	(2804.2)	(4202.3)	(3148.3)	(3483.1)	(3793.5)	(2804.8)
Logprice	5.590	5.768	5.662	5.743	5.791	5.760	5.790	6.148	5.547
	(1.711)	(1.606)	(1.852)	(2.029)	(1.731)	(1.724)	(2.789)	(1.483)	(1.567)
FAR	1.445	1.292	1.393	1.419	1.523	1.428	1.366	1.549	1.391
	(1.665)	(0.949)	(1.086)	(1.116)	(1.481)	(1.154)	(0.900)	(1.338)	(1.234)
Landsize	3.860	2.691	2.530	2.639	2.613	2.589	3.325	2.860	2.367
	(10.38)	(7.000)	(7.252)	(8.527)	(10.62)	(8.321)	(9.368)	(7.693)	(9.034)
New	0.454	0.422	0.428	0.490	0.397	0.430	0.508	0.497	0.383
	(0.498)	(0.494)	(0.495)	(0.500)	(0.489)	(0.495)	(0.500)	(0.500)	(0.486)
Firstclass	0.103	0.161	0.165	0.175	0.131	0.116	0.0619	0.114	0.173
	(0.304)	(0.368)	(0.371)	(0.380)	(0.337)	(0.320)	(0.241)	(0.318)	(0.378)
Secondclass	0.125	0.135	0.160	0.112	0.116	0.105	0.0647	0.113	0.137
	(0.331)	(0.342)	(0.366)	(0.315)	(0.321)	(0.306)	(0.246)	(0.317)	(0.344)
Years	57.45	58.18	57.47	56.78	58.67	56.40	56.72	58.54	56.94
	(12.60)	(13.11)	(13.68)	(14.07)	(13.35)	(14.58)	(13.14)	(12.33)	(14.76)
Light	26.04	35.70	32.48	33.04	36.74	32.73	47.62	42.41	26.24
	(15.15)	(17.98)	(19.08)	(19.37)	(19.95)	(20.10)	(16.45)	(18.25)	(17.20)
km_to_shore	215.0	257.5	258.3	210.0	291.6	313.3	29.13	42.04	444.2
	(263.0)	(302.8)	(299.0)	(275.3)	(370.5)	(344.3)	(22.24)	(53.81)	(340.5)
km_to_water	3.475	2.757	2.555	2.656	2.603	3.057	2.463	3.950	2.342
	(3.996)	(4.278)	(3.312)	(3.280)	(3.477)	(4.449)	(2.365)	(5.415)	(3.146)
N	2294	7844	11,364	13,823	18,167	26,196	11,749	21,545	46,394

Since the buffer zones may cover areas of different cities, we generate groups for the control and treatment samples by interacting the distance bands with city boundaries to control for city specific time-constant factors for cities in the same distance bands. Therefore, multiple groups in the same distance buffer exist, depending on how administrative boundaries divide the buffer zones. Finally, the city-distance groups are denoted by the subscript c. In the equation, the dependent variable $\ln(P_{ict})$ is the log of unit price of land parcel (in 10,000 RMB per hectare) i which locates in the city-distance group c and was transacted at time t. A_c and B_t are city-distance band and year-months fixed effects, respectively. X_{ict} are individual controls, including land characteristics and other geographic covariates. As discussed in the data section, land characteristic controls include floor area ratio (FAR), land size, length of leasehold, transaction methods, land origins, land classes, land use, and 5 km average level of night light. Geographic covariates include the shortest distance from each land parcel to inland water and coastal line. $I_{post-FNA}$ is a binary variable equal to 1 if land parcel i is sold after FNA, while $I_{treatment}$ is a binary variable equal to 1 if land parcel i is in the treatment group. Therefore, the coefficient of $I_{post-FNA} \times I_{treatment}$ implies the average treatment effect of FNA on surrounding land prices. The error term of Eq. (1) might be serially and spatially correlated, which may lead to problematic statistical inference of treatment effects. To address this problem, we follow Bertrand et al. (2004) and cluster the standard errors at the city-distance groups.

Apart from the spatial heterogeneous effects of FNA, the potential heterogeneous effects by time span are also of interest. To investigate this, we modify the model specification of Eq. (1) by adding the interactions of post-accident monthly dummies I_t and treatment dummies $I_{treatment}$ as follows:

$$\ln\left(P_{ict}\right) = A_c + B_t + \alpha X_{ict} + \sum_{t=Apr.2011}^{Dec.2011} \beta_t \times I_t \times I_{treatment} + \epsilon_{ict} \qquad (2)$$

Since the data cover nine months after FNA, we generate nine interactions between the treatment dummy and the monthly dummies. After relaxing the assumption of constant treatment effect β over time as demonstrated in Eq. (1), a salient feature of Eq. (2) is that it shows the dynamic effects of FNA in the post-accident period.[14] The validity of our DID estimations is built on the common trend assumption before the treatment. In the other words, there should be no significant difference between the price trend of the treatment group and control group before FNA. We can test this common trend assumption by adding interaction terms between the pretreatment monthly dummies and the treatment dummies in Eq. (2):

$$\begin{aligned} \ln(P_{ict}) = A_c + B_t + \alpha X_{ict} + \sum_{t=Oct.2010}^{Feb.2011} \lambda_t \times I_t \times I_{treatment} \\ + \sum_{t=Apr.2011}^{Dec.2011} \beta_t \times I_t \times I_{treatment} + \epsilon_{ict} \end{aligned} \qquad (3)$$

we absorb the transactions during July to September 2010 as the baseline groups in Eq. (3). Therefore, if the common pretreatment trends assumption holds, then the estimated coefficients λ_t should be statistically insignificant. Finally, we also extend Eq. (1) to investigate heterogeneous effects by the characteristics of the nuclear plants, including plant operating status, construction year, and capacity. For example, the estimated effects near operating plants might be different from the plants under construction or proposed plants. Hence, we generate interactions between plant characteristics and treatment dummies as follows:

$$\ln(P_{ict}) = A_c + B_t + \alpha X_{ict} + \sum_k \beta_k \times char_k \times I_{post-FNA} \times I_{treatment} + \epsilon_{ict} \qquad (4)$$

where $char_k$ denotes the kth associated characteristics of the nuclear power plant matched with land parcel i. Hence, the coefficient β_k indicates the average treatment effect of FNA on land prices for plants with characteristics k.

Overall, the DID based identification strategy will provide credible causal effect inferences for this study. Using proximity to nuclear

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[14] In the regression analysis, we do not include land transactions in March 2011 in our sample. This is because the FNA started on March 11 and became worse on March 15, dividing March into two halves. The progressive feature of this disaster makes it difficult to have a clear cut-off for event timing.

plant sites as a criteria for defining treatment and control groups fits well into the special context of this paper because the impacts of FNA on risk perception tend to differ spatially.[15] Moreover, the land market policies during the investigation window largely focused at the national level, and are unlikely to be regional-specific or differ with the distance to nearest nuclear plants. One potential concern on the validity of our identification strategy is about the general economic impacts of nuclear plants, which may subsequently affect the land prices. For example, Ando (2015) shows heterogeneous effects of nuclear power plant establishment on the local economic growth. However, we consider that the potential growth effect of nuclear plants will not influence our causal inferences for three reasons: First, in our regressions, we include the 5 km night light around each land parcel and city-distance band fixed effects to partially capture the local economic activity. Second, the economic growth effect of nuclear plants tends to exist in the long run,[16] however, our study only focuses on a much shorter time period (9 months) after FNA. Third, and more importantly, as the key assumption for the DID estimations in this study is that there is no significant difference between the changes of land prices for treatment group and control group before FNA, in Section 5, we will show that this common trend assumption indeed holds by estimating Eq. (3).

Table 3
DID estimates using different distance bands for the treatment group.

	(1)	(2)	(3)
Treatment group	0–20 km	20–40 km	40–60 km
Control group	100–140 km	100–140 km	100–140 km
$I_{Apr.\,2011} \times I_{treatment}$	-0.251^{*}	-0.185^{**}	−0.169
	(0.140)	(0.083)	(0.108)
$I_{May\,2011} \times I_{treatment}$	−0.166	−0.009	0.074
	(0.129)	(0.102)	(0.100)
$I_{Jun.\,2011} \times I_{treatment}$	−0.412	−0.107	−0.170
	(0.443)	(0.110)	(0.151)
$I_{Jul.\,2011} \times I_{treatment}$	0.118	-0.193^{*}	−0.004
	(0.109)	(0.099)	(0.093)
$I_{Aug.\,2011} \times I_{treatment}$	−0.005	0.030	−0.014
	(0.118)	(0.112)	(0.116)
$I_{Sep.\,2011} \times I_{treatment}$	−0.125	0.010	0.057
	(0.175)	(0.107)	(0.103)
$I_{Oct.\,2011} \times I_{treatment}$	−0.006	−0.046	0.101
	(0.134)	(0.094)	(0.095)
$I_{Nov.\,2011} \times I_{treatment}$	−0.200	−0.062	0.023
	(0.130)	(0.127)	(0.108)
$I_{Dec.\,2011} \times I_{treatment}$	0.205	0.033	−0.060
	(0.126)	(0.100)	(0.132)
Control variables	Yes	Yes	Yes
N	26,841	32,267	35,752
Adj. R^2	0.584	0.567	0.597

Note: Using Eq. (2) as the regression model, this table shows the monthly treatment effects of FNA on land prices within different distance bands. In Column 1, the treatment areas are defined as 0–20 km circles around nuclear plants. In Column 2, the treatment areas are the 20–40 km rings away from the nuclear plants, while in Column 3, the treatment areas are the 40–60 km rings. The 100–140 km rings are used as control groups across three columns. The pre-treatment period in the DID estimations is from July 2010 to February 2011. The core variables are products of a time dummy I_t and a treatment indicator $I_{treatment}$, the coefficients of them represent the time-varying treatment effect estimates. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

5. Results

5.1. Searching around the distance bands

Using the regression model of Eq. (2), we estimate the treatment effects of FNA on land prices within various distance bands. Additionally, we consider the potential dynamic effects over time. The regression results are reported in Table 3, and show that there was a significant effect in April 2011 in the zone nearest nuclear plants (0–20 km around nuclear power plants). That is, conditional on a set of variables, land prices fell by about 25% one month after FNA. However, the coefficients of the other months are statistically insignificant, indicating that the significant effects of FNA on land prices only appear in a very short term in this band.

In the next distance band, 20 km to 40 km away from the nuclear plants, the estimated effects of FNA in different periods show similar patterns as the 20 km band. Although the magnitude of the first month's treatment is slightly lower than the nearest band, it is still statistically and economically significant. Land value decreased by around 18.5% in the first month after FNA. The impacts of FNA in the other months are statistically insignificant.

Column 3 reports the estimation results for the zone 40–60 km away from nuclear plants. All of the coefficients are statistically insignificant, indicating that there were no significant short-term or long-term effects of FNA on land prices within this distance band. A comparison of the estimation results from Columns 1 to 3 suggests that the potential effects of FNA on land markets appear to taper off after 40 km from nuclear plants. Therefore, we believe that 40 km is a credible cut-off boundary to define the treatment group. In fact, this distance is similar to the physical impact buffer of FNA in Fukushima, which can be observed from the contamination areas of FNA measured in April 2011 (Appendix A).

5.2. Main results

Using the 0–40 km as the treatment buffer and 100–140 km as the control buffer, Table 4 reports the monthly treatment effects of FNA on land prices. In Columns 1 and 2, we estimate Eq. (3) to investigate whether there are common trends between treatment groups and control groups. Specifically, in Column 1, we estimate the coefficients of λ_t from October 2010 to February 2011 in the pretreatment period, we find that the pretreatment coefficients are statistically insignificant. In Column 2, we absorb October 2010 into the baseline group and conduct the estimation again, the results are very similar to what we obtain in Column 1. Both of these estimations suggest that the trends of land prices of treatment groups and control groups are not statistically different.

After assuring that the common trends assumption holds in our analysis, in Column 3, we formally investigate the dynamics of treatment effects by using Eq. (2). In general, pooling the transactions in the 0–40 km sample produces similar coefficients as the data in 0–20 km and 20–40 km distance bands. Land prices within 40 km fell by approximately 18% in April 2011. These effects became statistically insignificant after April 2011. These results appear to support our hypothesis that individuals tend to place greater emphasis on recent information. Thus, the effect of FNA on land prices is stronger in the short run.

Next, we estimate the treatment effects of FNA on land prices in different grouped time spans. The purpose of grouping posttreatment months into different aggregate periods is to observe if there is any trend of the treatment effects. Moreover, it also facilitates our exploration heterogeneous effects in different time spans in the next section. In Column 1 of Table 5, we present the regression results of Eq. (1) by assuming homogeneous effects of FNA over time. The results show that the magnitude of coefficient decreases to −0.074

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[15] The distance-based method of assigning treatment group and control group is similar to the method used in Gawande et al. (2013), which investigates the effect of nuclear waste transportation on property values along the route.

[16] Ando (2015) shows that the income and employment effects of nuclear facilities in Japan last for 30 years.

Table 4
Main results: estimated effects within the 40km radius.

	(1)	(2)	(3)
$I_{Oct.\,2010} \times I_{treatment}$	−0.103		
	(0.082)		
$I_{Nov.\,2010} \times I_{treatment}$	0.164	0.186	
	(0.152)	(0.150)	
$I_{Dec.\,2010} \times I_{treatment}$	0.053	0.077	
	(0.073)	(0.067)	
$I_{Jan.\,2011} \times I_{treatment}$	0.028	0.051	
	(0.092)	(0.089)	
$I_{Feb.\,2011} \times I_{treatment}$	−0.094	−0.071	
	(0.083)	(0.079)	
$I_{Apr.\,2011} \times I_{treatment}$	−0.162**	−0.139*	−0.180**
	(0.082)	(0.076)	(0.077)
$I_{May\,2011} \times I_{treatment}$	−0.046	−0.022	−0.064
	(0.103)	(0.095)	(0.095)
$I_{Jun.\,2011} \times I_{treatment}$	−0.208	−0.185	−0.225
	(0.190)	(0.187)	(0.195)
$I_{Jul.\,2011} \times I_{treatment}$	−0.107	−0.084	−0.125
	(0.087)	(0.083)	(0.085)
$I_{Aug.\,2011} \times I_{treatment}$	0.054	0.077	0.035
	(0.106)	(0.105)	(0.099)
$I_{Sep.\,2011} \times I_{treatment}$	−0.017	0.006	−0.036
	(0.121)	(0.111)	(0.109)
$I_{Oct.\,2011} \times I_{treatment}$	−0.037	−0.014	−0.056
	(0.102)	(0.097)	(0.101)
$I_{Nov.\,2011} \times I_{treatment}$	−0.088	−0.064	−0.107
	(0.114)	(0.109)	(0.106)
$I_{Dec.\,2011} \times I_{treatment}$	0.072	0.095	0.053
	(0.103)	(0.097)	(0.100)
Control variables	Yes	Yes	Yes
N	34,500	34,500	34,500
Adj. R^2	0.560	0.560	0.560

Note: Using Eq. (3) as the regression model, this table shows the monthly treatment effects of FNA on land prices before and after the event. In Column 1, the absorbed baseline period is July to September 2010. In Column 2, the absorbed baseline period is July to November 2010. In Column 3, the absorbed baseline period is July 2010 to February 2011. These regressions use land parcels in 0–40 km to the nearest nuclear power plant as treatment group and land parcels in the 100–140 km distance band as control group. The core variables are products of a time dummy I_t and a treatment indicator $I_{treatment}$, the coefficients of them represent the time-varying treatment effect estimates. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

but is statistically insignificant. In Columns 2 and 3, we use various combinations of post-accident months to distinguish the short-run, mid-run, and long-run effects of FNA. In Column 2, April 2011, May to August 2011 and September to December 2011 are respectively considered to be the short-run period, mid-run period and long-term period. The results show that the coefficient for April 2011 is the same as that in Column 1. Additionally, there is a clearly decreasing trend of magnitudes of short-term, mid-term, and long-term coefficients, implying that the estimated effects tend to decline over time. In contrast, in Column 3, we equally divide the nine post-event months into three groups. Although the magnitudes of the coefficients also decrease over time, the estimated parameter for the short-term (April 2011 to June 2011) is marginally insignificant. Therefore, we prefer categorizing Column 2, which can highlight the short-term impacts of FNA, in the previous manner to further investigate other heterogeneous treatment effects.

There are two possible explanations for the short-lived effects of the FNA on land prices. First, people may have shifted their attention from the FNA over time. Fig. 1 in Section 1 displays the frequency of Google searches involving the keywords "nuclear power plant". It shows that the search frequency in China soared to their peak levels immediately after the FNA, but then declined to the normal frequency within one to two months. This pattern is similar in 5 other countries including France, Germany, Japan, UK and the US. Second, the Chinese believed that the nuclear power plants are safe in China. Soon after the FNA, the Chinese Government started a comprehensive safety review of all nuclear power plants, which were all announced to be safe after the inspection (He et al., 2014, Wang et al., 2014). The study by He et al. (2014) shows that "Chinese citizens tended to choose the government as the most trustworthy source when it came to information provision on nuclear risks and in cases of nuclear accidents" and "in responding to nuclear accidents, Chinese citizens trusted most of all governmental authorities" (page 448).

5.3. Heterogeneous effects

5.3.1. Heterogeneous effects by operating status of nuclear power plants

The impacts of FNA on land prices may vary with the operating status of the nuclear plants. This is because individual risk perceptions about nuclear energy are determined by the weight placed on the prior information available to them, as well as updated risk perceptions. It is possible that neighbourhoods near plants of different operating status will place different weights on updated risks. For example, individuals living near existing plants and those being constructed may put a higher weight on updated risk perceptions because they are more likely to care about the potential exposure risk. In contrast, people living near plants that are still being planned may put less weight on updated risk perceptions as nuclear energy is not seen as being immediately hazardous to them. To test this, we separate the plants' operating status in 2011 into three major groups: operating, under construction, and under planning. Table 6 reports the results of these heterogeneous effects by estimating Eq. (4), where the treatment indicators at different time scales interacted with these three statuses respectively.

The results show that the effects of FNA on land prices near operating plants or plants being constructed are significantly negative in the short run, with land prices falling about 33% in the first month after FNA. However, the effect of FNA on land prices around plants being planned is much weaker and statistically insignificant. Furthermore, land prices near plants under construction fell significantly between September and December 2011, implying that the increased risk perception against nuclear power may persist longer within these neighbourhoods.

5.3.2. Heterogeneous effects by plant construction year and size

We next investigate how the effects of FNA varied by plant characteristics. Hypothetically, individual risk perceptions may be influenced by features of nuclear power plants that they learned about from various channels, such as the mass media or social networks. In this section, we examine how the effects of FNA differed across two major pieces of information about nuclear power plants that people can easily obtain: the construction year and capacity of the plants. Plants constructed in earlier years tend to use older production techniques, making maintenance more difficult and increasing the chances of leaks. For the public, the construction year of a plant is more straightforward than the other reactor details as a signal of the technology and safety level. Therefore, individual risk perceptions may decrease with construction year. Moreover, electricity-generating capacity can also affect individual risk perceptions, as it is sensible to assume that larger plants may cause more damage in case of a nuclear accident. The regressions in Table 7 use land transactions associated with nuclear power plants with specific information on construction year and generating capacity.

To simplify the interpretation of our empirical study, we first create a variable which represents the gap between 2011 and

Table 5
Estimated effects within the 40km radius (different categorizations of months).

Panel A	(1)	Panel B	(2)	Panel C	(3)
$I_{\text{Apr. to Dec. 2011}} \times I_{treatment}$	−0.074	$I_{\text{Apr. 2011}} \times I_{treatment}$	-0.180^{**}	$I_{\text{Apr. to Jun. 2011}} \times I_{treatment}$	−0.159
	(0.068)		(0.077)		(0.105)
		$I_{\text{May to Aug. 2011}} \times I_{treatment}$	−0.098	$I_{\text{Jul. to Sep. 2011}} \times I_{treatment}$	−0.042
			(0.083)		(0.066)
		$I_{\text{Sep. to Dec. 2011}} \times I_{treatment}$	−0.029	$I_{\text{Oct. to Dec. 2011}} \times I_{treatment}$	−0.027
			(0.075)		(0.081)
Control variables	Yes	Control variables	Yes	Control variables	Yes
N	34,500	N	34,500	N	34,500
Adj. R^2	0.560	Adj. R^2	0.560	Adj. R^2	0.560

Note: Using Eq. (2) as the regression model, this table shows the time-varying treatment effects of FNA on land prices within different periods. The pre-treatment period in the DID estimations is from July 2010 to February 2011. In Column 1, the post-treatment period is grouped together. In Column 2, the post-treatment period is divided into three parts: April 2011, May to August 2011 and September to December 2011. In Column 3, we evenly divide the nine post-treatment months into three groups. These regressions use land parcels in 0–40 km to the nearest nuclear power plant as treatment group and land parcels in the 100–140 km distance band as control group. The core variables are products of a time dummy I_t and a treatment indicator $I_{treatment}$, the coefficients of them represent the treatment effect estimates of different periods. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

** Significant at the 5 percent level.

each plant's construction starting year by $y\_gap = 2011 - construction\_year$. Then we include a set of interaction terms obtained by multiplying *y_gap* and capacity with the treatment variables. Columns 1 and 3 of Table 7 report two regressions that include the treatment dummies and their interactions respectively. The results suggest that there is a significant negative effect of FNA on land prices within a 40 km radius, and this effect increases with *y_gap* in the short term.

Table 6
Heterogeneous effects by the operational status of nearest nuclear power plant.

	(1)
$I_{\text{Apr. 2011}} \times I_{treatment} \times I_{Operating}$	-0.336^{***}
	(0.122)
$I_{\text{Apr. 2011}} \times I_{treatment} \times I_{Constructing}$	-0.339^{***}
	(0.109)
$I_{\text{Apr. 2011}} \times I_{treatment} \times I_{Planning}$	−0.054
	(0.081)
$I_{\text{May to Aug. 2011}} \times I_{treatment} \times I_{Operating}$	−0.362
	(0.325)
$I_{\text{May to Aug. 2011}} \times I_{treatment} \times I_{Constructing}$	−0.028
	(0.087)
$I_{\text{May to Aug. 2011}} \times I_{treatment} \times I_{Planning}$	−0.018
	(0.077)
$I_{\text{Sep. to Dec. 2011}} \times I_{treatment} \times I_{Operating}$	−0.221
	(0.243)
$I_{\text{Sep. to Dec. 2011}} \times I_{treatment} \times I_{Constructing}$	-0.211^{**}
	(0.101)
$I_{\text{Sep. to Dec. 2011}} \times I_{treatment} \times I_{Planning}$	0.122
	(0.087)
Control variables	Yes
N	34,500
Adj. R^2	0.561

Note: Using Eq. (4) as the regression model, this table shows the time-varying treatment effects of FNA on land prices by plant operational status. The pre-treatment period in the DID estimations is from July 2010 to February 2011, while the post-treatment period is divided into three parts: April 2011, May to August 2011 and September to December 2011. These regressions use land parcels in 0–40 km to the nearest nuclear power plant as treatment group and land parcels in the 100–140 km distance band as control group. The coefficients represent the treatment effects of FNA on land prices in different periods by plant operating status. The core variables are products of a time dummy I_t, a treatment indicator $I_{treatment}$, and plant operating status indicator I_{status}. Therefore, the coefficients of them represent the treatment effect estimates of different periods by plant status. Control variables include land characteristics defined in Table 1 , city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

The heterogeneous effects of plant capacity are somewhat puzzling. Although the coefficient for short-term treatment is still significantly negative, the positive coefficient of its interaction with generating capacity implies that the short-term effects of FNA on land prices decrease with plant size, which contradicts our expectations. However, since plant capacity is negatively associated with *y_gap*, omitting either *y_gap* or capacity in the regressions in Columns 1 and 3 may bias the coefficients of heterogeneous effects.

Columns 2 and 4 of Table 7 report regressions results, including interaction terms between the treatment dummies and capacity and *y_gap* as independent variables. First, the coefficients of short-term effects remain statistically significant. Second, after considering both *y_gap* and plant capacity, no heterogeneous short-term effect detected. Nevertheless, in Column 2, we find heterogeneous long-term effects: the coefficient of $I_{\text{Sep. to Dec. 2011}} \times I_{treatment} \times y\_gap$ is 0.013 and $I_{\text{Sep. to Dec. 2011}} \times I_{treatment} \times y\_gap \times capacity$ is −0.022, both of which are marginally significant at the 10% level. This result suggests that, in the long run, the impact of FNA on land market tends to decrease with older plants, and this impact is larger for big plants. Results in Column 4 report similar findings except that the interaction term $I_{\text{Sep. to Dec. 2011}} \times I_{treatment} \times capacity$ is not statistically significant. Column 5 reports the regression results after controlling for all interaction terms. The major findings for heterogeneous effects are still in line with Columns 2 and 4.

5.4. Discussions

5.4.1. Testing the sensitivity of regression results to the choices of treatment groups and control groups

One possible concern of our identification strategy is related to the selected distance bands for the control and treatment groups. Although we have shown that the 40 km treatment group boundary is determined by stepwise regressions by different assumed treatment bands, it is still crucial to test whether our main results are sensitive to the selection of control groups. In this section, we examine the robustness of our results by changing the distance boundaries of the treatment and control groups.

In Column 1 of Table 8, the control groups are placed 80–120 km away from the power plants, while the treatment group boundary remains 40 km as in the main analysis section. The estimated coefficient for short-term effects is −0.118 and is significant at the 10% level, which is smaller than the result in Column 3 of Table 4. Column 2 places the treatment group boundary at 60 km,

Table 7
Heterogeneous effects by nuclear power plant construction year and capacity.

	(1)	(2)	(3)	(4)	(5)
$I_{Apr.\,2011} \times I_{treatment}$	−0.158*	−0.180*	−0.383***	−0.288**	−0.249
	(0.087)	(0.095)	(0.104)	(0.134)	(0.174)
$I_{May\ to\ Aug.\,2011} \times I_{treatment}$	−0.057	−0.127	−0.146	0.221	0.281
	(0.087)	(0.119)	(0.134)	(0.243)	(0.351)
$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment}$	−0.052	−0.163	−0.187	0.179	0.118
	(0.078)	(0.101)	(0.143)	(0.217)	(0.268)
$I_{Apr.\,2011} \times I_{treatment} \times y\_gap$	−0.009*	−0.005			−0.005
	(0.005)	(0.006)			(0.008)
$I_{May\ to\ Aug.\,2011} \times I_{treatment} \times y\_gap$	−0.011	0.003			−0.006
	(0.016)	(0.009)			(0.011)
$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment} \times y\_gap$	−0.006	0.013*			0.007
	(0.012)	(0.007)			(0.009)
$I_{Apr.\,2011} \times I_{treatment} \times capacity$			0.074***	0.038	0.030
			(0.020)	(0.049)	(0.059)
$I_{May\ to\ Aug.\,2011} \times I_{treatment} \times capacity$			0.020	−0.154	−0.167
			(0.030)	(0.130)	(0.154)
$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment} \times capacity$			0.059	−0.134	−0.119
			(0.038)	(0.103)	(0.116)
$I_{Apr.\,2011} \times I_{treatment} \times capacity \times y\_gap$		−0.005		−0.004	−0.002
		(0.005)		(0.006)	(0.006)
$I_{May\ to\ Aug.\,2011} \times I_{treatment} \times capacity \times y\_gap$		−0.016		−0.023	−0.021
		(0.017)		(0.020)	(0.018)
$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment} \times capacity \times y\_gap$		−0.022*		−0.023*	−0.025*
		(0.013)		(0.014)	(0.013)
Control variables	Yes	Yes	Yes	Yes	Yes
N	28,629	28,629	34,203	28,629	28,629
Adj. R^2	0.579	0.580	0.560	0.580	0.580

Note: Using Eq. (4) as the regression model, this table shows the time-varying treatment effects of FNA on land prices by plant capacity and construction year. The pre-treatment period in the DID estimations is from July 2010 to February 2011, while the post-treatment period is divided into three parts: April 2011, May to August 2011 and September to December 2011. These regressions use land parcels in 0–40 km to the nearest nuclear power plant as treatment group and land parcels in the 100–140 km distance band as control group. The coefficients represent the treatment effects of FNA on land prices in different periods by plant operating status. The core variables are products of a time dummy I_t, a treatment indicator $I_{treatment}$, plant capacity (in 1000 MWe), and the gap between 2011 and plant construction year ($y\_gap = 2011 - construction\_year$). Therefore, the coefficients of them represent the treatment effect estimates of different periods by plant characteristics. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

while keeping the control group boundary the same as Column 1. After extending the treatment boundary for 20 km, neither the short-term nor long-term impacts of FNA are found to be significant. This suggests that including area that are less affected into the treatment groups will lead to an imprecise estimation of the real treatment effects. Columns 3 and 4 replicate the above regressions but narrow the control group boundaries further to 100–120 km. The estimated treatment effects of FNA are reported to be slightly larger than those in Columns 1 and 2. In summary, evidence from these various combinations of treatment and control groups implies that: a) the conclusion of short-term effects of FNA on land prices is robust to the choice of control groups, and b) our inferred 40 km treatment boundary is a credible choice for assessing the effect of FNA on risk perception.

Table 8
DID estimates with different distance bands for treatment and control groups.

	(1)	(2)	(3)	(4)
Treatment group:	0–40 km	0–60 km	0–40 km	0–60 km
Control group:	80–120 km	80–120 km	100–120 km	100–120 km
$I_{Apr.\,2011} \times I_{treatment}$	−0.118*	−0.099	−0.148*	−0.126
	(0.071)	(0.066)	(0.076)	(0.077)
$I_{May\ to\ Aug.\,2011} \times I_{treatment}$	−0.089	−0.067	−0.115	−0.090
	(0.077)	(0.071)	(0.090)	(0.087)
$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment}$	−0.049	−0.031	−0.067	−0.047
	(0.070)	(0.058)	(0.078)	(0.070)
Control variables	Yes	Yes	Yes	Yes
N	45,272	56,416	27,743	38,887
Adj. R^2	0.615	0.619	0.566	0.587

Note: Using Eq. (2) as the regression model, this table shows the treatment effects of FNA on land prices for different combinations of treatment groups and control groups. The pre-treatment period in the DID estimations is from July 2010 to February 2011. The core variables are products of a time dummy I_t and a treatment indicator $I_{treatment}$, the coefficients of them represent the time-varying treatment effect estimates. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

* Significant at the 10 percent level.

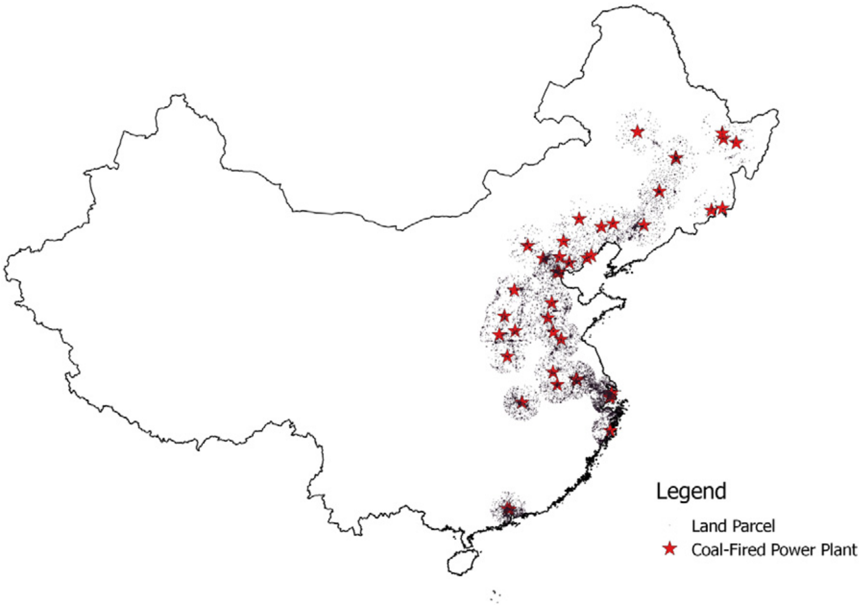

Fig. 6. The location of selected coal-fired power plants in mainland China.

5.4.2. A placebo test: the impacts of coal-fired power plants

In the previous sections, we have tested the impacts of FNA on land prices near the nuclear power plants in China. We find that the impacts of FNA on the land prices near the nuclear power plants tend to be short-lived. In this section, we conduct a placebo test to assure that the short-lived impacts we have found are only related to the FNA and the nuclear power plants. To do this, we randomly select 45 coal-fired plants in China, we geocode these selected coal-fired power plants and match them with the nearby land parcels using the same method that we have applied in the previous analysis. Fig. 6 shows the spatial locations of the selected thermal plants and the matched land parcels. It can be observed that the chosen coal-fired power plants mainly locate in the north and middle China, which is due to the uneven natural resources (inland water and coal) distribution. However, the distinct difference of geographic locations of coal-fired and nuclear power plants in southern and northern

Table 9
Placebo tests: the impacts of FNA on the prices of land near coal-fired power plants.

Panel A	(1)	(2)	Panel B	(3)	(4)
Treatment group: Control group:	0–20 km 100–140 km	0–40 km 100–140 km	Treatment group: Control group:	0–20 km 100–140 km	0–40 km 100–140 km
$I_{Apr.\,2011} \times I_{treatment}$	0.103	0.032	$I_{Apr.\,2011} \times I_{treatment}$	0.103	0.032
	(0.077)	(0.059)		(0.077)	(0.059)
$I_{May\,2011} \times I_{treatment}$	0.032	−0.031	$I_{May\ to\ Aug.\,2011} \times I_{treatment}$	0.020	0.016
	(0.084)	(0.068)		(0.057)	(0.046)
$I_{Jun.\,2011} \times I_{treatment}$	0.039	0.041	$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment}$	−0.021	−0.002
	(0.104)	(0.093)		(0.063)	(0.052)
$I_{Jul.\,2011} \times I_{treatment}$	0.034	0.037			
	(0.075)	(0.060)			
$I_{Aug.\,2011} \times I_{treatment}$	−0.022	0.017			
	(0.073)	(0.064)			
$I_{Sep.\,2011} \times I_{treatment}$	0.048	0.014			
	(0.073)	(0.066)			
$I_{Oct.\,2011} \times I_{treatment}$	−0.074	−0.059			
	(0.098)	(0.070)			
$I_{Nov.\,2011} \times I_{treatment}$	0.018	−0.011			
	(0.094)	(0.065)			
$I_{Dec.\,2011} \times I_{treatment}$	−0.075	0.032			
	(0.145)	(0.116)			
Control variables	Yes	Yes		Yes	Yes
N	34,651	44,253		34,651	44,253
Adj. R^2	0.689	0.673		0.689	0.673

Note: Using Eq. (2) as the regression model, this table shows the results of placebo tests of FNA on land prices around coal-fired power plants. The pre-treatment period in the DID estimations is from July 2010 to February 2011. We set two different distance bands for the treatment groups, while the control groups are all defined as 100–140 km distance bands around the coal-fired power plants. The core variables are products of a time dummy I_t and a treatment indicator $I_{treatment}$, the coefficients of them represent the time-varying false treatment effect estimates. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

Table 10
Estimated effects on land auction prices.

	(1)
$I_{Apr.\,2011} \times I_{treatment}$	−0.195**
	(0.095)
$I_{May\ to\ Aug.\,2011} \times I_{treatment}$	−0.001
	(0.057)
$I_{Sep.\ to\ Dec.\,2011} \times I_{treatment}$	0.028
	(0.065)
Control Variables	Yes
N	19,345
Adj. R^2	0.697

Note: Using Eq. (2) as the regression model, this table shows the time-varying treatment effects of FNA on land prices within different periods. In particular, we restrict the regression sample to land parcels sold via public auctions, including English auctions, two-stage auctions, and sealed bids. The pre-treatment period in the DID estimations is from July 2010 to February 2011. These regressions use land parcels in 0–40 km to the nearest nuclear power plant as treatment group and land parcels in the 100–140 km distance band as control group. The core variables are products of a time dummy I_t and a treatment indicator $I_{treatment}$, the coefficients of them represent the treatment effect estimates of different periods. Control variables include land characteristics defined in Table 1, city-distance band fixed effects, and year-months fixed effects. Robust standard errors clustered at group-level (city-distance band combinations) are in parentheses.

** Significant at the 5 percent level.

China enables us to avoid mixing the impacts of nuclear power plants on land prices after FNA in this placebo test.

We apply the same regression method to test whether the land prices near the coal-fired plants have experienced similar changes after the FNA. Our hypothesis is that if the FNA not only affects people's risk perception regarding nuclear power, but also any other forms of energy production in the same magnitude, then we should find similar regression results as in the previous sections. Table 9 presents the placebo estimation results. Using the same control group of land parcels that locate within 100–140 km of each coal-fired power plants, in Columns 1 and 2, we highlight the monthly "treatment" effects of FNA by two different treatment group definitions: 0–20 km and 0–40 km. As it is shown that all the estimated effects in different treated months are statistically insignificant, the short-term effects in April 2011 is even positive, which are substantially different from the estimated effects near the nuclear power plants. In Columns 3 and 4, we examine whether there are any trends of the estimated effects in different time spans. In contrast to our previous results, the estimated coefficients appear to decrease over time, which is opposite to what we have found in Table 4. In summary, our placebo test provides evidence that FNA only affects the risk perceptions related to nuclear power.

5.4.3. Regression using the auction sales

In this section, we attempt to provide evidence on the potential mechanisms of the estimated effects of FNA on the land prices. As the land transactions we used in the regressions are limited to the primary land market, where the local governments are the sellers and they have market power in their own land markets. Therefore, to ascertain that the short-term negative price effects of FNA on neighbourhood land markets we estimated are driven by the increased risk perception of the buyers, rather than the temporary changes of other factors such as strategic sales of the governments after FNA. We restrict our regression sample to land transactions that are sold via three major auction types in Chinese land market: two-stage auction, English auction and sealed bid, which account for about 56% of our total observations.

The advantages of using this sub-sample in our analysis are twofold. First, the land sold via public auctions are typically hot land parcels (Cai et al., 2013). As we described in the background section, the land development planning and sequence of land sales are determined by a local land planning committee each year, so it is less likely that the local government can change their publicized land selling schedule temporarily. Second, different from the mechanism of negotiated sales, in which the seller (local government) and buyer are negotiating a price, and the land sale can be closed if the negotiated price is higher than the reserve price set by the government. The public auction sales, however, are much more competitive. If the nuclear risk perception of bidders has increased after the FNA, then it should be reflected in the final transaction prices. Table 10 shows the regression results using this sub-sample. The estimated short-term effects are similar to our findings in column 2 of Table 5 in terms of magnitude and significance level. Therefore, we argue that the price effects of FNA are mostly driven by the public's increased risk perception.

6. Conclusions

FNA has caused dramatic damage in Japan, and has also had severe impacts on the development of nuclear energy worldwide. Many countries have acted quickly to enhance the regulation of nuclear energy after the disaster. Estimating and understanding the impacts of FNA on the public's perception of the risk of nuclear energy outside Japan are particularly important. If individuals overreact to the disaster, then the immediate policy response of governments will be driven by these overreactions and may not be efficient in the long run. Using a comprehensive dataset of land transactions in China before and after FNA, this paper examines the effects of FNA on land prices near nuclear power plants in China, so as to assess the impact of changes in the public acceptance of nuclear energy after FNA.

The estimations from the difference-in-differences approach suggest that, first, there is a significant negative impact of FNA on land price within areas 40 km outside nuclear power plants. In particular, land prices drop by an average of about 18% one month after FNA. This 40 km buffer is similar to the extent of radiation leakage in Fukushima in Japan, indicating that even though the disaster did not affect China directly, its influences on risk perceptions can also be widespread and considerable. Second, we find the impacts are heterogeneous in various aspects. We find that the impacts were mainly concentrated in April 2011, the first month after FNA, which is a clear evidence of overreaction in the market. In addition, the effects of FNA varied significantly by plant running status. In the short run, land prices dropped significantly near operating and constructing plants, while there are still long-lived effects for the plants being constructed. Moreover, the estimated effects tend to differ by plant construction year and size as well.

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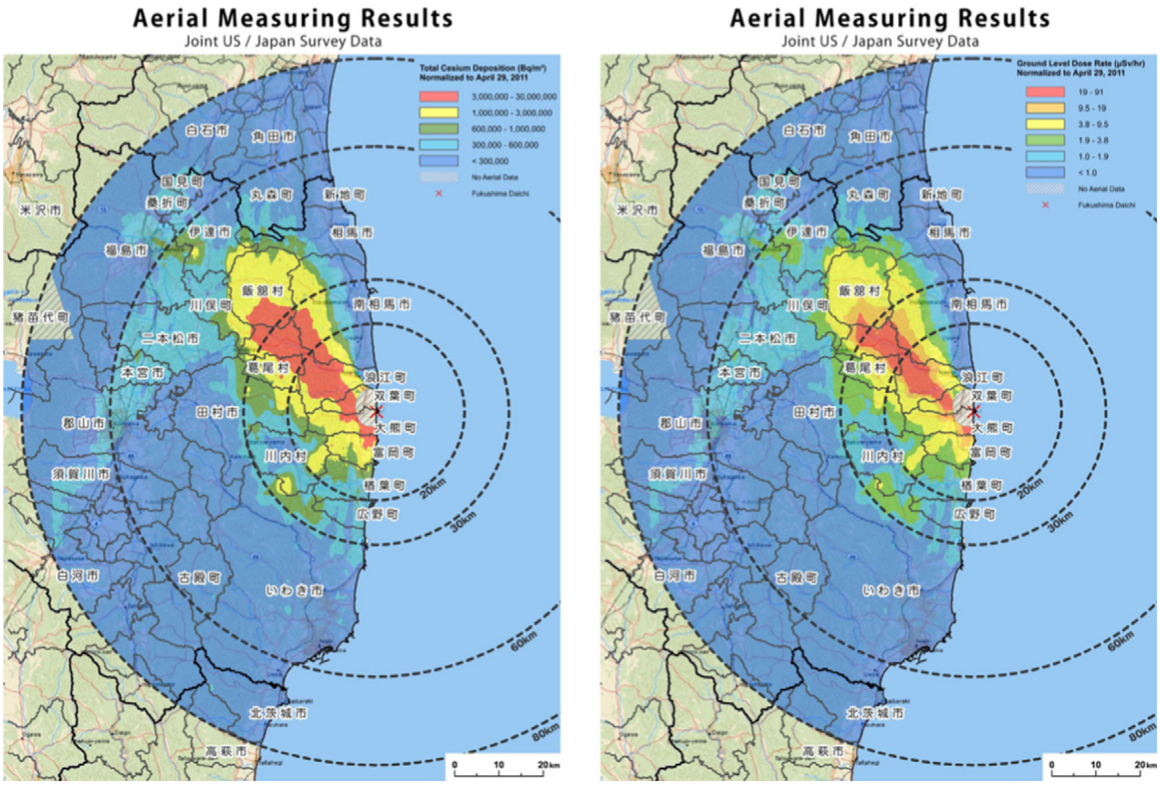
Appendix A. The Contaminated Area of FNA in April 2011

The Contaminated Area of FNA in April 2011



(a) (b)

Note: Graphs are from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. Airborne monitoring data are jointly collected by MEXT and U.S. Department of Energy on April 6 to 29, 2011, within the 80 km radius of Fukushima Dai-ichi Nuclear Power Plant. The readings in the graphs measures the deposition of radioactive substances (cesium 134 and cesium 137) 1m above the ground surface.

References

Abadie, A., Dermisi, S., 2008. Is terrorism eroding agglomeration economies in central business districts? Lessons from the office real estate market in downtown Chicago. J. Urban Econ. 64 (2), 451–463.

Ando, M., 2015. Dreams of urbanization: quantitative case studies on the local impacts of nuclear power facilities using the synthetic control method. J. Urban Econ. 85, 68–85.

World Nuclear Association, 2014. Nuclear Power in China.

Barone, G., Mocetti, S., 2014. Natural disasters, growth and institutions: a tale of two earthquakes. J. Urban Econ. 84 (6), 52–66.

Bauer, T.K., Braun, S., Kvasnicka, M., 2013. Distant event, local effects? Fukushima and the german housing market. Working Paper.

Beron, K.J., Murdoch, J.C., Thayer, M.A., Vijverberg, W.P.M., 1997. An analysis of the housing market before and after the 1989 Loma Prieta earthquake. Land Econ. 73 (1), 101–113.

Bertrand, M., Duflo, E., Mullainathan, S., 2004. How much should we trust differences-in-differences estimates? Q. J. Econ. 119, 249–275.

Bin, O., Polasky, S., 2004. Effects of flood hazards on property values: evidence before and after hurricane Floyd. Land Econ. 80 (4), 490–500.

Boes, S., Nuesch, S., Wuthrich, K., 2015. Hedonic valuation of the perceived risks of nuclear power plants. Econ. Lett. 133, 109–111.

Bondt, W.F.M.D., Thaler, R., 1985. Does the stock market overreact? Journal of Finance 40 (3), 793–805.

Brooks, R.M., Patel, Ajay, Su, T., 2003. How the equity market responds to unanticipated events. J. Bus. 76 (1), 109–133.

Cai, H., Henderson, J.V., Zhang, Q., 2013. China's land market auctions: evidence of corruption? 44 (3), 488–521.

Chay, K.Y., Greenstone, M., 2005. Does air quality matter? Evidence from the housing market. J. Polit. Econ. 113 (2), 376–424.

Currie, J., Davis, L., Greenstone, M., Walker, R., 2013. Do housing prices reflect environmental health risks? Evidence from more than 1600 toxic plant openings and closings. National Bureau of Economic Research Working Paper Series, No. 18700.

Davis, L.W., 2012. Prospects for nuclear power. Journal of Economic Perspectives 26 (1), 49–66.

Deng, G., Gan, L., Hernandez, M.A., 2015. Do natural disasters cause an excessive fear of heights? Evidence from the wenchuan earthquake. J. Urban Econ. 90, 79–89.

Ederington, L.H., Lee, J.H., 1993. How markets process information: news releases and volatility. J. Financ. 48 (4), 1161–1191.

Gawande, K., Jenkins-Smith, H., Yuan, M., 2013. The long-run impact of nuclear waste shipments on the property market: evidence from a quasi-experiment.. J. Environ. Econ. Manag. 65 (1), 56–73.

Gayer, T., Hamilton, J.T., Viscusi, W.K., 2000. Private values of risk tradeoffs at superfund sites: housing market evidence on learning about risk. Rev. Econ. Stat. 82 (3), 439–451.

Greenstone, M., Gallagher, J., 2008. Does hazardous waste matter? Evidence from the housing market and the superfund program. Q. J. Econ. 123 (3), 951–1003.

He, G., Mol, A., Zhang, L., 2014. Lu, y. J. Risk Res. 17 (4), 435–451.

Henderson, J.V., Storeygard, A., Weil, D.N., 2012. Measuring economic growth from outer space. Am. Econ. Rev. 102 (2), 994–1028.

Huang, L., Zhou, Y., Han, Y., Hammitt, J.K., Bi, J., Liu, Y., 2013. Effect of the Fukushima nuclear accident on the risk perception of residents near a nuclear power plant in China. Proceedings of the National Academy of Sciences. vol. 110. pp. 19742–19747. 49.

Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47 (2), 263–291.

Leggett, C.G., Bockstael, N.E., 2000. Evidence of the effects of water quality on residential land prices. J. Environ. Econ. Manag. 39 (2), 121–144.

Muller, N.Z., Mendelsohn, R., 2009. Efficient pollution regulation: getting the prices right. Am. Econ. Rev. 1714–1739.

Qin, Y., Zhu, H., Zhu, R., 2016. Changes in the distribution of land prices in urban China during 2007–2012. Reg. Sci. Urban Econ. 57, 77–90.

Thomson, E., 2011. China's nuclear energy in light of the disaster in Japan. Eur. Geogr. Econ. 52 (4), 464–482.

Viscusi, W.K., 1990. Sources of inconsistency in societal responses to health risks. Am. Econ. Rev. 80 (2), 257–261.

Wang, Y., Li, N., Li, J., 2014. Media coverage and government policy of nuclear power in the People's Republic of China. Prog. Nucl. Energy 77, 214–223.

Wong, G., 2008. Has SARS infected the property market? Evidence from Hong Kong. J. Urban Econ. 63 (1), 74–95.

Zhou, Y., 2011. China's spent nuclear fuel management: current practices and future strategies. Energy Policy 39, 4360–4369.