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Nuclear Power Plant Closures and Local Housing Values: Evidence from 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 which 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 and employing a difference-in-differences approach, we find that Fukushima reduced housing prices near nuclear power plants that were in operation before Fukushima by 4.9%. Housing prices near sites that were shut down right after the accident even fell by 9.8%. Our results suggest that on the German housing market, the negative economic effects of the closure of nuclear power plants dominate potential positive changes in local amenities.

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 to a major accident at the Fukushima Daiichi nuclear power plant operated by Tokyo Electric Power Company (TEPCO). This accident brought nuclear safety to the forefront of global attention. Nowhere, however, not even in Japan itself, did the Fukushima Daiichi accident have such repercussions on public opinion and energy policy as in distant Germany. Following mass anti-nuclear protests across Germany and a historic defeat in a state election in Baden-Württemberg, Germany's coalition government closed eight of the country's 17 nuclear power plants (henceforth, NPPs) in August 2011.[1] Scrapping a recent decision to extend the life of nuclear reactors by an average of 12 years, the German government also declared the phasing out of the 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 accident on Germany's energy policy is manifest. Not as easily seen, the Fukushima accident, and the U-turn in Germany's nuclear energy policy it caused, is likely to affect local economies in Germany. Plant closures and the nuclear phase-out might harm employment and reduce local business tax revenues in regions with NPPs. Such adverse local economic shocks have in fact been frequently discussed in the local and national press.[3] The decision to phase out nuclear energy, in particular the closure of nuclear power plants, has also reduced the actual risk of a nuclear fall-out in German regions that host a NPP facility, while the accident itself may well have changed people's subjective perceptions of the risk of nuclear energy. Such changes in the (perceived) exposure to the risk of a nuclear accident should, in turn, affect local amenities. In a simple Rosen-Roback spatial equilibrium model (Rosen, 1979; Roback, 1982), both local labor demand shocks and changes in local amenities will be capitalized in housing values if the elasticity of local housing supply is sufficiently low (Glaeser and Gyourko, 2005; Moretti, 2011).

This paper uses data on individual houses listed for sale from Germany's largest internet platform for real estate to investigate the effect of Fukushima on the German housing market. Our empirical analysis compares the prices of houses located close to NPP sites with the prices of houses located further away from such sites before and after the Fukushima accident (*difference-in-differences* approach). We find that prices for real estate in the vicinity of NPPs that were in operation before Fukushima fell by almost 5%

[1] The year 2011 saw the permanent retirement of 13 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 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 (International Atomic Energy Agency, 2012).

[2] After the Fukushima Daiichi accident, Japan decided to phase out its NPPs by the end of the 2030s. The new government under prime minister Shinzo Abe, however, announced to re-start those NPPs that pass new and stricter security standards. Other countries, such as Belgium, Italy and Switzerland have re-evaluated their nuclear programs (International Atomic Energy Agency, 2012). Switzerland decided in May 2011 to not extend operation times of existing NPPs anymore and to ban the construction of new reactors. The first Swiss NPP will presumably 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 following a referendum in 1987. In Belgium, plans to extend remaining operation times of the country's two oldest NPPs were scrapped in July 2012, and the two NPPs are now scheduled to close in 2015. The last Belgian NPP will close in 2025.

[3] For instance, the German weekly magazine *Der Spiegel* wrote in its online edition on 2 June 2011: "The nuclear phase-out puts strain on local municipalities: Eight NPPs are closed lightning fast. As a consequence, the municipalities will lose millions in business taxes." And the *Südhessen Morgen*, a local newspaper, wrote about the situation in the Hessian town of Biblis: "The closing down of the nuclear power plant is a major blow for Biblis. [...] It will lead to significant losses of purchasing power and to distortions on the housing market."

after Fukushima. This negative effect on housing prices could either reflect adverse economic effects of the nuclear phase-out or higher perceived risks of a nuclear accident. We expect economic effects to be more important near sites that were closed immediately (as they face immediate job losses), while perceived risks should be less important near such sites (as they are no longer in operation). We document that housing prices near sites that were closed after Fukushima fell by almost 10%, which suggests that economic rather than risk-related effects are of prime importance for falling housing prices. Consistent with this conjecture, we find that after Fukushima, employment fell sharply in municipalities whose NPP sites were closed.

Our main identifying assumption for a causal interpretation of our results is that conditional on control variables, which include a large set of individual house characteristics, housing prices in treatment and control regions would have followed the same trend in the absence of Fukushima. We corroborate this identifying assumption in various ways. For example, we show that pre-Fukushima trends in prices did not differ statistically between houses close to and further away from a NPP site. We also show that our results do not change when we restrict the estimation sample to a more homogeneous set of regions (e.g., by excluding house offers from urban districts).

Our study relates to an extensive literature that has investigated 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; Folland and Hough, 2000), 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 (Anselin and Lozano-Gracia, 2008; Caruthers and Clark, 2010; Cho et al., 2008; Cohen and Coughlin, 2008; Debrezion et al., 2007; Hughes and Sirmans, 1992). Our study contributes to this literature in several ways. First, our study is one of the first large-scale studies of NPPs, and, to the best of our knowledge, the first large-scale study of NPPs outside the US. Second, it is also one of the first studies to analyze the closure of a facility. Since the opening of a facility may trigger important adjustment processes, with households sorting across neighborhoods (Davis, 2011), the closure of a facility might not just reverse the effect of its opening.[4] Third, our setting precludes anticipation effects that may otherwise complicate the identification of the effects of a site closure or opening. Potential home buyers or sellers could neither anticipate the Fukushima accident nor the subsequent change in Germany's energy policy. Moreover, the availability of house-level data from before and after the Fukushima Daiichi accident allows us to more forcefully control for differences between locations with and without a NPP site. Finally, our study assesses the relative importance of the potentially positive economic effect of large plants, with their potential to boost local employment and lead to positive economic spillovers (Greenstone et al., 2010), and their local disamenities.

Our setting has the unique feature that it permits us to study the response of housing prices to a distant event that did not in any physical way affect individual houses. The radiation released by the Fukushima Daiichi accident in Japan did not have a measurable impact on the environment in Germany, and neither

[4] Kiel and McClain (1995) show that the effect on property prices of an incinerator is not constant over time but varies over the siting process and the operation time of the facility. However, the authors do not consider the closure of the incinerator. Currie et al. (2015), in their analysis of the effect of toxic industrial plants on the housing market, distinguish explicitly between plant openings and plant closures. They find that plant openings decrease housing prices within 0.5 miles of the plant by around 11 percent, whereas plant closures have no effect on housing prices. Davis and Hausman (2016) study the closure of a large nuclear plant in California but focus on the effect of the closure on carbon dioxide emissions and the private cost of electricity generation.

did the tsunami that caused this accident. In recent work, Fink and Stratmann (2015) study the effect of the nuclear accident in Fukushima on housing prices in the United States. Using monthly zip-code level data on median home prices before and after Fukushima, the authors find that prices in regions close to nuclear reactors did not fall relative to prices in regions further away. This finding is at odds with the hypothesis that housing prices in the vicinity of NPP sites may have suffered because residents updated their nuclear risk perceptions after the Fukushima Daiichi accident. Other than in Germany, no NPP in the United States was closed and none suffered a reduction in its remaining operation time.

The paper proceeds as follows. Section 2 provides background information on Germany's NPP sites, and reviews the chronology of government responses and changes in Germany's energy policy following the nuclear accident in Japan. It also discusses potential mechanisms through which the Fukushima Daiichi accident and the resulting change in Germany's nuclear energy policy may have affected housing prices near German NPPs. Section 3 describes the real estate data and the identification strategy we use in our empirical analysis. This section also provides summary statistics, disaggregated by distance to NPP sites, on basic amenities of property for sale prior to and after the Fukushima Daiichi accident. Section 4 presents and discusses our regression results. Section 5 concludes.

2 Background

2.1 Fukushima and German Energy Policy: A Chronology of Events

When the Tohoku earthquake and tsunami struck Japan on 11 March 2011, there were 15 NPPs in operation at ten sites in Germany (see Figure 1 for their location in Germany).[5] Another two NPPs, Brunsbüttel and Krümmel, had been inoperative for several years[6] lacking a final decision to close them permanently.

Only three days after the Tsunami in Japan, the German federal government announced a 3-month nuclear moratorium that took immediate effect. During the moratorium, the seven oldest NPPs (including the already inoperative NPP Brunsbüttel) were temporarily shut down within three days of the government's announcement (see Table A-1 in the Appendix). On 22 March 2011, the government set up two commissions, one to assess security standards at German NPPs (the so-called *Reaktorsicherheitskommission*), and one to inquire into the risk of atomic energy that the German population was still willing to bear after the Fukushima Daiichi accident (the so-called *Ethikkommission*).

Despite these initiatives, the ruling Christian Democratic Party of Chancellor Angela Merkel suffered a historic defeat in the state election in Baden-Württemberg on 27 March 2011. After ruling the state since its foundation in 1952, the Christian Democrats were ousted from office by a coalition of Social Democrats and Greens. The Greens, which traditionally oppose nuclear energy, scored their all-time best state election result, and their top candidate became the first green leader of a German state (*Ministerpräsident*). Commentators agreed that the Fukushima accident had significantly influenced the election result.[7] In the eyes

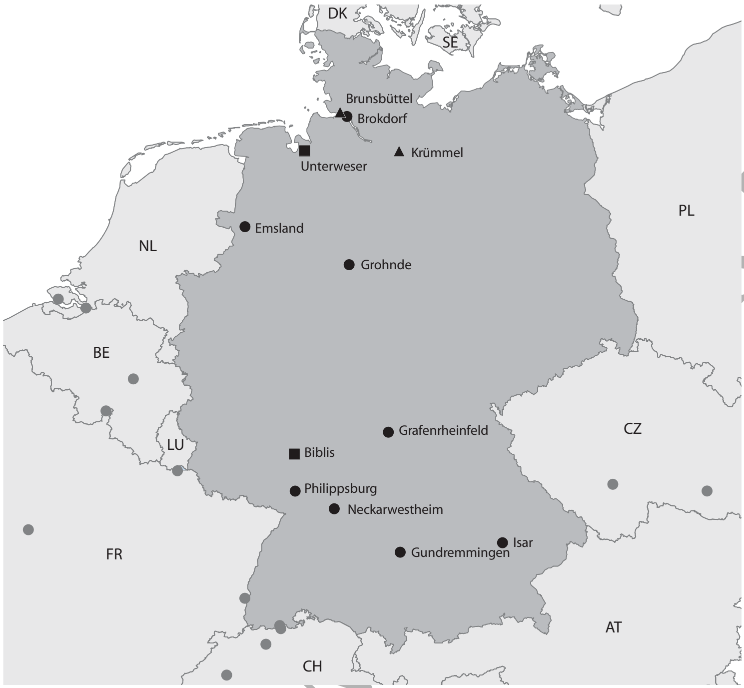
[5] One of these NPPs, Biblis-B, had been disconnected from the grid two weeks before Fukushima for regular inspection scheduled for 25 February 2011 to 22 May 2011 (Deutsches Atomforum, 2012).

[6] NPPs Brunsbüttel and Krümmel had shut down in the summer of 2007. Brunsbüttel has remained inoperative ever since, while Krümmel has resumed operation only for a short time in June 2009 (Department of Nuclear Safety, 2011, 2012).

[7] See, for instance, the online comments in *Die Zeit* ("Die Wahl der Spätentscheider") or *Rheinische Post* ("Fukushima 21: Das

of many voters, the accident had proven wrong the pro-nuclear energy policy of the federal coalition government of the Christian Democratic Party and the Liberal Democratic Party, which only half a year earlier had extended remaining operation times of the existing NPPs in Germany.[8]

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



Note: Foreign nuclear power plant (NPP) sites are marked by grey dots and without name. German NPP sites are marked by black dots, triangles, or squares and with name. Black dots indicate operating NPP sites that were not (fully) closed after Fukushima (Brokdorf, Emsland, Grohnde, Grafenrheinfeld, Philippsburg, Neckarwestheim, Gundremmingen, and Isar), black squares indicate operating NPP sites that were (fully) closed after Fukushima (Unterweser, Biblis), and black triangles indicate non-operating NPPs at the time of the Fukushima accident (Brunsüttel, Krümmel), all of which were closed after Fukushima.

On 30 May 2011, shortly after the two commissions had issued their final reports, the German federal government announced that it would permanently shut down all seven NPPs that had been temporarily shut down under the moratorium. The government also decided to permanently close the notoriously accident-stricken NPP Krümmel, which had already been inoperative since the summer of 2007. In addition, the government also reversed its previous decision to extend the operation times of the nine remaining NPPs. The German Parliament approved these measures by a great majority on 30 June 2011 in the 13th Amendment to the Atomic Energy Act (*13. Gesetz zur Änderung des Atomgesetzes*). Taking effect on 6 August 2011, the seven moratorium NPPs and NPP Krümmel lost their operating license (see Table A-1). None of these eight NPPs had been re-connected to the grid after the moratorium expired in mid-June. The last NPP in Germany will now close in 2022. Most Germans either welcomed the government decision (44%)

waren keine normalen Wahlen") on 28 March 2011.

[8]The Christian Democrats and the Liberals had already announced plans to extend the operation times of existing NPPs during their campaign for the national election in September 2009. After a lengthy discussion about the exact terms of the extensions, the coalition parties agreed on 5 September 2010 that the operation times of NPPs should be increased by an average of 12 years per reactor. The corresponding law was approved by the German parliament on 28 October 2010.

or considered the closure date for the last NPP as even "too late" (31%) (Infratest dimap, 2011b).

2.2 Fukushima and the German Housing Market: Theoretical Considerations

In a simple Rosen-Roback spatial equilibrium model (Rosen, 1979; Roback, 1982), differences in local housing prices reflect either differences in earnings or differences in amenities (Glaeser and Gyourko, 2005). Within such a framework, Fukushima and the nuclear phase-out in Germany might affect housing prices through two channels. First, the actual or planned closure of a NPP might reduce (expected) earnings by reducing local labor demand. Second, the Fukushima accident and the subsequent nuclear phase-out might affect the value of local amenities by changing the actual or perceived risk of NPP sites. Both changes in local labor demand and changes in the actual or perceived risk of NPP sites will be capitalized in housing prices if the elasticity of local housing supply is sufficiently low. We will use variation in site closures to gauge the respective importance of these different causal pathways.[9]

First, consider the negative labor demand shock. The nuclear phase-out in Germany is likely to have adverse effects on local labor demand both directly at NPP sites and indirectly through spillovers.[10] NPP sites are usually important local employers. The German electric utilities company *RWE*, for instance, used to employ around 700 workers at the NPP site in the small Hessian town of Biblis. Subcontractors employed another 300 workers at the site. All in all, the NPP Biblis provided work for almost 1000 workers – in a town of just 9000 inhabitants. Ten months after NPP Biblis was closed, RWE announced that it would reduce employment at the site from 645 to 470 workers by the end of 2012 (RWE AG, 2012). Another 50 of its workers, along with the great majority of workers from subcontracting firms, had already left the site by that time.[11] Moreover, the closure of a NPP might also reduce labor demand through spillover effects in the region. In regular intervals, usually once a year, large-scale renewal and maintenance work takes place at NPP sites. The maintenance work, which often lasts for several weeks, requires many external engineers and assembly operators to work at the site in addition to the regular work force. These external workers often stay in local hotels and eat in local restaurants. The closure of a NPP is therefore likely to hurt also the local hotel and restaurant industry. In the short run, effects might be strongest in regions in which a NPP site was closed immediately. But even in regions where only the operation time of the local NPP was reduced, housing prices might fall if people anticipate adverse labor demand effects to materialize in the future.

Second, consider the potential change in local amenities. Fukushima might affect local amenities– and hence housing prices–through its effect on the perceived and actual risk of nuclear energy.[12] After

[9]In related work, Currie et al. (2015) outline a partial equilibrium model in which the opening of a toxic plant affects housing prices through increases in productivity (and hence wages) and decreases in local amenities. The paper aims to isolate local disamenities of toxic plants by comparing housing prices within 0.5 miles or 1 mile of plants with prices measured 1-2 miles away from plants, assuming that the economic benefits accrue equally to homes within two miles of the plant.

[10]There are numerous newspaper articles on these adverse effects of site closures on local economies. See, for instance, the online articles in *Frankfurter Rundschau* on 2 October 2012 ("Eine Stadt sucht ihre Zukunft") or in *Kreiszeitung Wesermarsch* on 10 March 2012 ("Beschäftigte hoffen auf Rückbau").

[11]Many of the remaining 500 workers will for now continue working at the site. Regular inspections in the post-operation period and the dismantling of the NPP in the future still require specialized staff. The employment effects of the nuclear phase-out will therefore not materialize at once, not even at sites which were closed immediately.

[12]Over time, local amenities might also suffer from the negative labor demand shock. Deteriorating labor market conditions might, for instance, reduce business tax revenues, the most important source of revenue for local municipalities, and therefore also decrease investment into communal areas or public transport.

Fukushima, people might perceive nuclear energy to be more risky than before the accident. Right after the accident, the majority of Germans (70%) thought that a severe nuclear accident comparable to that in Japan could also happen in Germany (Infratest dimap, 2011a); and the share of those in favor of a nuclear phase-out increased to 71%, up from 62% in August 2010. Even the German chancellor Angela Merkel, a trained physicist, explained the change in Germany's energy policy by a change in her assessment of the risk of nuclear energy. In a parliamentary speech on 9 June 2011, she stated that "[b]efore Fukushima, I accepted the residual risk of nuclear energy because I was convinced that this risk will not materialize in a high-tech country with high security standards [...] Fukushima made us aware of the fact that even in a high-tech country such as Japan, the risk of nuclear energy cannot be controlled with certainty."[13] If Fukushima has indeed increased the perceived risk of nuclear energy, people might be less willing to live close to a NPP (might value local amenities less). This should ceteris paribus cause housing prices to fall. However, the political decision to phase out nuclear energy has reduced the actual life span of NPPs and even led to the immediate closure of two NPP sites (Biblis, Unterweser). The phase-out has therefore reduced the actual risk of a nuclear accident, and therefore people might be more willing to live close to a NPP (might value local amenities more).[14] Whether the positive effect on housing prices (through a reduced actual risk) or the negative effect (through an increased perceived risk) prevails is unclear. However, the overall risk effect is likely to be positive near NPPs that were closed immediately after Fukushima. After all, local residents no longer live near an operating NPP, and increases in their risk perceptions of operating NPPs are therefore no longer relevant for their housing decisions.[15]

To summarize, the Fukushima accident is likely to decrease local housing prices near German NPPs if the accident increased the perceived risk of nuclear energy. The nuclear phase-out, which followed the accident, is also likely to decrease housing prices if the phase-out adversely affects local labor markets. The phase-out, however, also tends to increase local housing prices by reducing the actual risk of a nuclear disaster through site closures and cuts in maximum remaining operating times. A priori, therefore, the overall effect on housing prices near German NPPs is ambiguous. As discussed above, the relative importance of changes in risk perceptions, risk exposure, and labor market conditions will differ between sites that were closed right after the accident and those that were not. In the empirical analysis, we will exploit regional variation in sites closures to gauge the respective importance of these different causal pathways.

3 Empirical Strategy and Data

3.1 Empirical Strategy

To identify the effect of the Fukushima Daiichi accident on the prices of houses located next to a NPP site, we apply a difference-in-differences (DiD) approach by estimating variants of hedonic price functions of

[13] Translation by the authors. The speech can be accessed in German on http://www.bundesregierung.de/Content/DE/Bulletin/2011/06/59-1-bk-regerkl-bt.html.

[14] As housing prices reflect both the present and the future risk of a nuclear disaster, they may not only appreciate near NPPs that were closed but also near NPPs that only saw a reduction in their remaining maximum operation time.

[15] Admittedly, NPPs carry some risk for their environment even after they are closed. For instance, fuel rods still have to be cooled in the immediate post-operation period, as they would melt otherwise.

the following type:

$$Y_{ijt} = X_{ijt}\beta + \gamma NPP_{ij} + \delta(NPP_{ij} \times Fukushima_t) + D_j + D_t + \varepsilon_{ijt} \qquad (1)$$

where Y_{ijt} is the log asking price of property i in region j in month t, X_{ijt} is a vector of house characteristics, NPP_{ij} is a dummy for property located in the vicinity of a NPP site, and $Fukushima_t$ is a dummy for the time period after the Fukushima Daiichi accident. D_j is a full set of region dummies, D_t a full set of time dummies, and ε_{ijt} is an error term.

The treatment effect of interest is δ. It captures differences in the pre- to post-Fukushima change in the average price of houses located next to and further away from a NPP site. The vector X_{ijt} controls for observable property characteristics and therefore also for changes in the composition of houses listed for sale over time. 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. In our baseline specification, the NPP_{ij} dummy is equal to one if a house is located within 5km of a NPP site (we analyze the effect on houses further away than 5km in additional regressions). The dummy captures time-invariant mean level differences in the price of houses located in the vicinity of NPP sites. D_j controls for time-invariant differences in housing prices between small regional units. In our baseline specification, we define these regional units on the zip-code level, of which there are 8,116 in our estimation sample. Standard errors are clustered at the level of *Raumordnungsregionen*, regional planning areas which roughly reflect commuting zones. Finally, the full set of month dummies D_t controls for country-wide changes in housing prices over time.

Potential buyers and sellers in the German housing market could not anticipate the Fukushima accident and the subsequent change in Germany's energy policy. We can therefore rule out anticipation effects and hence that the treatment (Fukushima) had an effect on housing prices in the pre-treatment period. The main identifying assumption of our difference-in-differences approach is that conditional on controls, prices of houses located close to and further away from a NPP site would have followed the same trend in the absence of Fukushima. We corroborate this identifying assumption by a series of robustness and specification checks. In particular, we test for differences in pre-Fukushima trends between houses in treatment and control regions, add regional time trends and exclude urban areas to increase the homogeneity of the analyzed regions. In additional robustness checks, we also add additional property-to-NPP distance measures to see how quickly any potential Fukushima effect levels off with distance, use municipality and county instead of zip-code fixed effects, and confine the estimation sample to new offers only. Finally, we also test whether the treatment effect differs between operating NPP sites that were shut down after Fukushima and NPP sites that were not. Exploiting regional variation in sites closures allows us to to gauge the respective importance of the different causal pathways (changes in the value of local amenities and economic conditions) that may underlie observed associations between changes in houses prices and closeness of property to NPP sites (see Section 2.2).

3.2 Data and Descriptive Statistics

For our analysis, we use monthly house price data provided by the commercial internet platform *ImmobilienScout24*, Germany's leading online property broker.[16] Data on individual housing prices and house characteristics stem from property offers that individuals place on this platform.[17] The data set covers a large part of the housing supply in Germany and, given its large sample size, is therefore suitable for the analysis of regional housing prices (Bauer et al., 2013). The data set provides information on property characteristics and the exact geocode of each property. *ImmobilienScout24* records asking prices rather than transaction prices. This can be a potential drawback, especially if the difference between asking and transaction prices varies systematically with property amenities or characteristics of localities. However, in a recent analysis for rural areas in the German state of Rhineland-Palatinate, Dinkel and Kurzrock (2012) show that while asking prices on *ImmobilienScout24* do exceed actual transaction prices by an average of 15%, asking price premiums do not vary systematically with either house or neighborhood characteristics.

Our estimation sample consists of single-unit houses that were offered for sale between March 2007 and March 2013. We exclude housing listings for which information on property characteristics is missing. We also exclude observations with very unusual property characteristics.[18] Moreover, we drop offers dating from March 2011 from our estimation sample, as this is the month that the accident at Fukushima occurred. Finally, we also exclude the 731 observations of houses that are located within 5km from the French NPP of Fessenheim or the Swiss NPP of Leibstadt.[19] After these restrictions, the total sample consists of an unbalanced panel of 6,478,698 offers for 1,635,600 houses.

[16] See http://www.immobilienscout24.de/. Bauer et al. (2013) provide a detailed description of the data.

[17] Fees for posting an offer on *ImmobilienScout24* depend on posting duration (two weeks, one month, three months), the type of real estate offered (e.g. 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.

[18] We exclude houses with a reported base area of less than 50 or more than 10,000 square meters, houses with a reported living space of less than 25 or more than 500 square meters, and houses with an asking price of less than 1,000 or more than 10 Mio. Euro. Furthermore, we exclude houses with more than 11 rooms and houses that are older than 200 years.

[19] The Fessenheim NPP is located in north-eastern France, little more than 1 km away from the French-German border. It is the oldest NPP in France that is still in operation. In September 2012, French president Francois Hollande announced that the Fessenheim NPP will be closed by the end of 2016. Hollande had promised the closure of this site during his election campaign in early 2012. The Leibstadt NPP is located in northern Switzerland, right at the Swiss-German border. It is the youngest NPP in Switzerland. The exact closing date of the NPP is still under discussion but current plans schedule the closure for 2034.

TABLE 1: SUMMARY STATISTICS BY DISTANCE TO NPP SITE, BEFORE AND AFTER FUKUSHIMA

	Before Fukushima					After Fukushima					DiD
	Distance to next NPP < 5 km			≥ 5 km	≥ 25 km	Distance to next NPP < 5 km			≥ 5 km	≥ 25 km	
	all	operating	non-operating			all	operating	non-operating			[(6) − (1)]− [(9) − (4)]
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Price (Euro)	217,586	233,615	178,196	264,692	264,597	226,222	232,414	206,790	268,061	267,843	5,267
	[103,320]	[110,295]	[69,515]	[193,186]	[196,315]	[115,604]	[118,540]	[103,516]	[220,801]	[223,999]	(8,498)
Log Price (Euro)	12.188	12.261	12.009	12.316	12.312	12.199	12.231	12.101	12.282	12.277	0.045
	[0.462]	[0.459]	[0.421]	[0.571]	[0.576]	[0.533]	[0.520]	[0.560]	[0.652]	[0.658]	(0.033)
Age (years)	33.024	31.163	37.598	29.215	29.158	40.976	40.256	43.232	36.790	36.745	0.377
	[30.621]	[31.293]	[28.392]	[29.990]	[29.962]	[32.373]	[32.916]	[30.504]	[32.563]	[32.557]	(1.316)
In construction (%)	3.615	4.516	1.399	5.085	5.040	2.280	2.952	0.173	3.903	3.886	-0.152
	[18.666]	[20.767]	[11.747]	[21.968]	[21.876]	[14.929]	[16.927]	[4.152]	[19.366]	[19.327]	(1.315)
Living space (m^2)	146.252	150.314	136.270	152.747	152.653	152.595	155.123	144.662	156.489	156.358	2.602
	[50.392]	[51.288]	[46.645]	[55.572]	[55.845]	[52.723]	[52.724]	[51.942]	[59.350]	[59.524]	(3.531)
Base area (m^2)	700.898	658.047	806.202	729.524	739.245	740.618	680.371	929.679	810.401	822.010	-41.157
	[682.403]	[654.769]	[735.526]	[776.146]	[784.590]	[752.178]	[618.603]	[1045.826]	[871.125]	[881.044]	(36.443)
Detached house (%)	27.846	27.724	28.148	33.367	33.109	25.320	26.109	22.842	29.289	29.147	1.551
	[44.826]	[44.766]	[44.977]	[47.152]	[47.060]	[43.487]	[43.927]	[41.994]	[45.5091]	[45.444]	(2.688)
Observations	14,580	10,363	4,217	4,546,480	4,217,770	7,192	5,454	1,738	1,910,446	1,768,295	6,478,698

NOTE: Columns (1) to (4) and (6) to (9) show the mean of each variable for property located within or outside a 5 km range of a NPP site. Among the property within the 5 km range, we further distinguish between property near sites that were operating before Fukushima and those that were not (NPPs Brunsbüttel, Krümmel). Columns (5) and (10) show the mean of each variable for the control group of property in our baseline specification from column (4) of Table 2. Averages are calculated for the pre-Fukushima period March 2007 to February 2011 and for the post-Fukushima period April 2011 to March 2013. Standard deviations are reported in square brackets (columns (1) to (10)). Standard errors clustered at the level of regional planning units (*Raumordnungsregionen*) are reported in round brackets (column (11)).

Table 1 provides summary statistics for sale offers prior to and after the Fukushima accident for houses located at least 5 km and less than 5 km away from a NPP site (see columns (1) and (6), and (4) and (9)). Average offer prices increased pre- to post-Fukushima both for houses within 5 km of a NPP site (+8,636 Euro) and for houses located more than 5 km away from a NPP site (+3,369 Euro). The difference of these two differences, i.e., the unconditional difference-in-difference (DiD) estimate, is 5,267 (see column (11) of Table 1). This suggests that Fukushima had a small positive effect on housing prices near NPP sites. The unconditional DiD estimate, however, is not statistically different from zero. The same holds for the unconditional DiD in log prices (+4.5%), the dependent variable of our regression analysis. However, the descriptives also suggests that the change in housing prices near operating NPPs differed greatly from the change in housing prices near non-operating NPPs. Prices near the NPP sites of Brunsbüttel and Krümmel that were already inactive before the Fukushima disaster increased by almost 28,600 Euro after Fukushima (see columns (3) and (8)). In contrast, prices near operating NPPs fell by about 1,200 Euro (columns (2) and (7)). It is therefore important to distinguish between housing prices near operating and non-operating NPPs, and the effect that Fukushima had on their respective development.

Finally, Table 1 also shows that there are pronounced differences in property characteristics between houses in treatment and control regions. Houses near NPP sites, and especially those near the non-operating sites of Brunsbüttel and Krümmel, tend to be considerably cheaper. They are also older and of smaller square footage. Moreover, houses near NPP sites are less likely to be under construction or to be a detached property. These differences in levels exist both before and after Fukushima. Unconditional DiD estimates reported in column (11) of Table 1, however, suggest that Fukushima had no statistically significant effect on average property characteristics of houses offered near NPP sites.

4 Results

4.1 Main Results

The starting point of our regression analysis is the unconditional DiD estimate of the effect that Fukushima had on log housing prices near NPP sites (see column (11) of Table 1). Controlling for time and zip code fixed effects, we estimate a treatment effect of -2.5% (see column (1) of Table 2). The effect, however, is not statistically significant. We next add property characteristics to account for potential changes in the composition of offers over time (see column (2) of Table 2). The coefficient estimate of the treatment effect changes only slightly to -3.2% but is now measured much more precisely (and statistically significant at the 10% level). The estimate suggests that Fukushima decreased housing prices near German NPPs by 3.2% relative to housing prices further away from NPPs.

So far, our regression analysis may mask important differences in the treatment effect on houses near operating and non-operating NPPs. The NPP sites of 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). Therefore, housing prices in the vicinity of the two non-operating plants might already have reflected the possibility of a permanent closure before Fukushima. Column (3) of Table 2 reports separate treatment effects for houses near operating and non-operating NPPs. The differences are striking. Fukushima appears to have had no effect on housing prices near non-operating NPPs. This result is consistent with the conjecture that local housing prices near these sites already reflected the possibility of a permanent site closure. Housing prices near NPPs that were operating before Fukushima, in contrast, declined markedly. Specification (3) suggests that asking prices of houses in the vicinity of an operating NPP site fell by 4.8% after the Fukushima accident. Therefore, real estate offered in the vicinity of operating NPP sites suffered a marked relative devaluation.

The effects of the Fukushima accident on the housing market in Germany need not be confined to real estate within 5 km of an operating NPP site. If they are not, our control group of houses located at least 5 km away from an operative NPP site may be contaminated. To assess this possibility, we consider a fourth specification. Column (4) of Table 2 reports treatment effects both for houses located less than 5 km from an operative NPP site and for houses located 5-10 km, 10-15km, 15-20km, and 20-25km from an operative NPP site. The control group now consists of houses located at least 25 km away from such a site (summary statistics for this control group before and after Fukushima are provided in columns (5) and (10) of Table 1). Reassuringly, the treatment effect for houses in the immediate vicinity of an operative NPP remains virtually unchanged at -4.9%. In contrast, houses located 5 to 10 km from a operative NPP site experienced only a small, but statistically insignificant, decrease in their offer price (-1.9%). Estimated treatment effects for property that is located even further away from an operative NPP site are of even smaller magnitude and throughout also statistically insignificant. These findings suggest that the impact of Fukushima on housing prices in Germany was confined to real estate in the immediate vicinity of NPP sites. Our choice of a 5 km cutoff for NPP_i therefore appears adequate. In our further analysis, we will maintain this threshold to define property within close range of NPP sites and use specification (4) as our baseline. For the sake of brevity, however, we will henceforth neither report the (always statistically insignificant) effects on houses near non-operating NPPs nor those on houses located 5-25km from an operative NPP site. Instead, we will concentrate on the effect that Fukushima had on houses in the immediate vicinity ($<$ 5km) of operating NPPs.

4.2 Robustness Checks

The key assumption for our difference-in-differences estimator to be unbiased is that the asking prices of the treatment group (houses located within 5 km of an operating NPP site) and the control group (houses located at least 25 km from an operative NPP site) would have followed the same time trend in the absence of the Fukushima accident. We corroborate this assumption in two ways. First, we restrict the estimation sample to a more homogeneous set of regions for which differential time trends are less likely. Second, we control for regional time trends and test directly for differentials trends between treatment and control regions.

The estimation results on various restricted estimation samples are reported in Table 3. Column (1) reproduces – from column (4) of Table 2 – the treatment effect for houses near operating NPPs of our baseline specification. In column (2), we restrict the estimation sample to property offers within 50 km of NPP sites.[20] The estimated treatment effect (-5.7%), however, remains close to our baseline estimate of

[20] In this restricted estimation sample, the number of 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. 14.7% of all observations in our unrestricted

TABLE 2: MAIN REGRESSION RESULTS

	(1)	(2)	(3)	(4)
Treatment effect:				
NPP<5km × Post-Fukushima	-0.025 (0.032)	-0.032* (0.017)		
operat. NPP<5km × Post-Fukushima			-0.048*** (0.016)	-0.049*** (0.016)
non-operat. NPP<5km × Post-Fukushima			0.014 (0.031)	0.014 (0.031)
5km ≤ operat. NPP < 10km × Post-Fukushima				-0.019 (0.015)
10km ≤ operat. NPP < 15km × Post-Fukushima				-0.011 (0.016)
15km ≤ operat. NPP < 20km × Post-Fukushima				-0.009 (0.012)
20km ≤ operat. NPP < 25km × Post-Fukushima				-0.009 (0.008)
Month dummies	yes	yes	yes	yes
Zip code fixed effects	yes	yes	yes	yes
Property characteristics	no	yes	yes	yes

NOTES: The endogenous variable is the log of the nominal house price posted. All regressions include a dummy for the post-Fukushima period. Regressions in columns (1) and (2) include a NPP dummy that indicates whether a house on offer is located within 5 km from a NPP site and an interaction of this indicator with the dummy for the post-Fukushima period. In columns (3) and (4), we instead add separate NPP dummies for houses near NPPs that were operating and non-operating right before the Fukushima accident, along with their respective interactions with the dummy for the post-Fukushima period. In column (4), we add further NPP dummies which indicate whether a house on offer is located between 5 and 10 km, 10 and 15 km, 15 and 20 km or 20 and 25 km from a NPP site that was operating right before the Fukushima accident and the interactions of these additional distance measures with the post-Fukushima dummy. 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 posted on the internet platform ImmobilienScout24 in the months March 2007 to March 2013 (March 2011 offers are excluded). The sample size is 6,478,698 (offer × month observations). The number of zip code fixed effects is 8,116. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the level of 96 regional planning units (*Raumordnungsregionen*).

-4.9%.[21] As a further check, we exclude all offers from Germany's 25 largest cities.[22] Again, the estimated treatment effect (now -4.0%) differs only little from our baseline estimate (column (3)). Excluding urban city districts from the estimation sample (column (4)), or cities with more than 100,000 inhabitants (column (5)), also only reduces somewhat the magnitude of the estimated treatment effect. In a final specification (column (6)), we replace our air distance measure (< 5 km) with a distance measure based on driving time (< 10 minutes). As is evident, the estimated treatment effect remains very close to that of our baseline estimation.[23]

We next control for regional time trends and test directly for different trends between treatment and

estimation sample are from East Germany (including Berlin). This figure falls to 0.2% if we restrict the estimation sample to property offers within 50 km of NPP sites. 12.6% (6.1%) of all observations in our unrestricted estimation sample are from Germany's 25 (5) largest cities. This figure falls to 9.7% (4.7%) if we restrict the estimation sample to property offers within 50 km of NPP sites.

[21] We also ran regressions in which we considered only offers within 5 km or outside 50 km (25 km) of a NPP site. The estimated treatment effect of -4.9% (-5.1%), however, again hardly differs from our baseline estimate.

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

[23] In this specification, we also replaced the other distance based variables and their respective interactions with equivalents based on driving time. None of the treatment effects for longer driving times to operative NPP sites (10-15, 15-20, and 20-25 minutes) is statistically significant. The same holds true for treatment effects within 10 minutes from inoperative sites.

TABLE 3: ROBUSTNESS CHECKS I: REGIONAL AND POPULATION-BASED RESTRICTIONS ON ESTIMATION SAMPLE, DRIVING-TIME DISTANCE MEASURE

	(1)	(2)	(3)	(4)	(5)	(6)
Treatment effect:						
operating NPP						
$<$ 5km $\times$ Post-Fukushima	-0.049*** (0.016)	-0.057*** (0.017)	-0.040** (0.016)	-0.038** (0.017)	-0.037** (0.016)	
$<$ 10min $\times$ Post-Fukushima						-0.050*** (0.018)
Estimation sample:						
Property $<$ 50km from NPP	no	yes	no	no	no	no
Excl. 25 most populous cities	no	no	yes	no	no	no
Excl. city districts	no	no	no	yes	no	no
Excl. cities $>$ 100k residents	no	no	no	no	yes	no
Observations	6,478,698	1,960,929	5,661,200	5,174,323	5,204,878	6,478,698

NOTES: The endogenous variable is the log of the nominal house price posted. To ease comparison, column (1) reproduces – from column (4) of Table 2 – the treatment effect of our baseline specification. The NPP dummy indicates whether a house on offer is located within 5 km from a NPP site that was operating right before the Fukushima accident. All regressions include time, NPP and post-Fukushima dummies, zip-code fixed effects, and property characteristics (see notes to Table 2). Estimates reported in columns (2) to columns (5) are based on restricted estimation samples. Column (2) reports estimates for property within 50km of a NPP site. Column (3) estimates are based on a restricted estimation sample that excludes property offers from the 25 most populous cities in Germany. The estimation sample for column (4) excludes property from city districts, and the estimation sample for column (5) excludes property from cities with more than 100,000 inhabitants. Column (6) reports results from a regression where we used driving time ($<$ 10 minutes) instead of air distance ($<$ 5*km*) to define our main treatment region. Additional driving time indicators considered in this regression (but not reported in the table) include indicators for driving times of 10-15 minutes, 15-20 minutes, and 20-25 minutes. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the level of regional planning units (*Raumordnungsregionen*).

control regions (see Table 4). First, we add a linear time trend and its interaction with our NPP dummy to the set of regressors. As shown in column (1) of Table 4, however, there is no evidence that linear price trends differed between real estate close to NPP sites and real estate further away from such sites. Our point estimate of the treatment effect also remains negative, large, and statistically significant (-6.9%). In an alternative specification (see column (2)), we add 96 linear time trends at the two-digit zip code level to the set of regressors. The estimated treatment effect of -4.9%, however, is identical to our baseline estimate. We next interact dummies for the months 1-12, 13-24, and 25-36 before the Fukushima Daiichi accident with the NPP dummy. Reassuringly, the coefficients of these interaction variables are statistically insignificant (see column (3) of Table 4).[24] 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 -4.5%. The lack of evidence for a differential pre-Fukushima trend also suggests that the September 2010 decision of the government to extend maximum remaining operation times of German NPPs had no effect on real estate prices in the vicinity of NPP sites. We further explore whether the treatment effect changed over time after the treatment. For this purpose, we split the post-Fukushima estimation sample in two periods of twelve months each. The results in column (4) suggest that the treatment effect changed little over the two periods (-4.6% vs. -5.2%). Finally, we allow for

[24]The three interaction variables are also jointly insignificant. Furthermore, the one for $t-1$ is statistically no different from the one for $t-3$.

differential trends before and after the Fukushima Daiichi accident in a single specification (see column (5)). The results, however, are virtually unchanged. Figure 2 illustrates the findings of this regression graphically.

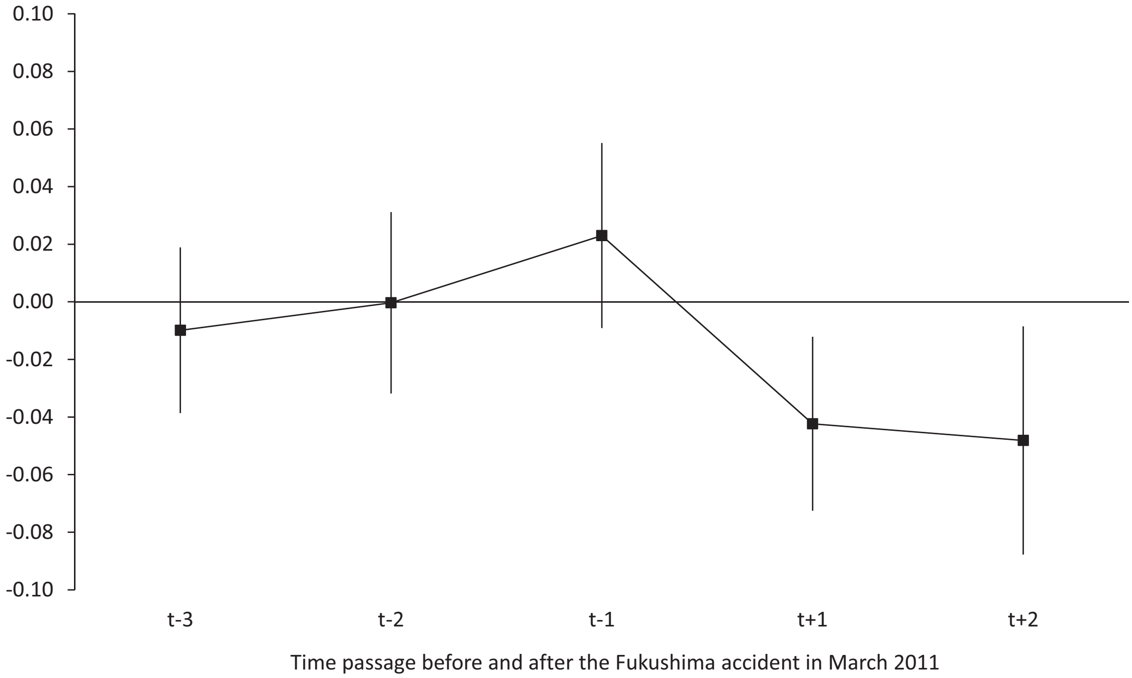
TABLE 4: ROBUSTNESS CHECKS II: LINEAR TIME TRENDS, TREATMENT LEADS AND LAGS

	(1)	(2)	(3)	(4)	(5)
After Fukushima:					
NPP $<$ 5km $\times$ Post-Fukushima	-0.069*** (0.024)	-0.049*** (0.014)	-0.045** (0.020)		
NPP $<$ 5km $\times$ Fukushima$_{t+2}$				-0.052** (0.021)	-0.048** (0.024)
NPP $<$ 5km $\times$ Fukushima$_{t+1}$				-0.046*** (0.015)	-0.042** (0.018)
Before Fukushima:					
NPP $<$ 5km $\times$ Fukushima$_{t-1}$			0.023 (0.020)		0.023 (0.20)
NPP $<$ 5km $\times$ Fukushima$_{t-2}$			-0.0003 (0.019)		-0.0003 (0.019)
NPP $<$ 5km $\times$ Fukushima$_{t-3}$			-0.010 (0.017)		-0.010 (0.017)
Time Trend:					
NPP dummy $\times$ linear time trend	0.001 (0.001)				
Zip-code level linear time trends	no	yes	no	no	no

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 operating right before the Fukushima accident. All regressions include time, NPP and post-Fukushima dummies, zip-code fixed effects, and property characteristics (see notes to Table 2). Compared to our baseline specification in column (5) of Table 2, specification (1) adds a linear time trend and its interaction with the NPP dummy to the set of regressors. Specification (2) adds 96 linear time trends at two-digit zip code levels to the set of regressors. In specifications (3) and (5), the NPP dummy is interacted with time dummies that divide the 48 months period before Fukushima in four periods of one year each. In specifications (4) and (5), the NPP dummy is interacted with time dummies that divide the 24 months period after Fukushima in two periods of one year each. Sample size in all regressions is $6,478,698$ (offer $\times$ month observations). ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the level of regional planning units (*Raumordnungsregionen*).

We also conduct several other tests to assess the robustness of our main finding. The results of these tests are reported in Table A-2 in the Appendix. 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 price of the new offers may respond more quickly to changes in the value of amenities and local economic conditions. Excluding old offers leaves us with $1,542,592$ observations, a fourth of our overall sample size, but does not change our estimate of the treatment effect (see column (2) of Table A-2). As an alternative robustness check, we limit the estimation sample to the last monthly offer price recorded for a property, as this price arguably more closely proxies the final sales price. Again, however, we find a significant negative treatment effect (not shown). Second, we drop all observations from the four-month period March to June 2011. Restricting the estimation sample in this way provides for a clear divide between sales offers before Fukushima (March 2007 to February 2011) and sales offers after the post-Fukushima change in Germany's energy policy (July 2011 to March 2013). With the parliament's decision on 30 June 2011, future operating and closure times of individual NPPs were fixed and any uncertainty on the future of individual NPPs resolved. The estimate of the treatment effect, however, is also not affected by this change in the estimation

FIG. 2: GRAPHICAL REPRESENTATION OF TREATMENT LEADS AND LAGS



Notes: Plotted estimates are from column (5) of Table 4. The point estimates are marked by a dot. The vertical bands indicate the 90% confidence interval of each estimate.

sample (column (3) of Table A-2). 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, again does not change our results (column (4) of Table A-2). The same holds true if we use county fixed effects, i.e., larger political-administrative regional clusters (column (5) of Table A-2).

4.3 Causal Pathways and Heterogenous Treatment Effects

We have shown that Fukushima had a sizeable negative effect on housing prices near NPPs that were operating at the time of the disaster. In principle, this negative effect can be explained by two causal pathways (see Section 2.2). First, the nuclear power phase-out in Germany could be interpreted as a negative local labor demand shock that – in a spatial equilibrium model – should capitalize in the value of housing. Second, people might perceive the risk of a nuclear accident to be greater after Fukushima than before the disaster, decreasing the value of local amenities and thus housing prices. The relative importance of these two channels, however, should differ between sites that were closed right after the accident and those that were not. On the one hand, adverse economic effects should, at least in the short run, be larger near sites that were closed completely (and we will later in this section provide evidence that this is indeed the case). On the other hand, increases in the perceived risk of nuclear energy should be less relevant (if relevant at all) near closed sites. If the negative effect of Fukushima on housing prices was mainly due to economic reasons, we would therefore expect the effect to be larger near NPP sites that were closed after the accident. If, in contrast, the negative effect of Fukushima was mainly due to updated risk assessments, we would expect the effect to be smaller near closed sites.

In an additional regression, we therefore distinguish not only between houses near non-operating and operating NPPs, but also among the latter group between houses near sites that were closed and that were not closed after Fukushima. The results of this regression are reported in column (2) of Table (5) (column (1) reproduces our baseline result on the treatment effect for houses near operating and non-operating NPPs). As evident, Fukushima decreased the price of houses located near NPP sites that were operating before Fukushima but closed after the accident by as much as 9.8%. In contrast, the fall in prices is considerably smaller (-3.4%) for houses near operating sites that were not closed after the accident. Finally, and as seen previously, Fukushima did not have a statistically significant effect on housing prices near NPP sites that were inactive at the time of the accident. The results suggest that economic reasons are of prime importance for the decline of offer prices in the vicinity of NPP sites.[25]

TABLE 5: HETEROGENOUS TREATMENT EFFECTS: TREATMENT EFFECTS BY NPP CLOSURE TYPE

	(1)	(2)
Treatment effects:		
Operating NPP $<$ 5km $\times$ Post-Fukushima	-0.049*** (0.016)	
Operating NPP, closed $<$ 5km $\times$ Post-Fukushima		-0.098*** (0.014)
Operating NPP, not closed $<$ 5km $\times$ Post-Fukushima		-0.034* (0.017)
Non-operating NPP $<$ 5km $\times$ Post-Fukushima	0.014 (0.031)	0.014 (0.031)

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 operating or not operating before the Fukushima accident. All regressions include time dummies, the respective NPP dummies, property characteristics, and zip-code fixed effects (see notes to Table 2). Compared to our baseline specification in column (4) of Table 2, reproduced for convenience in column (1), specification (2) distinguishes among the operating NPP sites between those sites that were fully closed after Fukushima and those that were not. Sample size in all regressions is $6,478,698$ (offer $\times$ month observations). ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the level of regional planning units (*Raumordnungsregionen*).

In fact, municipalities with a NPP already felt the negative effects of the nuclear phase-out if their NPP site was closed right after Fukushima. Table 6 provides estimates from simple DiD regressions that compare pre- to post-Fukushima changes in three economic outcomes – namely employment, unemployment, and overnight stays – of municipalities with and without a NPP. Specifically, we regress, at the municipality level, each economic outcome on NPP dummies that indicate whether a municipality has a NPP, interaction terms between the NPP dummies and a dummy for the post-treatment period, and a full set of year dummies. We

[25] A potential objection against this interpretation is that more risky NPP sites might have been closed first. Our results in Table 5 would then also imply that housing prices fell stronger near risky sites, which one may read as evidence for an increase in perceived risks after Fukushima. However, and as previously discussed, perceived risks should be less, not more, relevant near sites that were closed after Fukushima. Moreover, in unreported regressions, we find no evidence that the effect of Fukushima on housing prices was any different near sites that reported an above median number of malfunctions in 2000-2010.

distinguish between municipalities with NPPs that were i) operating before Fukushima and closed thereafter, ii) operating before Fukushima and not closed thereafter, and iii) non-operating before Fukushima. We use yearly data for 2008 to 2014, excluding data for 2011.[26]

After Fukushima, employment fell by as much as 7.7% in municipalities with a NPP site that was closed after Fukushima relative to municipalities without a NPP (see column (1) of Table 6). No such effect can be observed for municipalities with a NPP that was already inactive before Fukushima and for municipalities with a NPP that is still in operation. We do not find statistically significant differences in unemployment trends between municipalities with and without a NPP site (see column (2)). This finding indicates that the operators of NPP sites have reduced employment mostly without layoffs. In line with this interpretation, RWE announced in early 2012 that it would mostly reduce employment at its NPP site in Biblis through regular turnover, (early) retirements, and relocations to other sites (RWE AG, 2012).

The closure of reactors after Fukushima also severely affected overnight stays at local hotels, which regularly accommodate engineers and assembly operators from subcontracting firms (see column (3) of Table 6). Overnight stays in Stadland, the municipality that hosts the closed NPP site of Unterweser, decreased from 21,041 in 2010 to 18,391 in 2013. Data for Biblis, the second site which was closed after Fukushima, are not available, but reports from local newspapers suggest that the local hotel and restaurant industry suffers greatly from the closure.[27] Negative effects on overnight stays are not yet visible for municipalities with NPP sites that are still operating.

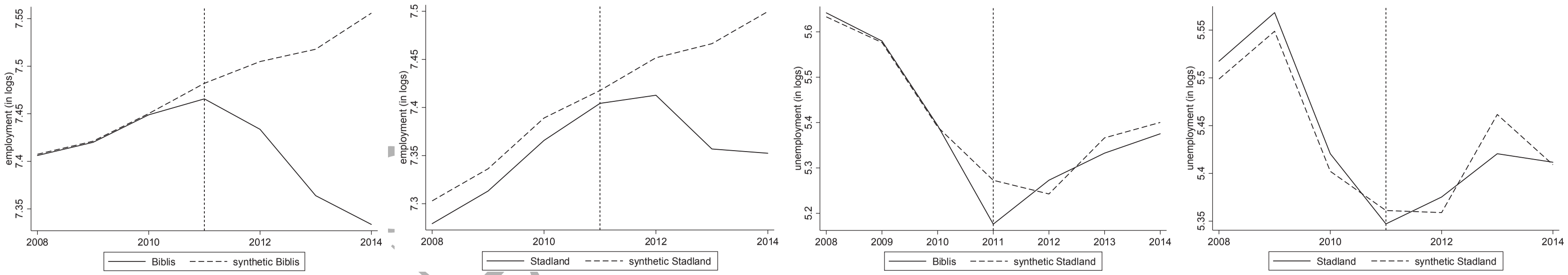
TABLE 6: OTHER OUTCOMES: DiD ESTIMATES AT MUNICIPALITY LEVEL

	(1)	(2)	(3)
	Dependent variable		
	Employment (in logs)	Un-employment (in logs)	Overnight stays (in logs)
Municipality with...			
operating NPP, closed × Post-Fukushima	-0.077**	-0.015	-0.198***
	(0.037)	(0.040)	(0.011)
operating NPP, not closed × Post-Fukushima	-0.009	-0.040	-0.004
	(0.025)	(0.026)	(0.060)
non-operating NPP, closed × Post-Fukushima	-0.010	0.057	-0.006
	(0.012)	(0.065)	(0.042)
Observations	43,914	49,717	14,276

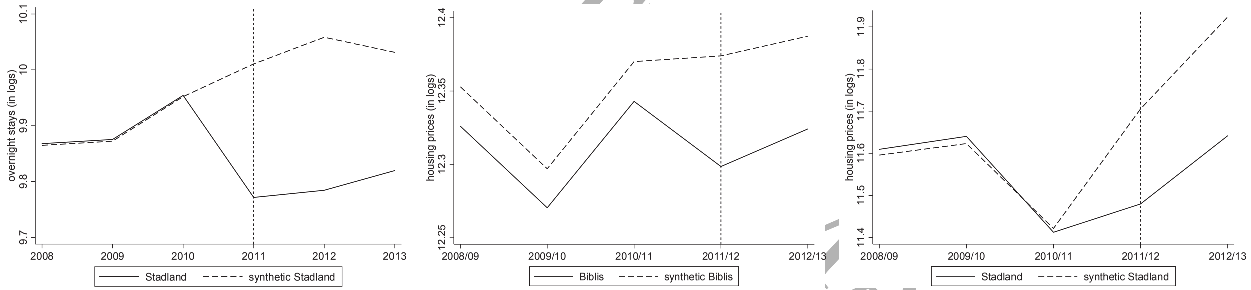
NOTES: The endogenous variable is the log of total employment (column (1)), the log of total unemployment (column (2)), and the log of the number of overnight stays (column (3)). Employment is measured at the place of work. The three NPP dummies indicate whether a municipality has a NPP site that i) was operating before Fukushima and was closed thereafter, ii) was operating before Fukushima and was not closed thereafter, and iii) was non-operating before Fukushima. Regressions include dummies for municipalities with a NPP, a dummy for the respective post-treatment period, and interaction terms. The sample consists of all municipalities in West Germany for which annual data are available in the years 2008 to 2014. Data for 2011 are excluded. Data on overnight stays are only available until 2013. Data on overnight stays are not available for the following four municipalities with a NPP: Brockdorf, Biblis, Grafenrheinfeld, Grundremmingen. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the municipality level.

[26]Data on employment and unemployment come from the German employment agency, data on overnight stays come from the statistical offices of the German Länder. Data on overnight stays is only available until 2013.

[27]See, for instance, the online article in *Frankfurter Rundschau* on 2 October 2012 (”Eine Stadt sucht ihre Zukunft”).



(a) Biblis: Employment (b) Stadland: Employment (c) Biblis: Unemployment (d) Stadland: Unemployment



(e) Stadland: Overnight stays (f) Biblis: Housing prices (g) Stadland: Housing prices

FIG. 3: Trends in economic outcomes: Municipality with closed site vs. synthetic municipality

Notes: Data on overnight stays are not available for the municipality of Biblis.

Taken together, the results in Table 6 tentatively suggest that the nuclear phase-out has already significant negative economic effects on municipalities with a NPP site that was closed after Fukushima. To further corroborate this finding, we separately study the effect of Fukushima on employment, unemployment and overnight stays in Biblis and Stadland, using synthetic control methods (SCM).

SCM evaluates the impact of a treatment (here: Fukushima) on one aggregate unit (here: the municipality of Biblis or Stadland) using a number of control units to build a suitable control group (Abadie et al., 2010; Abadie and Gardeazabal, 2003). The control group – or synthetic control unit – is the weighted average of non-treated units that best reproduces pre-treatment characteristics of the treated unit. The impact of the treatment is then the post-treatment difference in the outcome variable between treated unit and synthetic control unit. SCM has the advantage over the simple DiD estimates in Table 6 that the choice of the control unit is data-driven and based on quantifiable characteristics.

We restrict the set of possible control units to municipalities that are located in the same administrative district (*Regierungsbezirk*) as the treated unit, so as to improve the comparability of treated and control units. We also exclude municipalities that are located either in the same county as the treated unit or in a county with a NPP. This makes it less likely for the treatment to also have an effect on control units. These sample restrictions leave us with at most 161 and 178 possible control units for Biblis and Stadland, respectively.[28]

The synthetic control unit is constructed as a weighted average of potential control units. Weights are chosen so that the resulting synthetic unit best reproduces the values of pre-treatment outcomes and other predictors of post-treatment outcomes. Unfortunately, we do not have data on suitable predictor variables other than lagged outcome variables. Therefore, our set of predictors only includes the pre-treatment values of our outcome variables in the period 2008-2010 (and the resulting synthetic control unit best approximates the pre-treatment path of the outcome variable).

The results are illustrated in Figure 3. Panel (a) compares employment in Biblis and its synthetic counterpart in the period 2008-2014. Prior to Fukushima, employment in synthetic Biblis closely tracks the trajectory of employment in Biblis. After Fukushima, the trajectories diverge. Employment strongly decreases in Biblis, whereas it continues to increase in synthetic Biblis. The difference in employment between Biblis and its synthetic counterpart, which is close to zero in the pre-Fukushima period, stands at -22.1% in 2014. Our analysis, therefore, suggests that Fukushima decreased employment in Biblis by more than a fifth. Fukushima also decreased employment in Stadland, although the effect is less pronounced than in Biblis (see Panel (b)). Panels (c) and (d) consider unemployment trajectories. In line with our DiD estimates, we do not find unemployment trajectories of treated and synthetic control units to diverge after Fukushima. Therefore, Fukushima appears to have had no effect on unemployment in Biblis and Stadland. Panel (e) compares overnight stays in Stadland and its synthetic counterpart in the period 2008-2013 (data on overnight stays are not available for Biblis). While the number of overnight stays are virtually identical before 2011, they are 28.6% and 22.4% lower in Stadland than in its synthetic counterpart in 2012 and 2013, respectively. The SCM estimate of the effect of Fukushima on overnight stays is therefore in line with the corresponding DiD estimate.[29]

[28] The exact number of possible control units depend on the outcome considered, as data on some municipalities are missing.

[29] Similar to Abadie et al. (2010) and Abadie and Gardeazabal (2003), we also run placebo regressions to evaluate the significance of our SCM estimates. In particular, we apply SCM to the control municipalities that do not have a NPP site. We then compare the

Overall, the DID and SCM estimates reported in Table 6 and Figure 3, respectively, are consistent with the conclusion drawn from our analysis of treatment heterogeneity by closure type. Adverse economic effects rather than a decrease in the value of local amenities through higher perceived risks appear to be the prime causal pathway by which the Fukushima accident caused a fall in the price of real estate in the vicinity of NPPs in Germany.

Panels (f) and (g) of Figure 3 complete our analysis: They show the development of average housing prices in Biblis and Stadland, calculated from *ImmobilienScout24*, around the closing time of the nuclear sites. Panel (f) compares (unconditional) averages of housing prices in Biblis and its synthetic counterpart.[30] Prior to Fukushima, average housing prices in synthetic Biblis are slightly higher than in Biblis but follow a similar trend. After Fukushima, housing prices fell visibly in Biblis but increased slightly in synthetic Biblis. The gap in average housing prices increased from 2.7% in the year before Fukushima to 7.5% in the year after Fukushima. Panel (g) shows that the relative fall in average housing prices is even more pronounced for Stadland. While housing prices are virtually identical before Fukushima, they are 22.6% and 28.2% lower in Stadland than in synthetic Stadland in the two years following Fukushima. These findings are broadly consistent with our previous conclusion drawn from the disaggregated data that housing prices near closed sites fell strongly in the aftermath of Fukushima.

5 Discussion and Conclusion

The nuclear accident at Fukushima on 11 March 2011 caused a fundamental change in Germany's energy policy. Within days of the accident, the German government decided to temporarily close eight of 17 nuclear reactors. In June 2011, the government made the closure permanent, and also declared the phasing out of Germany's remaining nine NPPs by 2022. This paper shows that the nuclear disaster in distant Japan – and the U-turn in Germany's energy policy it caused – has large adverse effects on housing prices near German NPPs. Using data from Germany's largest internet platform for real estate, we show that housing prices near NPPs that were operating at the time of the Fukushima disaster fell by almost 5% after the disaster.

We argue that adverse economic effects of the nuclear phase-out are the prime reason for the observed fall in houses prices. NPP sites are often dominant local employers, benefitting also subcontracting firms and the local hotel and restaurant industry. The small Hessian town of Biblis with its 9,000 inhabitants is a prime example in this regard. Around 1,000 people worked at the NPP site before Fukushima, and external engineers and assembly operators joined the regular workforce during renewal and maintenance work. Our analysis suggests that within three years of the nuclear phase-out, the closure of the local NPP site reduced employment in Biblis by more than 20%. Given these large negative economic effects of site

average treatment effects of the placebo regressions to those estimated for Biblis and Stadland. We calculate the average treatment effect as the difference between the average post-Fukushima and pre-Fukushima gap between treated and control unit. We find that especially the negative treatment effects on employment in Biblis and overnight stays in Stadland are unusually large relative to the effects estimated in the placebo regressions. In fact, only in seven (four) out of 159 (70) placebo regressions do we find negative effects on employment (overnight stays) that are larger than the effect estimated for Biblis (Stadland).

[30]Municipality averages are calculated for three 12-months-periods before and two 12-months-periods after the Fukushima accident in March 2011. In some municipality-year cells, the average house price is based on only a small number of observations and is thus subject to potentially large sampling error. SCM does not quantify such sampling error but instead focuses on the uncertainty about the ability of the control group to reproduce the counterfactual (Abadie et al., 2010).

closures, we expect the decrease in housing prices to be largest near sites such as Biblis, which were closed immediately after Fukushima. Evidence supports this conjecture. We find that housing prices near NPP sites that were shut down after Fukushima fell by as much as 9.8% after the accident. This corresponds to a 19,848 EUR reduction in value for the average house (the mean housing value within 5 km of a plant that closed after Fukushima is 202,533 EUR in our sample). For Biblis alone, which currently has 2,744 residential buildings, these estimates imply an aggregate loss in housing value of approximately 54 million EUR. With a scheduled total retirement of ten NPP sites by 2022, Germany's nuclear phase-out is hence likely to entail a total loss in housing value of quite a sizable magnitude.

Our analysis suggests that the positive, significant, and fairly localized labor market effects of NPP sites might well outweigh the disamenities of such sites. This finding might explain why several previous studies have found no detrimental effect on housing prices in the immediate vicinity of NPP sites. It also suggests that the longer-term effects of Fukushima on local housing prices near (former) NPP sites will largely depend on how successful local economies will adjust to the nuclear phase-out. Future research can fruitfully explore this issue. Furthermore, the U-turn in Germany's energy policy caused by the Fukushima accident will require the construction of additional wind, geothermal, and solar power production capacity, as well as of supportive infrastructure, such as reservoir power stations and long-distance transmissions lines. The opening of plants and facilities in the next years will provide ample opportunities to study also the effects of such plants and facilities on local economies.

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

	NPP name	NPP site	NPP state	NPP in operation (March 2011)	Post-Fukushima NPP shut down: temporary[1]	permanent[2]	NPP background/technical features: operating 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

NOTES: [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 German federal government announced on 30 May 2011 the list of NPPs that were to be closed permanently and the remaining operation times of NPPs that were to remain active. All of the NPPs that were temporarily shut down during the moratorium had to shut down permanently. These measures took effect on 6 August 2011. 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 (Department of Nuclear Safety, 2011). [4] NPPs Brunsbüttel and Krümmel had been inactive 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.

TABLE A-2: ROBUSTNESS CHECKS III: NEW OFFERS, PRE- AND POST-MORATORIUM PERIOD, REGIONAL EFFECTS

	(1)	(2)	(3)	(4)	(5)
Treatment effect:					
NPP $<$ 5km $\times$ Post-Fukushima	-0.049***	-0.050**	-0.050***	-0.050***	-0.050***
	(0.016)	(0.021)	(0.018)	(0.017)	(0.019)
Type of offers	all	new offers	all	all	all
Sample incl. 04-06/2011	yes	yes	no	yes	yes
Regional fixed effects	zip code	zip code	zip code	municipality	county
Observations	6,478,698	1,542,592	6,242,276	6,478,698	6,478,698

NOTES: The endogenous variable is the log of the nominal house price posted. To ease comparison, column (1) reproduces–from column (4) of Table 2–the treatment effect of our baseline specification. The NPP dummy indicates whether a house on offer is located within 5 km from a NPP site that was operating right before the Fukushima accident. All regressions include time, NPP and post-Fukushima dummies, regional fixed effects, and property characteristics (see notes to Table 2). Column (2) reports estimates for a restricted estimation sample, in which only sales offers are considered that are newly posted in a given month (inflow sample). Column (3) reports estimates for a restricted sample, in which all observations from the four-month period March to June 2011 are dropped. Columns (4) and (5) report results when using municipality and county fixed effects, respectively, instead of zip code fixed effects. ***, **, * denote statistical significance at the 1%, 5%, and 10% level. Standard errors are clustered at the level of regional planning units (*Raumordnungsregionen*).