Fukushima and the German Housing Market*

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Abstract. The Fukushima Daiichi accident in Japan in March 2011 caused a fundamental change in Germany's energy policy that led to the immediate shut down of nearly half of its nuclear power plants. Using data from Germany's largest internet platform for real estate prices, this paper investigates whether the Fukushima Daiichi accident had an effect on the German housing market. For identification, we exploit the unexpectedness of the nuclear accident in Japan, variation in the distance to nuclear power plant sites of property that is offered for sale, and post-Fukushima variation in site closures across regions. Our results show that offer prices for real estate fell considerably after Fukushima in the vicinity of nuclear power plant sites and that such falls were strongest near sites that were shut down.

Keywords: Fukushima, Nuclear Power Plants, Housing Prices, Germany.
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1 Introduction

On 11 March 2011, Japan was struck by a devastating earthquake and tsunami, which led a to a major accident at Tokyo Electric Power Company's (TEPCO's) Fukushima Daiichi nuclear power plant. The Fukushima Daiichi accident brought nuclear safety to the forefront of global attention. Nowhere, however, not even in Japan itself, did it have such repercussions on public opinion and energy policy as in distant Germany. Following mass anti-nuclear protests across Germany, and a historic defeat at the polls, Germany's coalition government closed eight of the country's seventeen nuclear power plants (henceforth, NPPs) in August 2011.[1] Scrapping a recent decision of its own to extend the life of nuclear reactors by an average of twelve years, the government also declared the phasing out of Germany's remaining nine NPPs by 2022, a decision that made Germany the biggest economy to announce plans to give up nuclear energy.[2]

The impact of the Fukushima Daiichi accident on German energy policy is manifest. However, the energey sector need not be the only area where it had an impact. The housing market in Germany too may have been affected by the events in Japan. If the Fukushima Daiichi accident changed people's perceptions of the risk of nuclear energy, or closures of NPP sites affected the local economy, residential property near NPP sites may have lost in attractiveness and hence value. Housing prices, in fact, are a most useful indicator to gauge the likely importance of such effects, particularly if they haven't yet materialized in full, such as the economic consequences of site closures. For residential property is both an asset and a durable (and immobile) consumption good. As such, its present value will depend not only on current conditions, but also on expected future conditions (and hence the development) in localities that are of importance for the value of real estate.

Using data from Germany's largest internet platform for real estate prices, this paper investigates whether the Fukushima Daiichi accident in Japan had an effect on house prices in Germany. For identification, we exploit the unexpectedness of the nuclear accident in Japan, variation in the distance of residential property to NPP sites, and variation in NPP site closures across regions. Our results show that offer prices for real estate fell considerably after Fukushima in the vicinity of nuclear power plant sites. Such falls appear strongest near sites that were shut down wholesale. They are still substantial, however, for real estate near sites that were only partially closed[3] and/or saw reductions in their remaining operation time. Offer prices near inoperative NPP sites, in contrast, appear unaffected by the Fukushima Daiichi accident and change in German energy policy.

[1] The year 2011 saw the permanent retirement of thirteen reactors in the world. Twelve of these retirements were due to the Fukushima Daiichi accident in Japan - four at the Fukushima Daiichi plant itself and eight in Germany. The thirteenth reactor that permanently retired was an old reactor in the United Kingdom, 43-year-old Oldbury nuclear power station reactor 2. At the end of 2011, there were 435 reactors in operation worldwide, 2% less than at the beginning of the year. Seven new NPPs were connected to the grid in 2011, five in 2010, two in 2009, and none in 2008 (International Atomic Energy Agency, 2012a).

[2] Other countries, such as Belgium, Italy and Switzerland have re-evaluated their nuclear programmes (International Atomic Energy Agency, 2012a). In Switzerland, a slow phase-out was decided on May 25 2011 by not extending operation times of existing plants and by banning the construction of new reactors. The first Swiss NPP will close in 2019, the last in 2034. In Italy, a referendum held in June 2011 stopped plans of the Berlusconi-led government to build a new NPP, thereby keeping Italy non-nuclear. Italy's four NPPs had been closed (the last in 1990) following a referendum in 1987. In Belgium, plans to extend remaining operating times of the country's two oldest NPPs were scrapped in July 2012 (they are now scheduled to close in 2015). The last Belgian NPP will close in 2025.

[3] These are multi-block sites that suffered closure of one block only. In Germany, NPP sites operate at most 2 blocks.

Our study relates to an extensive literature in economics that has examined the effects of undesirable facilities on local housing markets, such as fossil fuel plants (Davis, 2011; Blomquist, 1974), nuclear power plants (Nelson, 1981; Gamble and Downing, 1982), hazardous waste sites and waste incinerators (Gayer et al., 2000; Greenstone and Gallagher, 2008; Kiel and McClain, 1995), and major infrastructure projects, such as airports, railroads, or highways. Our study adds to this literature in several ways. This study is the first large-scale study of nuclear power plants. It is also one of the few that exploits an exogenous source of variation for the opening, respectively closure of undesirable facilities. A third, and unique feature of our study is grounded in the specific setting we investigate, i.e. the response of real estate prices to a distant event that did not in any physical way directly affect this estate.[4]

The paper proceeds as follows. Section 2 provides background information on Germany's stock of NPPs and NPP sites and reviews the chronology of government responses and changes in Germany's energy policy following the nuclear accident in Japan. Section 3 describes the real estate data we use in our analysis. It also provides summary statistics, disaggregated by distance to NPP sites, on basic amenities of property that is offered for sale prior to and after the Fukushima Daiichi accident. Section 4 discusses our empirical strategy and highlights several issues of importance for identification. Section 5 presents and discusses our main regression results. Finally, Section 6 concludes and highlights questions that warrant further research.

2 Background

When Fukushima struck on 11 March 2011, there were 17 nuclear power plants (NPPs) at 12 sites in Germany (see Figure 1). Of these, 2 NPPs (NPP sites), Brunsbüttel and Krümmel, had been inoperative, or disconnected from the grid, for several years.[5]

Only three days after the tsunami (on 14 March 2011), the German federal government announced a 3-month nuclear moratorium that took immediate effect. During the moratorium, the seven oldest nuclear power plants (those built before 1980) of Germany's total stock of seventeen NPPs were temporarily shut down.[6] And on 22 March 2011, the government set up two commissions, one to assess security standards at German NPPs, and one to inquire into the risk of atomic energy that the German population was still willing to bear after the Fukushima Daiichi accident.[7] Despite these initiatives, the ruling Christian Democrats of Chancelor Merkel suffered a historic defeat in the state election in Baden-Wuerttemberg on 27 March 2011 and were ousted from office after ruling the state for nearly 60 years (since its very foundation in 1952) by a coalition of Social Democrats and Greens. The Greens scored their all-time best state election result and their top candidat was elected as new Minister-President of the state, the first of his party to ever hold such an office in Germany. In the eyes of voters, the Fukuhsima Daiichi accident has vividly proved wrong the pro-

[4]The radiation released by the Fukushima Daiichi accident in Japan had no measurable impact on the environment in Germany. The same holds true for the tsunami that caused this accident.

[5]NPPs Brunsbüttel and Krümmel had been shut down in the summer of 2007. Brunsbüttel has remained inoperative ever since. The same applies to Krümmel, except for one brief short-time operation in June 2009 (Department of Nuclear Safety, 2011, 2012). A third NPP, Biblis-B, had been disconnected from the grid but two weeks before Fukushima for regular inspection, scheduled for 25 February 2011 to 22 May 2011 (Deutsches Atomforum, 2012).

[6]Temporary shut-downs were executed within three days of the government's announcement.

[7]The first commission was the reactor security commission (*Reaktorsicherheitskommission*, or RSK), the second an 'ethics commission' (*Ethikkommission*) which was created just for this purpose.

nuclear energy policy of the federal coalition government of Christian Democrats and Liberal Democrats, which only five months earlier (in September 2010) had significantly extended remaining operation times of existing NPPs in Germany.[8]

FIG. 1: Nuclear power plant sites in and close to Germany, March 2011

Note: German nuclear power plant (NPP) sites are marked by black dots and with name. Foreign NPPs are marked by grey dots and without name.

After the two commissions had issued their final reports (17 May 2011, respectively 28 May 2011), the German federal government announced on 30 May 2011 that it would shut down permanently all seven NPPs that had been (and, at that time, still were) temporarily shut down under the moratorium as well as NPP Krümmel, a notoriously accident-stricken NPP that had been effectively inoperative since the summer of 2007. In addition, maximum operation times of the nine remaining NPPs were to be cut again to levels reminiscent of the status quo prevailing before the government's September 2010 decision to extent them. A law providing for these measures was submitted to Parliament and passed by great majority on 30 June 2011.[9] Taking effect on 6 August 2011, the seven moratorium NPPs and NPP Krümmel lost their operating license.

[8] Extensions varied between eigth years for older plants (those built before 1980) and fourteen years for younger NPPs.

[9] 13th Amendment to the Atomic Energy Act (*13. Gesetz zur Änderung des Atomgesetzes*).

TABLE 1: NUCLEAR POWER PLANTS (NPPS) AND NPP SITES IN GERMANY

	NPP name	NPP site	NPP state	NPP in operation (March 2011)	Post-Fukushima NPP shot down: temporary[1]	permanent[2]	NPP background/technical features: operative since[3]	reactor type	capacity (MWe)
1.	Biblis-A	1	HE	yes	yes	2011 / 08 / 06	1974	PWR	1,225
2.	Biblis-B	1	HE	yes	yes	2011 / 08 / 06	1976	PWR	1,300
3.	Brokdorf	2	SH	yes	no	2021 / 12 / 31	1986	PWR	1,480
4.	Brunsbüttel[4]	3	SH	no	yes	2011 / 08 / 06	1976	BWR	806
5.	Emsland	4	NI	yes	no	2022 / 12 / 31	1988	PWR	1,400
6.	Grafenrheinfeld	5	BY	yes	no	2015 / 12 / 31	1981	PWR	1,345
7.	Grohnde	6	NI	yes	no	2021 / 12 / 31	1984	PWR	1,430
8.	Gundremmingen-B	7	BY	yes	no	2017 / 12 / 31	1984	BWR	1,344
9.	Gundremmingen-C	7	BY	yes	no	2021 / 12 / 31	1984	BWR	1,344
10.	Isar-1	8	BY	yes	yes	2011 / 08 / 06	1977	BWR	912
11.	Isar-2	8	BY	yes	no	2022 / 12 / 31	1988	PWR	1,485
12.	Krümmel[4]	9	SH	no	no	2011 / 08 / 06	1983	BWR	1,402
13.	Neckarwestheim-1	10	BW	yes	yes	2011 / 08 / 06	1976	PWR	840
14.	Neckarwestheim-2	10	BW	yes	no	2022 / 12 / 31	1988	PWR	1,400
15.	Philippsburg-1	11	BW	yes	yes	2011 / 08 / 06	1979	BWR	926
16.	Philippsburg-2	11	BW	yes	no	2019 / 12 / 31	1984	PWR	1,468
17.	Unterweser	12	NI	yes	yes	2011 / 08 / 06	1978	PWR	1,410

NOTE: [1] Temporary shut downs during the 3-month moratorium were announced on 14 March 2011 and took effect within three to four days. [2] The list of NPPS to be permanently closed and the remaining operation times of NPPs that were to remain active were announced by the German federal government on 30 May 2011. All of the NPPs temporarily shut down during the moratorium had to permanently shut down. These measures took effect on 6 August 2011 with the passage into law of an amendment to the Atomic Energy Act (*13. Gesetz zur Änderung des Atomgesetzes*). None of the NPPs temporarily shut down during the moratorium, and neither Brunsbüttel and Krümmel, resumed operation between the end of the moratorium in mid June and 6 August 2011. [3] Date of initial criticality (**?**). [4] NPPs Brunsbüttel and Krümmel have been inoperative since the summer of 2007, except for one short-time operation of Krümmel in June 2009 (Department of Nuclear Safety, 2011, 2012). BW=Baden-Wuerttemberg, BY=Bavaria, HE=Hesse, NI=Lower Saxony, SH=Schleswig Holstein. BWR=Boiling water reactor. PWR=Pressurised water reactor.

None of these eight NPPs had been re-connected to the grid after the moratorium expired in mid-June.[10]

3 Data

For our analysis, we use monthly house price data provided by the internet platform ImmobilienScout24, Germany's leading online property broker.[11] Data on individual house prices and house characteristics stem from property offers that individuals place on ImmobilienScout24.[12] Our estimation sample consists of single-unit houses that were offered for sale between March 2009 and May 2012.[13] Total sample size is 3,254,614 (897,209 offers).

TABLE 2: SUMMARY STATISTICS

	Before Fukushima		After Fukushima	
	Distance to next NPP		Distance to next NPP	
	≥ 5 km	< 5 km	≥ 5 km	< 5 km
	(1)	(2)	(3)	(4)
Price (Euro)	263,876	221,200	265,752	219,772
Age (years)	31.4	35.6	36.4	39.9
In construction (%)	4.8	4.7	3.0	2.2
Living space (m^2)	154.2	149.2	156.0	151.9
Base area (m^2)	753.5	714.7	803.1	732.6
Detached house (%)	32.3	27.5	30.1	27.7
Observations	2,144,085	7,546	1,098,735	4,248

NOTE: Characteristics (averages) of houses offered for sale, before and after Fukushima Daiichi accident. Averages are calculated for the period March 2009 to February 2011 and for April 2011 to May 2012.

Table 2 provides summary statistics for sale offers prior to and after the Fukushima incidence in March 2011 for houses located $\geq$5km and $<$5km from a NPP site. As is evident, average offer prices increased somewhat pre- to post-Fukushima for houses located more than 5 km from a NPP site ($+1,876$ Euro, or $+0.7\%$), but fell for houses within 5 km of a NPP site ($-1,428$ Euro, or -0.6%).[14] While suggestive of a differential development of house prices in the vicinity of NPP sites to house prices in other regions, Table 2 also shows that there exist some pronounced mean differences between locations in the type and price of real estate that is offered for sale. Houses near NPP sites tend to be cheaper, older, of smaller base area, and less often a detached property. In our empirical analysis, we will control for these observable differences.

[10] Although they had the right to resume operation at these sites until the law would finally take effect, the three operators of NPPs in Germany (E.ON, RWE, and EnBW) that were affected by the moratorium had declared by 17 June 2011 that they would not excercise this right.

[11] See http://www.immobilienscout24.de/.

[12] The posting of an offer on ImmobilienScout24 is costly. Fees depend on posting duration (two weeks, one month, three months), the type of real estate offered (e.h. houses or flats), and the type of offer (for sale, for rent). Postings can be modified anytime during purchased posting time. Posting durations are automatically extended (and additional fees payable) if purchased posting time expires and individuals have not deactivated their posting beforehand. Individuals are reminded by ImmobilienScout24 of pending expiration deadlines.

[13] We exclude March 2011 offers from our estimation sample, as this month saw the accident at Fukushima Daiichi (on 11 March 2011).

[14] The difference of these two changes ($-3,304$ Euro), however, is not statistically different from zero.

We will also control for unobservable time-constant differences at regional level that may confound the relationship between distance of real estate to NPP sites and pre- to post-Fukushima changes in the price of such real estate. These controls for regional fixed effects, and our empirical strategy more generally, are described in the next section.

4 Empirical Strategy

To analyze the effect of the Fukushima Daiichi accident on the prices of houses located next to a NPP site, we run regressions of the following type (or variants of it):

$$Y_{ijt} = \alpha + X_i\beta + \gamma NPP_i + \zeta Fukushima_t + \delta(NPP_i \times Fukushima_t) + D_j + D_t + \varepsilon_{ijt}, \quad (1)$$

where Y_{ijt} is the log offer price of property i in region j in month t, X_i a vector of house characteristics, NPP_i a dummy for property located in the vicinity of a NPP site, $Fukushima_t$ a dummy for the time period after the Fukushima Daiichi accident, D_j a full set of region dummies, and D_t a full set of month dummies. The indicator NPP_i and the set of region dummies D_j control for regional fixed effects. The first, a site-based measure, controls for time-invariant mean level differences in housing prices in the vicinity of NPP sites.[15] The second, a geographical-administrative-based measure, controls for time-invariant mean level differences in housing prices between small regional units. The full set of time dummies D_t captures aggregate (trend) changes in house prices over time (for the period April 2009 to May 2012, with March 2009 being the baseline). Variables in vector X_i control for basic characteristics of houses that are offered for sale, such as their age, living space, and base area (for a full list, see Table 2). The (treatment) effect of interest is δ. It captures the differential change pre- to post-Fukushima in average offer prices of houses in the vicinity of NPP sites to those of houses located further away from such sites. Throughout, we cluster standard errors at the region level.

In our baseline specification, we set NPP_i equal one if a house is located within 5km of a NPP site (and zero otherwise). For D_j, we choose zip code regions (there are 9,277 such geographical regions in our estimation sample). However, we also conduct a series of robustness and specification checks. Amongst others, we add additional property-to-NPP distance measures, allow for differential pre-Fukushima trends in offer prices of real estate that is located within 5 km of a NPP site, use municipality instead of zip-code fixed effects, and confine the estimation sample to new offers only.

We also run more elaborate specifications, in wich we allow the treatment effect to differ between NPP sites that were shut down post Fukushima and NPP sites that were not. This allows us to assess whether full site cloure had a different impact on house prices than partial site closure and mere reductions in maximum remaining operation times of NPPs.

[15] As shown in Table 2, average house prices in our data are about one sixth lower in the vicinity of NPP sites.

5 Results

5.1 Main Results

We start by estimating a simple regression of the log of the price of a house that is offered for sale in month t on an indicator value that takes the value one if the house is located less than 5 km from a NPP site, a post-Fukushima dummy that takes the value one in months after March 2011, an interaction of these two variables, and time dummies for each month in the sample. The main parameter of interest is the coefficient on the interaction term. The estimate of this treatment effect, reported in column (1) of Table 3, is negative but small (-2.6%) and statistically insignificant. When we add zip-code fixed effects to control for (time-invariant) regional differences (column (2)), however, the treatment effect more than doubles in absolute terms (-6.2%) and is now statistically significant. This finding of a sizeable adverse effect proves robust when property characteristics are added to account for changes in the composition of offers over time (column (3)).[16] The results of this most elaborate specification suggest that the offer price of houses in the vicinity of a NPP site fell by 5.8% after the Fukushima accident (relative to the offer prices of houses not in the vicinity of a NPP). Real estate offered in the vicinity of a NPP site, therefore, suffered a marked relative devaluation.

TABLE 3: MAIN REGRESSION RESULTS

	(1)	(2)	(3)
Treatment effect:			
NPP $<$ 5km $\times$ Post-Fukushima	-0.026	-0.062**	-0.058***
	(0.031)	(0.028)	(0.016)
NPP dummy	yes	yes	yes
Time dummies	yes	yes	yes
Zip code fixed effects	no	yes	yes
Property characteristics	no	no	yes

NOTES: The endogenous variable is the log of the nominal house price posted. The NPP dummy indicates whether a house on offer is located within 5 km from a NPP site that was operative right before the Fukushima accident. Property characteristics include age (and its square), a dummy for property still under construction, living space (and its square), base area (and its square), and a dummy for detached houses. The estimation sample comprises sales offers for single-unit detached and terraced houses houses posted on the internet platform ImmobilienScout24 in the months March 2009 to May 2012 (March 2011 offers are excluded). Sample size in all regressions is $3,254,614$ (offer $\times$ month observations). The number of zip-code-level regional clusters is $9,277$. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the zip code level.

The effects of the Fukushima accident on the housing market in Germany, however, need not be confined to real estate within 5 km of a NPP site. If they are not, our control group of houses located at least 5 km away from a NPP site may be contaminated. To assess this possibility, we consider three further specifications. In these specifications, and in all regressions that follow, we take specification (3) of Table 3 as the baseline, and include property characteristics, time and region fixed effects as controls. Column (2) of Table 4 reports

[16] In fact, the estimated treatment effect is hardly changed. This speaks against any compositional effect of the Fukushima Daiichi accident on the structure of houses offered for sale that is related to distance to a NPP site and of consequence for offer prices.

treatment effects both for houses located less than 5 km from a NPP site and for houses located 5-10 km from a NPP site. The control group now consists of houses located at least 10 km from a NPP site. Reassuringly, the treatment effect for house in the immediate vicinity of a NPP remains at -5.8%. In contrast, houses located 5-10 km from a NPP site experienced only a small, and statistically insignificant, decrease in their offer prices of (-1.4%). The treatment effect falls further to -1.2% and -0.6% for house located 10-20 km, respectively 20-30 km, from a NPP site (see columns (3) and (4) of Table 4). Also in these two specifications, the treatment effect for houses within 5 km range of a NPP remains at -5.8%. These findings suggest that the impact of the Fukushima Daiichi accident on house prices in Germany was heavily concentrated, if not altogether confined to, real estate in the immediate vicinity of NPP sites. Our choice of a 5km cutoff for NPP_i therefore appears adequate. In what follows, we will maintain this threshold to define property within close range of NPP sites.

TABLE 4: TREATMENT EFFECTS BY DISTANCE TO NPP SITES

	(1)	(2)	(3)	(4)
Treatment effects:				
NPP $<$ 5km $\times$ Post-Fukushima	-0.058***	-0.058***	-0.058***	-0.058***
	(0.016)	(0.016)	(0.016)	(0.016)
5km $\leq$ NPP $<$ 10km $\times$ Post-Fukushima		-0.014	-0.014	-0.014
		(0.009)	(0.009)	(0.009)
10km $\leq$ NPP $<$ 20km $\times$ Post-Fukushima			-0.012**	-0.012**
			(0.006)	(0.006)
20km $\leq$ NPP $<$ 30km $\times$ Post-Fukushima				-0.006
				(0.004)

NOTES: The endogenous variable is the log of the nominal house price posted. To ease comparison column (1) reproduces - from column (3) of Table 3 - the treatment effect of our baseline specification. The NPP dummies indicate whether a house on offer is located within 5 km, between 5 and 10 km, 10 and 20 km or 20 and 30 km from a NPP site that was operative right before the Fukushima accident. All regressions include time dummies, the respective NPP dummies, property characteristics, and zip-code fixed effects. Property characteristics include age (and its square), a dummy for property still under construction, living space (and its square), base area (and its square), and a dummy for detached houses. The estimation sample comprises sales offers for single-unit detached and terraced houses houses posted on the internet platform ImmobilienScout24 in the months March 2009 to May 2012 (March 2011 offers are excluded). Sample size in all regressions is $3,254,614$ (offer $\times$ month observations). The number of zip-code-level regional clusters is $9,277$. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the zip code level.

5.2 Robustness checks

We conduct several tests to assess the robustness of our main finding of a sizeable relative fall after Fukushima in offer prices of houses in the immediate vicinity of NPP sites. The results of these robustness checks are reported in Table 5. To ease comparison, column (1) of Table 5 reproduces the treatment effect of our baseline specification (from column (3) of Table 3).

First, we restrict the estimation sample to those sales offers that are newly posted (inflow sample) instead of considering all offers in a given month (stock sample). The structure of the current supply of houses, which is measured by all offers in a month, may depend heavily on the structure of new offers, if turnover on the supply side is large and new offers respond more strongly to changes in local (dis-) amenities.[17]

[17] In our data, turnover is large. The $797,398$ new offers in our estimation sample account for 24.5% of all observations.

However, as shown in column (2) of Table 5, restricting our estimation sample to sales offers that are newly posted, produces an estimated treatment effect (-5.7%) that is virtually identical to our baseline estimate.

TABLE 5: ROBUSTNESS CHECKS

	(1)	(2)	(3)	(4)
Treatment effect:				
NPP $<$ 5km $\times$ Post-Fukushima	-0.058*** (0.016)	-0.057*** (0.021)	-0.058*** (0.017)	-0.061*** (0.017)
Types of offer	all	new offers	all	all
Sample incl. 04-06/2011	yes	yes	no	yes
Regional fixed effects	zip code	zip code	zip code	municipality
Observations	3,254,614	797,398	3,018,066	3,254,614

NOTES: The endogenous variable is the log of the nominal house price posted. To ease comparison column (1) reproduces - from column (3) of Table 3 - the treatment effect of our baseline specification. The NPP dummy indicate whether a house on offer is located within 5 km from a NPP site that was operative right before the Fukushima accident. All regressions include time, NPP dummies and property characteristics. Column (2) reports estimates for a restricted estimation sample, in which only sales offers are considered that are newly posted in a month (inflow sample). Column (3) reports results when all sale offers posted in the four-month period March to June 2011 are dropped from the estimation sample. Column (4) reports results when using municipality fixed effects instead of zip code region fixed effects. The number of zip-code level regional clusters is $9,277$ in specification (1), $9,085$ in specification (2), and $9,263$ in specification (3). The number of municipality level regional clusters in specification (4) is $13,760$. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the level of the regional fixed effects.

Second, we drop from the estimation sample all sales offers posted in the four-month period March to June 2011 (instead of dropping only March 2011 sales offers). Restricting the estimation sample in this way provides for a clear divide between pre-Fukushima sales offers (January 2010 to February 2011) and post-Fukushima, as well as post-Moratorium, sales offers (July 2011 to May 2012). For with the parliament's decision on 30 June 2011, future operating and closure times of individual NPPs were fixed and any (remaining) uncertainty on the future of individual NPPs resolved. As it turns out, however, the estimate of the treatment effect is not affected by this change in the estimation sample either (see column (3)).

Third, we use municipality fixed effects instead of zip code region fixed effects. The use of these political-administrative clusters, which are more numerous than zip code regions (13,488 instead 8,887), also does not change our results markedly. The treatment effect increases albeit slightly in absolute magnitude to -6.1% (see column (4)).

Fourth, we restrict the estimation sample to property offers within 50 km, respectively 25 km, of NPP sites. These geographical restrictions provide for more homogeneity between treatment regions (which are mostly rural in character) and control regions and thereby limit also the likelihood and scope of any differences in group-specific time trends in offer prices.[18] For property offers within 50 km of NPP sites, however, the estimated treatment effect turns out to be identical to our baseline estimate (-5.8%); and for

[18] In these restricted estimation samples, property offers from East Germany (which has no NPP sites) are virtually zero, and the share of property offers from bigger cities is significantly reduced. 14.8% of all observations in our unrestricted estimation sample are from East Germany (including Berlin). This figure falls to 0.2%, and further to 0.1%, if we restrict the estimation sample to property offers within 50 km, respectively within 25 km, of NPP sites. 12.3% (5.8%) of all observations in our unrestricted estimation sample are from Germany's 25 (5) largest cities. This figure falls to 3.8% (1.2%) if we restrict the estimation sample to property offers within 50 km (25 km) of NPP sites.

property offers within 25 km of NPP sites, it shrinks but slightly in absolute magnitude (to -5.1%). We also excluded all offers from Germany's 25 largest cities.[19] Again, the estimated treatment (now -5.3%) differs but little from our baseline estimate.[20]

Fifth, the key assumption for our difference-in-differences estimator to be unbiased is that offer prices of the treatment group (houses located within 5 km of a NPP site) and control group (houses located at least 5 km from a NPP site) would have followed the same time trend in the absence of the Fukushima Daiichi accident. To analyze whether pre-treatment trends were the same in the treatment and control group, we add three leads of the treatment effect to the regression specification. Specifically, we interact dummies for the months $1-6$, $7-12$, and $13-18$ before the Fukushima Daiichi accident with the NPP dummy. Reassuringly, all three leads of the treatment effect are statistically insignificant (see column (2) of Table 6). We thus find no evidence that offer prices of the treatment and control group followed different trends before the Fukushima Daiichi accident. Moreover, the treatment effect remains statistically significant at -4.9%.

TABLE 6: TIME TREND, TREATMENT LEADS AND LAGS

	(1)	(2)	(3)	(4)	(5)
Lags:					
NPP $<$ 5km $\times$ Post-Fukushima	-0.058***	-0.049***		-0.063***	
	(0.016)	(0.018)		(0.023)	
NPP $<$ 5km $\times$ Fukushima$_{t+2}$			-0.052***		-0.057
			(0.020)		(0.038)
NPP $<$ 5km $\times$ Fukushima$_{t+1}$			-0.047**		-0.050
			(0.022)		(0.038)
Leads:					
NPP $<$ 5km $\times$ Fukushima$_{t-1}$		0.003	0.003		0.001
		(0.020)	(0.020)		(0.032)
NPP $<$ 5km $\times$ Fukushima$_{t-2}$		0.023	0.023		0.021
		(0.023)	(0.023)		(0.027)
NPP $<$ 5km $\times$ Fukushima$_{t-3}$		0.005	0.005		0.004
		(0.014)	(0.014)		(0.017)
NPP dummy $\times$ linear time trend	no	no	no	yes	yes

NOTES: The endogenous variable is the log of the nominal house price posted. To ease comparison column (1) reproduces - from column (3) of Table 3 - the treatment effect of our baseline specification. Fukushima dummies divide the 18 months period before Fukushima in three periods of six months each, and the period after Fukushima in two periods of seven months. All regressions include time dummies, an NPP dummy, property characteristics, and zip-code fixed effects. The NPP dummy indicate whether a house on offer is located within 5 km from a NPP site that was operative right before the Fukushima accident. Property characteristics include age (and its square), a dummy for property still under construction, living space (and its square), base area (and its square), and a dummy for detached houses. The estimation sample comprises sales offers for single-unit detached and terraced houses houses posted on the internet platform ImmobilienScout24 in the months March 2009 to May 2012 (March 2011 offers are excluded). Sample size in all regressions is $3,254,614$ (offer $\times$ month observations). The number of zip-code-level regional clusters is $9,277$. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the zip code level.

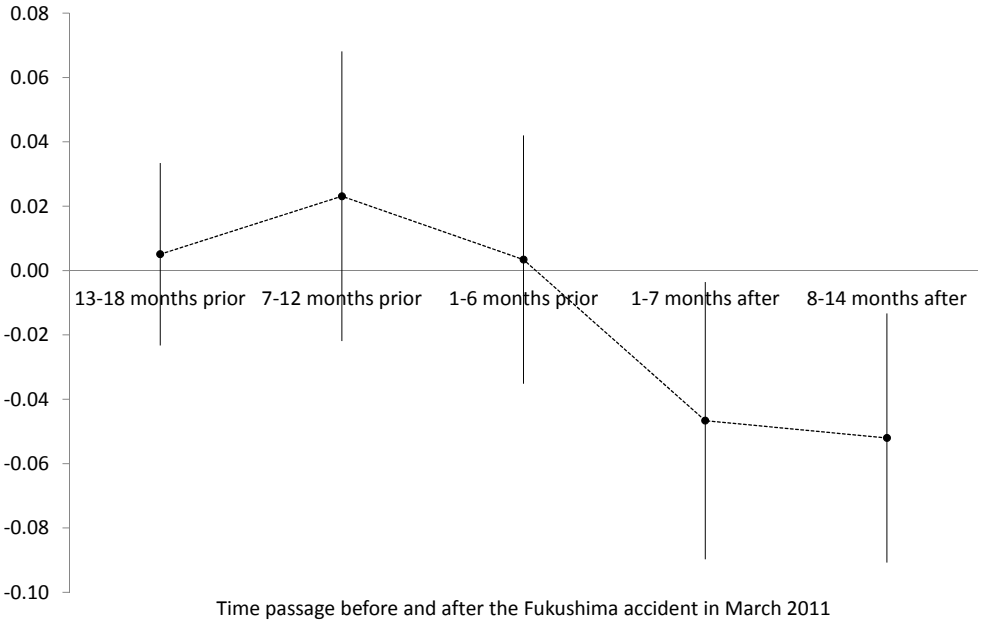
We can also analyze whether the treatment effect changed over time after the treatment. To do so, we split the post-Fukushima sample in two periods of seven months each. The results in column (3) suggests that the treatment effect remained virtually unchanged over the two periods (-4.7% vs. -5.2%). Figure 2 illustrates

[19] Each of these cities has more than $250,000$ residents. Four cities have more than one million inhabitants (Berlin, Hamburg, Munich, Cologne).

[20] Regression results for these robustness checks are not tabulated but can obtained from the authors upon request.

our findings on leads and lags of the treatment effect graphically. An alternative check on the parallel trend assumption adds a treatment-specific time trend to the regressors. The time trend is statistically insignificant (p-value of 0.746), and its inclusion increases the treatment effect only slightly to -6.3% (column (4)). Including both leads and lags and a treatment-specific time trend confirms our previous point estimates of the treatment effects, but reduces their statistical precision (column (5)).

FIG. 2: Leads and lags



Note: Estimated effect of offering a house that is located within 5 km of a NPP site on the log price before and after Fukushima. The point estimates are marked by a dot. The vertical bands indicate the 95% confidence interval of each estimate.

5.3 Heterogenous treatment effects

So far, the empirical analysis has focused on the price of property in the vicinity of NPPs that were *operative* before the Fukushima accident. Two additional NPP sites, Brunsbüttel and Krümmel, had already been inoperative for several years before Fukushima, but retained the possibility to be re-connected to the grid in the future. Intuitively, the Fukushima accident should have had a different effect on properties located in the vicinity of non-operative rather than operative NPPs. House prices in the vicinity of the two non-operative plants should have already reflected the possibility of a permanent closure before Fukushima. Furthermore, the Fukushima accident should not change the perceived risk of a nuclear disaster in a non-operative NPP. Therefore, column (1) of Table 7 also reports the treatment effect for houses located in the vicinity of a NPP site that were not in operation when the Fukushima accident occured (NPP sites Brunsbüttel and Krümmel). Consistent with conjectures, prices of houses next to inoperative NPP sites were not affected by the Fukushima accident (see column (1) of Table 7).

The effect of Fukushima on the prices of houses located next to a NPP site may not only depend on the

TABLE 7: TREATMENT EFFECTS BY CLOSURE TYPE

	(1)	(2)
Treatment effects:		
Operative NPP $<$ 5km $\times$ Post-Fukushima	-0.058***	
	(0.016)	
Operative NPP, closed $<$ 5km $\times$ Post-Fukushima		-0.108***
		(0.018)
Operative NPP, not closed $<$ 5km $\times$ Post-Fukushima		-0.046**
		(0.019)
Non-operative NPP $<$ 5km $\times$ Post-Fukushima	0.007	0.007
	(0.032)	(0.032)

NOTES: The endogenous variable is the log of the nominal house price posted. The NPP dummies indicate whether a house on offer is located within 5 km from a NPP site that was either inoperative or operative before the Fukushima accident. Among the operative NPPs, we further distinguishes between those that fully closed after Fukushima and those that were not. All regressions include time dummies, the respective NPP dummies, property characteristics, and zip-code fixed effects. Property characteristics include age (and its square), a dummy for property still under construction, living space (and its square), base area (and its square), and a dummy for detached houses. The estimation sample comprises sales offers for single-unit detached and terraced houses houses posted on the internet platform ImmobilienScout24 in the months March 2009 to May 2012 (March 2011 offers are excluded). Sample size in all regressions is $3,254,614$ (offer $\times$ month observations). The number of zip-code-level regional clusters is $9,277$. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the zip code level.

pre- but also on the post-accident operative status of the respective site. At NPP sites that saw immediate closures, adverse economic effects are likely to be larger in magnitude and more immediately felt than those at sites that experienced merely partial closure or only reductions in their maximum remaining operation times. At the same time, however, full site closures should eliminate (or at least substantially reduce) the risk of direct exposure to a nuclear accident of residents that live close to such NPP sites. Both of these changes in site fundamentals may affect the vaue of real estate in the vicinity of NPP sites. After the Fukushima Daiichi accident, NPP sites Biblis (NPPs Biblis-A and Biblis-B) and Unterweser were immediately closed. At the other sites, at least one block was allowed to stay in operation (although maximum operation times were cut back). One may expect that the effects of Fukushima, and especially the (expected) economic effects, were felt most strongly at those two sites that were closed immediately. The results reported in column (2) of Table (7) confirm this hypothesis. Relative property prices of real estate located next to NPP sites that were operative before Fukushima and were closed thereafter fell by 10.8%. In contrast, prices of house located next to NPPs that were not closed fell by only 4.6%.

5.4 Discussion and Further Results

We have seen that offer prices for houses near NPP sites fell significantly after the Fukushima Daiichi accident, most strongly near sites that were shut down completely. The latter finding suggests that economic reasons are of prime importance for the deterioration of offer prices in the vicinity of NPP sites. However, (expected) adverse effects on the local economy associated with full, respectively partial site closures, and reductions in maximum remaining operation times of NPPs need not be the only causal pathway by which the Fukushima Daiichi accident affected the German housing market. Residential property near NPP sites

may have lost in attractiveness and hence value also because the Fukushima Daiichi accident changed people's perceptions of the risk of nuclear energy. In the preceding analyses, we largely side-stepped the issue of potential pathways and focused exclusively on the overall net effect of the Fukushima Daiichi accident on house offer prices in Germany. In this section, we address this issue.

Identification of these two potential pathways, and quantification of their respective importance, is complicated by a number of factors. First, in our observation period, which extends but 14 months after the Faukushima Daiichi accident in Japan, economic effects of site closures (partial and complete) are unlikely to have materialized in full. The same holds true for the economic effects of reduced maximum operation times. Measurable proxies, such as local employment levels, local tax revenues, etc. in this period are thus of limited informational content for the overall economic effects that people anticipate to realize in the future. The latter, however, is of prime importance for the value of real estate, which, being an asset and a durable (and immobile) consumption good, depends heavily in its present value on expected future conditions, including the economic development in the locality in which the real estate is located. Second, several potential key economic indicators, such as local tax revenues and local migration data, are not yet available for most of our post-Fukushima Daiichi observations (our estimation sample extends well into the year 2012), which effectively precludes the use of such information in our analysis. And third, the magnitude of *both* potential causal pathways is related to remaining operation times of NPP sites, in one case positively, in the other negatively. For the longer the remaining operation time of a NPP site, the larger is the risk that a nuclear accident will occur at the site (assuming the risk of such an event per unit of time is constant), but the lower (more heavily discounted) is the present value of any adverse economic effects of future site closure. For identification, what is required is some exogenous source of variation between sites, respectively within the neighborhood of a particular site, in the likely economic and risk-based consequences of the Fukushima Daiichi accident and post-Fukushima changes in site fundamentals (closures, cuts in remaining operation time). In the following, we explore several such exogenous sources of variation.

To be added.

6 Conclusion

To be added.

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