Energy Policy 123 (2018) 433–442

Contents lists available at ScienceDirect

Energy Policy

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

Property values and tax rates near spent nuclear fuel storage

Kirstin Munro[a,*], George Tolley[b]

[a] St John's University, Queens, NY, USA
[b] University of Chicago, Chicago, IL, USA

ARTICLE INFO

Keywords:
Nuclear power
Spent nuclear fuel storage
Property taxes
Real estate values

ABSTRACT

This paper examines potential property value impacts when a nuclear power plant closes and spent fuel remains on site. We confirm earlier research that fails to find an impact on property values of proximity to a nuclear power site. Another contribution of this paper is our finding that a one percentage point increase in property taxes is associated with a 4.31% decrease in the sale price of a home. These results provide evidence for a positive impact of operating nuclear facilities on surrounding communities in the form of reduced residential property taxes for a given level of public expenditures.

1. Introduction

The Nuclear Waste Policy Act of 1982 assigned the responsibility for spent nuclear fuel disposal to the Department of Energy (DOE), with amendments selecting Yucca Mountain in Nevada as the primary candidate site for a permanent geological repository (U.S. Congress, 1983). The law requires the DOE to begin moving spent fuel to the repository by 1998. However, the project was terminated in 2010 before any spent fuel was moved, and all spent fuel will now remain at the reactor sites where it was produced in independent spent fuel storage installations (ISFSI) until a new solution is agreed upon and implemented.

At the same time, the combination of low fossil fuel prices, subsidies for wind and solar power, wholesale electricity markets, and high maintenance costs of aging plant infrastructures are influencing nuclear power plant operators to announce planned closures of these facilities in advance of the expiration of their operating licenses. Vermont Yankee was retired by Entergy Corporation in November 2014 in response to low energy prices ("Nuclear power plant announces layoffs," 2014), raising concerns about future power system reliability in the Northeast (ISO New England, 2018, 4). In Illinois, Exelon Generation reversed its decision to shut the Clinton and Quad Cities Nuclear Generating Stations following state legislation that provides subsidies to support the maintenance and continued operation of the plants (Exelon Generation, 2016). In June 2016, PG&E Corporation withdrew their operating license renewal application for their Diablo Canyon Power Plant in San Luis Obispo County, California, citing the challenge of managing a large base-load power source in the presence of increasing reliance on intermittent power generation from wind and solar sources (PG&E, 2016). The plant is expected cease operating when the reactor operating licenses expire in 2024 and 2025 ("California PUC OKs PG&E closing Diablo Canyon", 2018). A deal between New York Governor Andrew Cuomo and Entergy Corporation announced in January 2017 will result in the Indian Point Energy Center in Buchanan, NY, closing in advance of the expiration of its operating license (Press Office of New York Governor Andrew M. Cuomo, 2017).

As these nuclear power plants begin the process of closing and decommissioning, an important policy question is raised: what happens to residential property values in communities when a nuclear power plant stops operating? This paper will investigate possible property value impacts via two mechanisms using a hedonic price model for residential properties in Lake County, Illinois, within a 10 km radius of the spent nuclear fuel storage at the site of the former Zion Nuclear Power Station. First, we will consider the impact on property values of proximity to spent fuel at the site of a former nuclear power plant. Second, we will consider what happens to property values in a town following a decline in property tax payments from a non-operating nuclear power plant.

Several characteristics of the spent nuclear fuel storage site in Zion, Illinois, allow us to overcome confounding factors in past research on nuclear power and fuel storage sites, as well as past research on property taxes. The Zion location was undeveloped land near a residential area at the time of its selection for a power plant rather than in an area already dominated by heavy industry. The plant stopped operating in 1997 (Nuclear Regulatory Commission, 1997), 15 years prior to the earliest sales records in our dataset. As a result, the plant is no longer a major employer, and the plant site is not a source of traffic noise or congestion, though the existence and location of the site is well-known in the community (Carpenter, 2017). Rather than reduce overall

* Corresponding author at: Department of Economics and Finance, St. John's University, 8000 Utopia Parkway, Queens, NY 11439, USA.
E-mail address: munrok@stjohns.edu (K. Munro).

https://doi.org/10.1016/j.enpol.2018.08.035
Received 28 February 2018; Received in revised form 5 August 2018; Accepted 18 August 2018
0301-4215/

property tax revenues and public expenditures following the closure of the plant and the loss of its tax revenues, the taxing districts that had benefited from these tax revenues decided to keep revenues more or less constant—the lost revenues from the plant were replaced by increasing the taxes on other property tax payers. Results from our analysis may provide some insights into possible outcomes for residential property values at other sites where nuclear power plants are preparing to close or are undergoing decommissioning.

Founded in 1901 as a Christian utopian industrial cooperative community, Zion, Illinois, is located about 50 miles north of downtown Chicago and four miles south of the Wisconsin border on the shore of Lake Michigan. Undeveloped lakefront land in Zion was selected by Commonwealth Edison as the site for a nuclear power facility in the late 1960s. At the time the plant began operating, the small town was still struggling following the loss of a major employer, a mechanical lace factory, which closed in the early 1950s. The Zion Candy Factory, another major employer in the town that had its start as part of the Zion Institutions and Industries cooperative, was shuttered in the 1980s (Cook, 1996). The Zion nuclear plant stopped operating in 1997, 15 years prior to the end of its operating license in 2012 (Nuclear Regulatory Commission, 1997). In 1996 property tax payments from the Zion nuclear plant comprised 55% overall tax revenues in the township. Following the closure of the plant, the burden of approximately $28 million in lost tax revenues from the plant (in 2016 dollars) was shifted to other local property owners, nearly doubling their total tax burden, while local public expenditures decreased by 10% (Knabel, 2017).

This paper uses a hedonic price model to examine the potential impacts on a community when a nuclear power plant stops operating and spent fuel remains on site, impacts that may persist long after the plant is shut down. Our research confirms the results of earlier studies that fail to find an impact on residential property values of proximity to a nuclear power facility or its associated spent fuel (Nelson, 1981, Gamble and Downing, 1982, Clark et al., 1997, Metz and Clark, 1997). A second contribution of this paper concerns the impact on home sale prices of changes in property taxes following a nuclear plant closure. The decision of city officials to keep total revenues relatively constant following the closure of the plant allows us to estimate the impact of property taxes on property values. We find that a one percentage point increase in property taxes is associated with a 4.31% decrease in the sale price of a home, or $5371 in 2016 dollars for the mean property. Based on the estimated coefficient, the consumer's discount rate with respect to property tax differentials can be calculated as 6.95%.

We fail to find evidence of an impact of proximity to spent nuclear fuel and a former nuclear power generation facility on residential property values. However, these results suggest the existence of a positive impact of operating nuclear facilities on surrounding communities in the form of reduced residential property taxes for a given level of public expenditures. Stated a different way, when the property tax payments from a nuclear power generation facility cease, the subsequent increases in residential property tax rates required to maintain the previous level of public expenditures appear to have a negative impact on the sale prices of homes. These results are relevant not only for understanding the impacts of changing property taxes at other former nuclear power plant sites, but also for any communities whose property tax revenues are dependent on a large industrial or commercial tax payer.

2. Literature review

The theory of hedonic prices and the associated applied literature suggests that the final market price of a good or service can be broken down into constituent non-market characteristics that provide utility to the buyer. While consumers do not purchase product characteristics on the market directly, there exists an implicit market for these characteristics. Consumers have an implicit willingness to pay for characteristics that is embedded in a good's final market price (Lancaster, 1966; Rosen, 1974). If the characteristics are well-defined and measureable, such as the average horsepower of a car, their implicit prices can be derived statistically (Griliches, 1961; Taylor, 2017). The location of residential properties in space adds additional dimensions to the analysis of implicit prices for product attributes. Levels of public services and property tax payments are determined by the tax districts in which a home is located. And home buyers will pay more to be close to things from which they derive utility, like parks, or to avoid being close to things that give them disutility, like unpleasant noises and smells.

Harris et al. (1968) provide an early empirical test of the theory of hedonic prices with respect to commuting times, residential property prices, and income elasticities. Environmental disamenities were another pioneering application of this technique, with studies like Blomquist (1974) measuring the impact on property values of proximity to a municipal coal fired power plant and Ridker and Henning (1967) measuring the impact of air pollution levels on residential property values. The impact on residential property values of environmental amenities, such as proximity to open space (Lutzenhiser and Netusil, 2001), parks (Espey and Owusu-Edusei, 2001) and clean air (Harrison and Rubinfeld, 1978) have also been studied. More recently, Kinnaman (2009), Guignet (2013), and Kiel and Williams (2007) have measured the negative impacts on home prices associated with proximity to noxious facilities and toxic waste, and Muehlenbachs et al. (2015) finds evidence of a negative impact on housing values of shale gas development that is mitigated by the positive impacts of lease payments to land owners from energy companies. An important recent development in the analysis of housing markets is the incorporation of equilibrium sorting into hedonic models (Kuminoff, 2013).

A large body of published work using hedonic price analysis has demonstrated statistical associations between home prices and proximity to amenities and disamenities. However, the existing literature investigating the impact on housing values of nuclear power facilities and spent fuel has failed to establish a link between proximity to these sites and a decline in home prices (Nelson, 1981, Gamble and Downing, 1982; Clark et al., 1997; Metz and Clark, 1997; Yamane et al., 2013). The lone exception of which we are aware is Clark and Allison (1999), which finds a disamenity impact of proximity to the former Rancho Seco plant site near Sacramento, California, the magnitude of which had been decreasing with time. Several factors have been suggested as contributing to these overall results, including positive income and employment spillover impacts of the plants, and countervailing disamenity impacts associated with traffic from plant employees traveling to and from work. There is evidence that home owners and buyers have negative perceptions of nuclear power plants and spent fuel storage (Webb, 1980; Hageman, 1981; Bassett et al., 1996), and that public opinion of nuclear facilities following the Fukushima Daiichi incident was poor (Huang et al., 2013; Bird et al., 2014). However, these perceptions of risk and stigma do not appear to translate into systematic evidence of a reduction in home sale prices associated with proximity to a nuclear power plant or fuel storage.

An additional characteristic of a home that may influence its sale price is the basket of property taxes and public services associated with its location. Nuclear power plants may influence home values in their surrounding communities through payments, either property taxes or negotiated payments in lieu of taxes, made by the plant that allow for a higher level of public services for a given level of property taxes. During its last full year of operation, property tax payments associated with the Zion Nuclear Power Station comprised 55% of overall tax revenues in the township of Zion, effectively reducing the residential property tax liability for a particular level of public services. Holding the level of public services constant, one can expect that a lower residential property tax rate will be reflected in higher property values, as the differential stream of future liability payments is capitalized into the final sale price of a home. This positive influence of industrial tax payments on home prices would not be unique to nuclear power plants, but would also apply to any large industrial or commercial facility whose property tax payments comprise a substantial proportion of the overall tax base of its community.

Marshall discusses the capitalization of local property tax differentials into home sale prices (Marshall, 1920, G.11–16), and distinguishes between taxes that he calls *onerous* and ones that are *beneficial* or *remunerative*. An onerous tax pays for things like interest payments not directly valuable to the local tax payer. On the other hand, a beneficial tax pays for things that, due to natural monopolies or economies of scale, are useful to residents and that the public sector can provide more cheaply than individuals can purchase. If the public sector can obtain these goods at a lower cost than the household could, these economies of scale may result in a positive relationship between property tax rates and home sales prices. However, if local property taxes pay for goods and services that exhibit diseconomies of scale or that homebuyers do not enjoy, increases in property taxes may be negatively correlated with home sale prices. Beneficial taxes might be expected to increase house values while onerous ones might be expected to decrease them.

Tiebout (1956) proposes a model of equilibrium local taxation and public goods provision in which households can sort themselves between jurisdictions to select the basket of local taxes and public services that maximize the household's utility. Oates (1969) provides the original empirical test of Tiebout's model, fixing the household's discount rate at five percent to measure the extent of property tax capitalization reflected in the sale prices of homes, concluding that property taxes are fully capitalized. Yinger et al. (1988, 16–27, 32–36) provide a review of property tax capitalization studies, and show that the discount rates either inferred or assumed in these studies range from three percent to 11.4%.

Following Marshall, the relationship between property tax rates and home sale prices is not theoretically clear and is difficult to estimate empirically because local property taxes pay for goods and services that home owners may enjoy. Higher tax rates, in general, are correlated with higher levels of public services. Thus, both the tax rate and a proxy for the measure of services, for example school quality, can't both appropriately be included on the right-hand-side of a hedonic price equation. More recent studies by Feldman (2010) and Gallagher et al. (2013) attempt to use unique research designs to circumvent this empirical issue, with Feldman (2010) taking advantage of a change in the tax code as a natural experiment and Gallagher et al. (2013) including only very small homes in their sample to avoid public school amenity impacts. Both studies find that property taxes are fully capitalized into home values.

The discount rate selected for analysis matters, as even small differences in the discount rate can have large impacts on decision-making. Two studies measuring individual discount rates for durable household appliances indicate that the consumer's discount rate may be higher than the five percent assumed by Oates (1969). Hausman (1979, 50–51) calculates an individual discount rate between 14.8% and 26.4% for household appliances, and Dubin and McFadden (1984, 354) similarly estimate an individual discount rate of 20.5%. The Office of Management and Budget (1992) suggests a discount rate of seven percent as a baseline for benefit-cost analysis of federal programs, a value intended to reflect private returns to invested capital. The magnitude of the household's discount rate with respect to property tax differentials will depend on whether home buyers see residential property more like a long-term financial asset or an air conditioner.

The existing theoretical and empirical literature reviewed here suggests that residential properties are goods comprised of both physical and location-specific characteristics, and that buyers willingness to pay for these characteristics can be statistically isolated. These characteristics include the attributes of the home such as the size and number of bathrooms, the proximity to amenities or disamenities, and the property taxes and public goods associated with the jurisdictions in which the property is located. Features of the site of the former nuclear power plant in Zion, Illinois, allow us to design a research strategy to overcome confounding factors in past research on both nuclear power sites and property tax capitalization. However, recent developments in equilibrium sorting research (for example, Kuminoff et al., 2013) remind us that neither nuclear power plants nor people are located at random. The extent to which these results can be generalized to other sites will depend on the extent to which those sites exhibit the same sorting characteristics as the site of the former nuclear power generation facility in Zion, Illinois.

3. Data

Lake County, Illinois, Assessor's data for residential improved properties sold between January 1, 2013 and September 22, 2016 were obtained from the Lake County Assessor's Office. ArcGIS was used to measure the point distance from each parcel to the spent nuclear fuel site in Zion, Illinois. The final sample was further restricted to include properties in Lake County within 10 km of the spent nuclear fuel storage site and that sold for at least $50,000 and for less than $1000,000 with lot sizes under four acres and home sizes under 5000 square feet, leaving 3067 properties without missing data. Properties sold for under $50,000 were excluded because they do not represent typical market transactions: tear-downs, homes requiring major renovations, or transactions that were not arm's length. Similarly, properties sold for over $1000,000 had exceptional characteristics that made them not representative of typical homes in this market. The lot size was restricted to below four acres because these larger properties were unrepresentative of the overall housing market in the area, and were likely the sites of future subdivisions.

These properties are located in six towns: Zion, Waukegan, Beach Park, Winthrop Harbor, Wadsworth, and Gurnee. A list of the property characteristics, descriptive statistics, and hypothesized impact on sale prices are reported in Table 1 below.

The *Real Sale Price* is the sale price of the property in 2016 dollars. The *Real Assessed Value* is the value assigned by the Lake County Assessor for property tax purposes in 2016 dollars. *Bathrooms* is a whole number that indicates the number of full bathrooms in the home. > = *Average Condition* is a dummy variable set equal to one if the property was evaluated by the assessor as being in at least average physical condition, and zero otherwise. *Central AC* is a dummy variable set equal to one if the property has central air conditioning, and zero otherwise. *Distance to Nuclear Site* is the distance to the spent nuclear fuel storage location in Zion, Illinois, in kilometers. *Dist. To Commuter Rail* is the distance to the nearest Metra commuter rail station in kilometers. *Distance to Lakefront* is the distance to the shore of Lake Michigan in kilometers. *Tax Rate* is the reported 2015 tax year property tax rate for

Table 1
Sample descriptive statistics.

Variable	Mean	Std. Dev.	Min	Max	Pred. Sign
Real Sale Price	$124,558	$56,673	$50,610	$775,643	n/a
Real Assessed Value	$37,342	$16,844	$6847	$126,014	n/a
Bathrooms	1.614	0.599	1	4	+
Average Condition	0.998	0.044	0	1	+
Central AC	0.653	0.476	0	1	+
Distance to Nuclear Site	6.015	2.265	1.201	10.000	?
Dist. To Commuter Rail	5.563	2.501	0.262	10.151	?
Distance to Lakefront	3.893	1.860	0.333	9.799	?
Tax Rate	16.582	2.817	9.928	21.456	–
Building Size	2486	832	536	4992	+
Fireplaces	0.451	0.562	0	3	+
Year Built	1970	25.819	1846	2015	+
Lot Size	14,009	14,323	2335	174,240	+

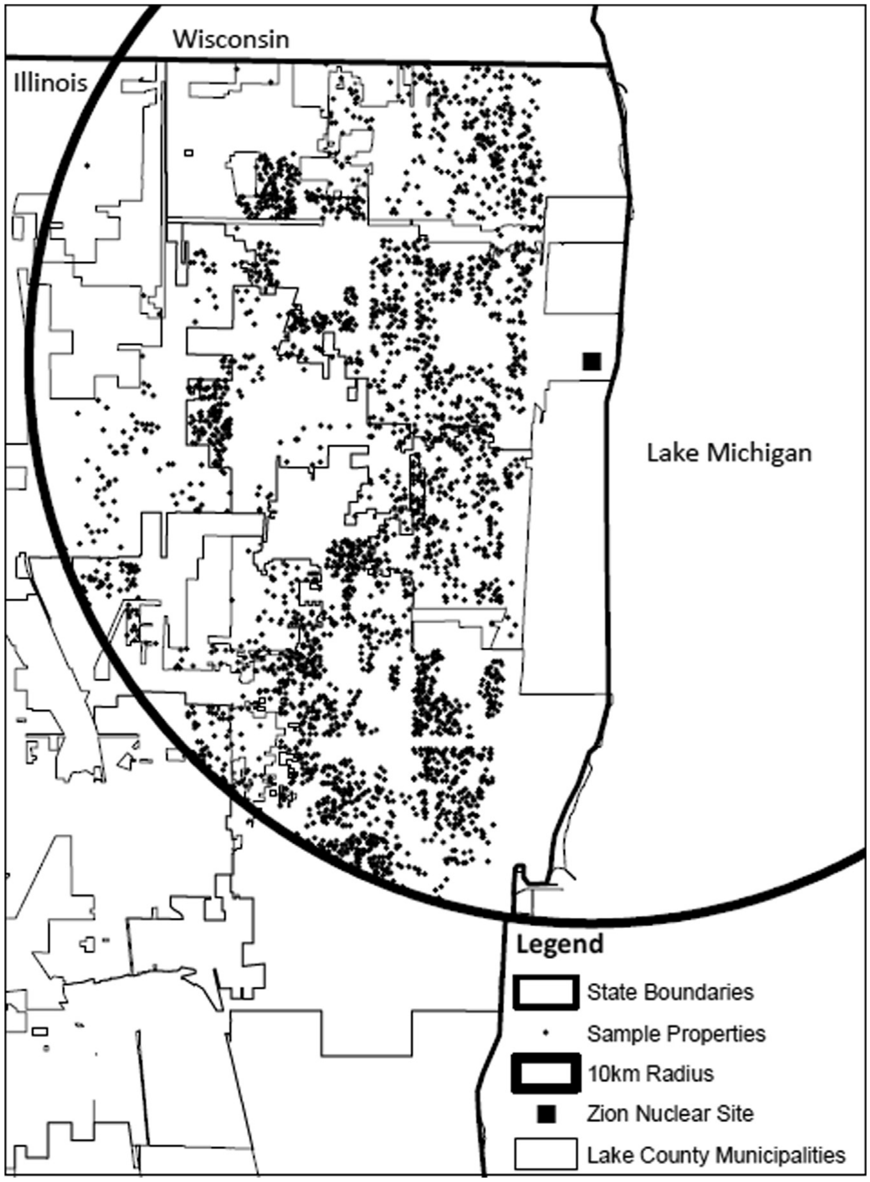

Fig. 1. shows the location of the Zion Nuclear Site and surrounding area.

the individual property. *Building Size* is the size of the dwelling in square feet. *Fireplaces* is a whole number that indicates the number of fireplaces. *Effective Year Built* is the year the structure was built, adjusted by the assessor to account for major renovations. *Lot Size* is the size of the property's lot in square feet (Fig. 1).

4. Methods

A standard hedonic home price model was specified for the sales data and property characteristics as follows:

ln(Nominal Sales Price) = *f (Physical Characteristics, Tax Rate, Distance to Nuclear Site, Quarter, Year)*

The dependent variable is the natural log of the nominal sales price of the home. *Physical Characteristics* are the number of bathrooms, the building condition, the presence of central air conditioning, the building and lot sizes in hundreds of square feet, the number of fireplaces, and the effective year built. The *Tax Rate* is the reported 2015 tax year property tax rate for the observation. The *Distance to Nuclear Site* is the distance to the spent nuclear fuel storage site location in Zion, Illinois, in kilometers. *Quarter* corresponds to a series of quarterly dummy variables that are set equal to one if the property was sold in that quarter, and equal to zero otherwise. The reference quarter is the first calendar quarter of the year—January through March. *Year* corresponds to a series of annual dummy variables that are set equal to one if the property was sold in that year, and equal to zero otherwise. The reference year is 2013.

The model was estimated several ways. First, the model was estimated using an ordinary least squares semi-log functional form, following the suggestion of Cropper et al. (1988) for hedonic price models in danger of omitted variable bias. More recent research on hedonic functional forms suggests dealing with omitted variables using spatial fixed effects (Kuminoff et al., 2010). However, since part of our objective is understanding the relationship between property taxes—-which are set at the municipal level—and housing values, we will focus our discussion on the models estimated using the functional form suggested by Cropper at al. (1988). The full results of the model with municipal-level controls, which contain the anomalous finding that proximity to the nuclear site is an amenity, are presented in the Appendix A Additional models estimated individually for each municipality and with additional spatial controls are also presented in the Appendix A. While Nelson (1981) and Gamble and Downing (1982) used a linear model specification, the semi-log model is consistent with the remaining hedonic literature on residential proximity to nuclear sites (Clark et al., 1997, Metz and Clark, 1997, Clark and Allison, 1999). Second, as a robustness check and to account for possible differences in sensitivities to property characteristics across the range of property values, the same model was estimated using a quantile regression at the 25th, 50th, and 75th percentile values of the dependent variable. A third robustness check is provided by the estimation of a maximum likelihood spatial-autoregressive model with spatial-autoregressive disturbances (Drukker et al., 2011) to test for possible bias in the OLS coefficients due to spatial autocorrelation.

Once the model is estimated, it is possible to calculate the property buyers' nominal discount rate with respect to property tax differentials if we assume full property tax capitalization (Oates, 1969). The net present value (NPV) of incurring $1 in additional residential property tax payments $\Delta\tau$ can be calculated as:

$$NPV = \Delta\tau \sum_{n=1}^{N} \frac{1}{(1+i)^n}$$

where i is the discount rate and N is the life of the house. If one assumes the house will exist for a long time, the summation can be simplified to $1/i$ (Yinger et al., 1988, 1–2) giving $NPV = \Delta\tau/i$, or rearranging:

$$i = \Delta\tau/NPV$$

For the mean real assessed property value in the sample of $37,329, a one percentage point increase in the property tax rate implies an additional $\Delta\tau = \$373.29$ annual property tax payment. The coefficient of the *Tax Rate* in the semi-log regression reported below gives an approximate estimated effect of a one percent increase in the property tax rate on assessed property value. This value multiplied by the mean real sales price of property in the sample of $124,562 will give the estimated reduction in home sales price associated with a one percentage point increase in the property tax rate, or NPV, assuming the ratio of sales value to assessed value remains the same. These values for $\Delta\tau$ and NPV substituted into the foregoing formula give the estimated capitalization rate i, as will be brought out below.

5. Results

The full model output is presented in Table 2 below. For the OLS and maximum likelihood spatial-autoregressive model results, all of the coefficients are of the expected sign and magnitude with $p < 0.01$ except a dummy variable measuring the condition of the property, with $p < 0.05$. In the OLS results, the coefficient for *Tax Rate* indicates that a one percentage point increase in property taxes is associated with a 4.31% decline in the sales price of a home. The coefficient for *Distance to Nuclear Site* is small in magnitude and has the negative sign of an amenity, though is not distinguishable from zero. The results for the maximum likelihood spatial-autoregressive model are consistent with the results of the OLS model, providing evidence that the OLS results are not biased by spatial autocorrelation. The results for the quartile regression are robust, though the variable capturing better than average condition loses significance due to the small number of properties rated as less than average condition. Tables for a model with municipal-level control variables, a model with additional spatial control variables, and models estimated for individual municipal-level samples are presented in the Appendix A.

6. Discussion

The area surrounding the spent nuclear fuel storage site in Zion, Illinois, is an ideal location for an investigation of the potential impacts on residential property values that persist long after a nuclear power plant stops operating and spent fuel remains on site. The Zion plant stopped operating 15 years prior to the earliest transactions in our dataset. This allows us to overcome confounding factors in past research on nuclear power and fuel storage sites, such as the traffic disamenity effects and the employment and income benefits associated with large industrial facilities like nuclear power plants. The Zion location was undeveloped land near a residential area before the plant was built, rather than an area dominated by heavy industry, and the character of residential properties in the 10 km area surrounding the plant is not unlike that of a typical exurban area. Thus, estimates for the distance to the spent nuclear fuel storage site are not confounded with other proximate industrial disamenities. These results confirm the finding from previous hedonic studies that failed to establish a link between proximity to these nuclear power generation and spent fuel storage sites and a decline in home prices (Nelson, 1981, Gamble and Downing, 1982, Clark et al., 1997; Metz and Clark, 1997).

The public finance decisions of Zion Township also make this location ideal for investigating the impact on residential property values associated with the decline in the property tax or payments in lieu of taxes from a nuclear power plant when the plant stops operating. While total property tax revenues have decreased in real terms by 10% since the plant closure, the proportion of those taxes paid by property owners other than the Zion plant have increased by 93%. Thus, while total revenues have remained close to constant, the tax burden has shifted from the Zion nuclear power plant to residential and commercial property tax payers, allowing for something of a natural experiment. These results indicate that a one percentage point increase in property taxes is associated with a 4.31% decrease in the sale price of a home, or $5371 in 2016 dollars for the mean property in the sample. If full property tax capitalization is assumed, the homebuyer's discount rate with respect to property tax differentials can be calculated as 6.95%. This is higher than the five percent assumed in the seminal Oates (1969) study, but lower than the values calculated by Hausman (1979) and Dubin and McFadden (1984). The proximity of our calculation of an implicit 6.95% discount rate to the Office of Management and Budget (1992) guideline of seven percent suggests homebuyers see their homes as something closer to a financial asset than a consumer durable good like an air conditioner. Put another way, if a discount rate of seven percent is assumed, we find full capitalization of tax rate differentials into the sales price of homes.

These findings are consistent with reports of homeowners in Zion complaining that they are unable to sell their homes due to the high property tax rates (Carpenter, 2017), which are on average 20.4% higher for sample observations in Zion than the observations in other towns. Because of the oblong shape of the city of Zion, there does not appear to be excessive correlation between distance to the nuclear site in Zion and the tax rate, with a pairwise correlation of −0.4467. However, the strong link between property tax rates and municipalities in the sample causes some potential problems for the use of these jurisdictions as control variables or for models estimated at the individual municipal level.(Table 3)

While these findings hold for the area surrounding the former nuclear power generation facility in Zion, Illinois, some caution is required in the interpretation of results in light of recent developments in equilibrium sorting research for housing market analyses (for example, Kuminoff et al., 2013). The extent to which these results can be generalized to other sites will depend on the extent to which those sites exhibit the same mix of residents and area characteristics as the site of the former nuclear power generation facility in Zion, Illinois.

7. Conclusion

While previous studies have found evidence that home owners and buyers have negative perceptions of nuclear power plants and spent fuel storage (Webb, 1980; Hageman, 1981; Bassett et al., 1996), our findings indicate that these perceptions do not appear to translate into market behavior. Metz and Clark (1997, 573) note that while we might expect spent nuclear fuel and power generation facilities to have a detrimental impact on nearby residential property values due to a

Table 2
The impact of property characteristics on home sale price.

	OLS	SARM (ML)	Quantile Regression		
			q25	q50	q75
Bathrooms	0.0808***	0.0722***	0.0856***	0.0855***	0.0919***
	(0.0108)	(0.0103)	(0.0193)	(0.0115)	(0.0131)
> =Average Condition	0.226**	0.225**	0.308*	0.194	0.0591
	(0.114)	(0.110)	(0.166)	(0.157)	(0.172)
Central AC	0.0638***	0.0603***	0.0871***	0.0734***	0.0557***
	(0.0120)	(0.0113)	(0.0205)	(0.0128)	(0.0145)
Nuclear Site Distance (km)	−0.00311	−0.00415	−0.00621	−0.00333	−0.00234
	(0.00261)	(0.00269)	(0.00508)	(0.00287)	(0.00298)
Tax Rate	−0.0431***	−0.0360***	−0.0490***	−0.0438***	−0.0436***
	(0.00217)	(0.00241)	(0.00384)	(0.00240)	(0.00223)
Building Size (100s sqft)	0.0158***	0.0151***	0.0162***	0.0157***	0.0147***
	(0.000742)	(0.000725)	(0.000727)	(0.000837)	(0.000669)
Fireplaces	0.0626***	0.0612***	0.0625***	0.0716***	0.0551***
	(0.00992)	(0.00967)	(0.0178)	(0.0104)	(0.0104)
House Build Date	0.00451***	0.00413***	0.00550***	0.00468***	0.00389***
	(0.000250)	(0.000245)	(0.000568)	(0.000363)	(0.000313)
Lot Size (100s sqft)	0.000425***	0.000407***	0.000420***	0.000461***	0.000464***
	(4.09e−05)	(3.79e−05)	(4.86e−05)	(4.99e−05)	(5.30e−05)
Quarterly Dummy Series, Reference is Q1					
Q2	0.0623***	0.0613***	0.0698***	0.0767***	0.0615***
	(0.0140)	(0.0136)	(0.0170)	(0.0149)	(0.0172)
Q3	0.112***	0.111***	0.142**	0.116***	0.107***
	(0.0142)	(0.0137)	(0.0221)	(0.0161)	(0.0144)
Q4	0.0895***	0.0878***	0.120**	0.0929***	0.0780***
	(0.0154)	(0.0154)	(0.0251)	(0.0197)	(0.0134)
Yearly Dummy Series, Reference is 2013					
2014	0.108***	0.107***	0.119***	0.101***	0.0986***
	(0.0135)	(0.0136)	(0.0287)	(0.0166)	(0.0147)
2015	0.143***	0.143***	0.156***	0.143***	0.149***
	(0.0135)	(0.0133)	(0.0248)	(0.0180)	(0.0199)
2016	0.219***	0.220***	0.252***	0.232***	0.210***
	(0.0150)	(0.0147)	(0.0247)	(0.0146)	0.0117
Constant	2.400***	−0.596	0.275	2.129***	4.003***
	(0.512)	(0.678)	(1.129)	(0.748)	(0.667)
N	3067	3067	3067	3067	3067
R-Squared	0.601		0.3391	0.4027	0.4423

y = ln(sale price), Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

negative popular image of these types of facilities, in practice home buyers and sellers are far more pragmatic in their considerations. Policy decisions about nuclear power and fuel storage need to be made on the basis of actual market behavior rather than speculation about how popular perceptions might influence markets.

We fail to find evidence of an impact of proximity to spent nuclear fuel and a former nuclear power generation facility on residential property values. This possibility of a disamenity effect of proximity to nuclear sites on residential property values has been a point of contention in legal and regulatory proceedings (Bostek v. Entergy Nuclear Generation Co., Nuclear Regulatory Commission, 2013). At the same time, our results provide evidence for the existence of a significant positive impact of operating nuclear facilities on surrounding communities in the form of reduced residential property taxes for a given level of public expenditures. This effect has been neglected or given relatively little attention in legal and regulatory cases. The decision on the part of policymakers in Zion, Illinois, to keep overall public expenditures relatively constant following the loss of tax revenues from the plant provides a natural experiment that allows us to test the impact on residential property sales prices of an increase in property taxes for a given level of public services. When the property tax payments from the facility cease, the increases in residential property tax rates that follow appear to have a negative impact on the sale prices of homes. These results apply not only to nuclear power plants, but also to any industrial or commercial facility making large tax payments to a community.

Table 3
Tax rates and distance to the zion nuclear site by town.

Town	Observations	Mean Tax	Min Tax	Max Tax	Mean Dist	Min Dist	Max Dist
Waukegan	1281	16.68	10.40	17.89	7.67	3.51	9.99
Zion	799	19.95	13.05	21.46	4.02	1.20	9.61
Beach Park	510	14.24	9.93	16.37	5.00	2.13	8.09
Winthrop Harbor	305	14.47	13.05	15.36	4.50	2.56	6.71
Wadsworth	97	11.20	9.95	14.20	7.95	6.41	9.99
Gurnee	75	10.52	10.37	13.22	9.53	8.82	10.00
Full Sample	3067	16.58	9.93	21.46	6.01	1.20	10.00

Major decisions are being made with respect to the country's nuclear power generation facilities in response to current short-run electricity market conditions, including the recent announcements of several plant retirements. The North American Electric Reliability Corporation and ISO New England have expressed concerns that multiple nuclear power plant retirements will threaten the reliability of the North American power grid (North American Electric Reliability Corporation, 2013; ISO New England, 2018). Results from our analysis may provide some insights into possible outcomes for residential property values at other sites where nuclear power plants are preparing to close or are undergoing decommissioning. Our study suggests that policymakers should take into account the full extent of community impacts, including possible impacts on residential property values, before making decisions to retire nuclear power generation facilities.

Acknowledgements

The authors gratefully acknowledge Catherine T. Mertes, Stephanie Burr, and Ben W. Murray for their assistance with this research.

Appendix A. Additional models

Model Estimated with Municipality-level Controls	
Bathrooms	0.0837***
	(0.0109)
> =Average Condition	0.232**
	(0.115)
Central AC	0.0616***
	(0.0121)
Nuclear Site Distance (km)	−0.0101**
	(0.00398)
Tax Rate	−0.0483***
	(0.00490)
Building Size (100s sqft)	0.0158***
	(0.00074)
Fireplaces	0.0592***
	(0.00994)
House Build Date	0.00468***
	(0.000263)
Lot Size (100s sqft)	0.000446***
	(0.000044)
Municipality Controls, Reference is Zion	
Beach Park	−0.0511
	(0.0312)
Winthrop Harbor	0.0109
	(0.0312)
Waukegan	0.0269
	(0.0191)
Wadsworth	−0.0136
	(0.0493)
Gurnee	−0.0268
	(0.0519)
Quarterly Dummy Series, Reference is Q1	
Q2	0.0616***
	(0.0140)
Q3	0.112***
	(0.0141)
Q4	0.0912***
	(0.0154)
Annual Dummy Series, Reference is 2013	
2014	0.107***
	(0.0136)
2015	0.143***
	(0.0136)
2016	0.219***
	(0.0151)
Constant	2.189***
	(0.557)
N	3067
R-squared	0.603
y = ln(sale price), Robust standard errors in parentheses	
***p < 0.01, **p < 0.05, *p < 0.1	

The Impact of Property Characteristics on Home Sale Price, with Additional Spatial Controls

Bathrooms	0.0790***
	(0.0108)
> =Average Condition	0.221**
	(0.113)
Central AC	0.621***
	(0.0120)
Nuclear Site Distance (km)	−0.0106
	(0.0244)
Tax Rate	−0.0426***
	(0.00226)
Building Size (100s sqft)	0.0158***
	(0.000744)
Fireplaces	0.0647***
	(0.00991)
House Build Date	0.00422**
	(0.000279)
Lot Size (100s sqft)	0.000398***
	(4.26e−05)
Distance to Commuter Rail	0.00476
	(0.0217)
Distance to Lakefront	0.00970*
	(0.00517)
Quarterly Dummy Series, Reference is Q1	
Q2	0.0610***
	(0.140)
Q3	0.112***
	(0.0142)
Q4	0.0884***
	(0.0154)
Annual Dummy Series, Reference is 2013	
2014	0.108***
	(0.0135)
2015	0.142***
	(0.0136)
2016	0.220***
	(0.0150)
Constant	2.967***
	(0.564)
N	3067
R-Squared	0.602

y = ln (sale price), Robust standard errors in parentheses
*** p < 0.01, **p < 0.05, *p < 0.1

The Impact of Property Characteristics on Home Sale Price, By Municipality

Winthrop Harbor		Zion	Waukegan	Beach Park	Wadsworth	Gurnee
Bathrooms	0.0664**	0.0734***	0.0921***	0.0375	0.0981	0.156**
	(0.0299)	(0.0201)	(0.0164)	(0.0292)	(0.0894)	(0.0631)
> =Average Condition	–	–	0.148	–	0.492**	–
			(0.108)		(0.230)	
Central AC	0.0697*	0.0920***	0.0549***	0.0322	−0.0117	0.218*
	(0.0396)	(0.0271)	(0.0160)	(0.0310)	(0.103)	(0.116)
Nuclear Site Distance (km)	0.0401	−0.170*	−0.233*	0.0335	1.234	−3.576
	(0.640)	(0.0884)	(0.119)	(0.262)	(3.699)	(52.88)
Tax Rate	0.0667	−0.0433***	−0.0435***	−0.0396***	−0.0235	0.120*
	(0.102)	(0.0104)	(0.0115)	(0.00847)	(0.0387)	(0.0704)
Building Size (100s sqft)	0.0150***	0.0122***	0.0192***	0.0140***	0.0166***	0.00954**
	(0.00204)	(0.00144)	(0.00125)	(0.00177)	(0.00405)	(0.00421)
Fireplaces	0.00998	0.0708***	0.0625***	0.0588**	0.0102	0.0655
	(0.0286)	(0.0185)	(0.0160)	(0.0255)	(0.0545)	(0.0617)
House Build Date	0.00583***	0.00230***	0.00465***	0.00671***	0.00251	0.0107***
	(0.000891)	(0.000501)	(0.000438)	(0.000837)	(0.00439)	(0.00289)
Lot Size (100 s sqft)	0.000332**	0.000549***	0.000668***	0.000453***	5.00e−05	0.00110***
	(0.000130)	(0.000108)	(0.000117)	(7.69e−05)	(0.000114)	(0.000291)
Distance to Commuter Rail	− 0.00717	0.131*	0.209*	− 0.0443	−0.813	3.533
	(0.620)	(0.0734)	(0.115)	(0.219)	(2.618)	(50.77)
Distance to Lakefront	− 0.0356	0.0660	0.0458***	0.00648	−0.400	0.412
	(0.105)	(0.0439)	(0.0174)	(0.0716)	(1.184)	(5.853)
Quarterly Dummy Series, Reference is Q1						
Q2	0.00624	0.0208	0.0955***	0.0603*	0.0561	−0.0743
	(0.0407)	(0.0273)	(0.0204)	(0.0352)	(0.106)	(0.122)
Q3	0.0654*	0.0650**	0.153***	0.0849**	0.0664	0.0844
	(0.0381)	(0.0281)	(0.0210)	(0.0360)	(0.0942)	(0.0857)
Q4	0.0614	0.0529*	0.105***	0.0974*	0.202*	0.181
	(0.0464)	(0.0281)	(0.0243)	(0.0389)	(0.101)	(0.116)
Annual Dummy Series, Reference is 2013						
2014	0.106**	0.0830***	0.133***	0.0539	0.0677	0.217**
	(0.0436)	(0.0260)	(0.0199)	(0.0331)	(0.104)	(0.0945)
2015	0.141***	0.121***	0.186***	0.0974***	0.0234	0.103
	(0.0430)	(0.0251)	(0.0203)	(0.0336)	(0.0814)	(0.117)
2016	0.0886*	0.175***	0.295***	0.186***	0.251**	0.261***
	(0.0462)	(0.0322)	(0.0218)	(0.0340)	(0.120)	(0.0970)
Constant	−1.445	7.118***	2.068**	−1.625	5.325	−12.48**
	(2.378)	(1.014)	(0.885)	(1.625)	(7.633)	(5.096)
N	305	799	1281	510	97	75
R-Squared	0.621	0.474	0.567	0.555	0.511	0.649

y = ln(sale price), Robust standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

References

Bassett Jr., , Gilbert, W., Jenkins-Smith, Hank C., Silva, Carol, 1996. On-site storage of high level nuclear waste: attitudes and perceptions of local residents. Risk Anal. 16 (3), 309–319.

Bird, Deanne K., Haynes, Katherine, van den Honert, Rob, McAneney, John, Poortinga, Wouter, 2014. Nuclear power in Australia: a comparative analysis of public opinion regarding climate change and the Fukushima disaster. Energy Policy 65, 644–653.

Blomquist, Glenn, 1974. The effect of electric utility power plant location on area property value. Land Econ. 50 (1), 97–100.

California PUC OKs PG&E closing Diablo Canyon., 2018. Power Markets Today, January 12. ⟨https://www.powermarketstoday.com/public/California-PUC-OKs-PGE-closing-Diablo-Canyon.cfm⟩.

Carpenter, John, 2017. WATCHDOGS: Zion's nuclear fallout; still reeling from '98 closing. Chicago Sun Times. January 7, 2017. ⟨http://chicago.suntimes.com/news/zions-nuclear-fallout-town-still-reels-from-1998-plant-closing/⟩.

Clark, David E., Allison, Tim, 1999. Spent nuclear fuel and residential property values: the influence of proximity, visual cues, and public information. Pap. Reg. Sci. 78 (4), 403–421.

Clark, David E., Michelbrink, Lisa, Allison, Tim, Metz, William C., 1997. Nuclear power plants and residential housing prices. Growth Change 28 (4), 496–519.

Cook, Philip L., 1996. Zion City, Illinois: Twentieth Century Utopia. Syracuse University Press, Syracuse, NY.

Cropper, Maureen, Deck, Leland B., McConnell, Kenneth E., 1988. On the choice of functional form for hedonic price functions. Rev. Econ. Stat. 70 (4), 668–675.

Drukker, D.M., Prucha, I.R., Raciborski, R., 2011. Maximum-likelihood and generalized spatial two-stage least-squares estimators for a spatial-autoregressive model with spatial-autoregressive disturbances. Working paper, University of Maryland, Department of Economics, ⟨http://econweb.umd.edu/~prucha/Papers/WP_spreg_2011.pdf⟩.

Dubin, Jeffrey A., Daniel, L. Mc.Fadden, 1984. An econometric analysis of residential electric appliance holdings and consumption. Econometrica 52 (2), 345–362.

Espey, Molly, Owusu-Edusei, Kwame, 2001. Neighborhood parks and residential property values in Greenville, South Carolina. J. Agric. Appl. Econ. 33 (3), 487–492.

Exelon Generation, 2016. Passage of future energy jobs bill boosts state economy and makes Illinois a leader in clean energy. [Press Release]. December 1, 2016. ⟨http://www.exeloncorp.com/newsroom/passage-of-future-energy-jobs-bill-boosts-state-economy-and-makes-illinois-a-leader-in-clean-energy⟩ (Accessed 14 January 2017).

Feldman, NaomiE., 2010. A reevaluation of property tax capitalization: the case of Michigan's proposal A. Unpublished working paper.

Gallagher, Ryan M., Kurban, Haydar, Perksy, Joseph J., 2013. Small homes, public schools, and property tax capitalization. Reg. Sci. Urban Econ. 43 (2), 422–428.

Gamble, Hays B., Roger, H. Downing, 1982. Effects of nuclear power plants on residential property values. J. Reg. Sci. 22 (4), 457–478.

Griliches, Zvi, 1961. Hedonic price indexes for automobiles: an econometric of quality change. In: Stigler, George J. (Ed.), The Price Statistics of the Federal Government. National Bureau of Economic Research, Cambridge, MA, pp. 173–196.

Guignet, Dennis, 2013. What do property values really tell us? A hedonic study of underground storage tanks. Land Econ. 89 (2), 211–226.

Hageman, Ronda K., 1981. Nuclear waste disposal: potential property value impacts. Nat. Resour. J. 21 (4), 789–810.

Harris, R.N.S., Tolley, G.S., Harrell, C., 1968. The residence site choice. Rev. Econ. Stat. 50 (2), 241–247.

Harrison Jr., David, Daniel, L. Rubinfeld, 1978. Hedonic housing prices and the demand for clean air. J. Environ. Econ. Manag. 5 (1), 81–102.

Hausman, Jerry A., 1979. Individual discount rates and the purchase and utilization of energy-using durables. Bell J. Econ. 10 (1), 33–54.

Huang, Lei, Zhou, Ying, Han, Yuting, Hammitt, James K., Bi, Jun, Liu, Yang, 2013. Effect of the Fukushima nuclear accident on the risk perception of residents near a nuclear power plant in China. Proc. Natl. Acad. Sci. USA 110 (49), 19742–19747.

ISO New England, 2018. Operational Fuel Security Analysis. January 17, 2018. ⟨https://www.iso-ne.com/static-assets/documents/2018/01/20180117_operational_fuel-security_analysis.pdf⟩ (Accessed 18 January 2018).

Kiel, Katherine A., Williams, Michael, 2007. The impact of superfund sites on local property values: are all sites the same? J. Urban Econ. 61 (1), 170–192.

Kinnaman, Thomas C., 2009. A landfill closure and housing values. Contemp. Econ. Policy 27 (3), 380–389.

Knabel, David. 2017. City of Zion Office of Accounts and Finance. Personal communication, January 11, 2017.

Kuminoff, Nicolai V., Christopher, F. Parmeter, Jaren, C. Pope, 2010. Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? J. Environ. Econ. Manag. 60 (3), 145–160.

Kuminoff, Nicolai V., Smith, V. Kerry, Timmins, Christopher, 2013. The new economics of equilibrium sorting and policy evaluation using housing markets. J. Econ. Lit. 51 (4), 1007–1062.

Lancaster, Kelvin J., 1966. A new approach to consumer theory. J. Political Econ. 74 (2), 132–157.

Lutzenhiser, Margot, Netusil, Noelwah R., 2001. The effect of open spaces on a home's sale price. Contemp. Econ. Policy 19 (3), 291–298.

Marshall, Alfred, 1920. Principles of Economics. Macmillan and CO., Ltd. Library of Economics and Liberty, London. ⟨http://www.econlib.org/library/Marshall/marP62.html⟩ (Accessed 1 December 0017).

Metz, William C., David, E. Clark, 1997. The effect of decisions about spent nuclear fuel storage on residential property values. Risk Anal. 17 (5), 571–582.

Muehlenbachs, Lucija, Spiller, Elisheba, Timmins, Christopher, 2015. The housing market impacts of shale gas development. Am. Econ. Rev. 105 (12), 3633–3659.

Nelson, Jon P., 1981. Three Mile Island and residential property values: empirical analysis and policy implications. Land Econ. 57 (3) (633-372).

North American Electric Reliability Corporation, 2013. 2013 Long-Term Reliability Assessment. December 2013. (Accessed 14 January 2017). ⟨http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2013_LTRA_FINAL.pdf⟩.

Nuclear power plant announces layoffs, 2014. *Brattleboro Reformer*. November 19, 2014. ⟨http://www.reformer.com/stories/nuclear-power-plant-announces-layoffs,325275⟩ (Accessed 14 January 2017).

Nuclear Regulatory Commission, 1997. NRC Staff Proposes $330,000 Fine Against Commonwealth Edison for Violations of NRC Requirements at Zion Nuclear Station. NRC News 09/03/1997. Online: ⟨https://www.nrc.gov/reading-rm/doc-collections/news/1997/97-079iii.html⟩. (Accessed 14 December 2016).

Nuclear Regulatory Commission, 2013. Partial Initial Decision in the Matter of Entergy Nuclear Operations, Inc., (Indian Point Nuclear Generating Units 2 and 3). ASLBP No. 07-858-03-LR-BD01. Available: ⟨https://www.nrc.gov/docs/ML1333/ML13331B465.pdf⟩.

Oates, Wallace E., 1969. The effects of property taxes and local public spending on property values: an empirical study of tax capitalization and the Tiebout Hypothesis. J. Political Econ. 77 (6), 957–971.

Office of Management and Budget. 1992. *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* Circular No. A-94: pp. 7-10.

PG&E, 2016. In Step With California's Evolving Energy Policy, PG&E, Labor and Environmental Groups Announce Proposal to Increase Energy Efficiency, Renewables and Storage While Phasing Out Nuclear Power Over the Next Decade. [Press Release] June 21, 2016. ⟨https://www.pge.com/en/about/newsroom/newsdetails/index.page?Title=20160621_in_step_with_californias_evolving_energy_policy_pge_labor_and_environmental_groups_announce_proposal_to_increase_energy_efficiency_renewables_and_storage_while_phasing_out_nuclear_power_over_the_next_decade⟩ (Accessed 1 September 2017).

Press Office of New York Governor Andrew M. Cuomo, 2017. Governor Cuomo Announces 10th Proposal of the 2017 State of the State: Closure of the Indian Point Nuclear Power Plant by 2021. [Press Release] January 9, 2017. ⟨https://www.governor.ny.gov/news/governor-cuomo-announces-10th-proposal-2017-state-state-closure-indian-point-nuclear-power⟩ (Accessed 14 January 2017).

Ridker, Ronald G., John, A. Henning, 1967. The determinants of residential property values with special reference to air pollution. Rev. Econ. Stat. 49 (2), 246–257.

Rosen, Sherwin, 1974. Hedonic prices and implicit markets: product differentiation in pure competition. J. Political Econ. 82 (1), 34–55.

Taylor, Laura O., 2017. "Hedonics" in Patricia. In: Champ, A., Boyle, Kevin J., Brown, Thomas C. (Eds.), A Primer on Nonmarket Valuation. Springer, New York, NY, pp. 235–292.

Tiebout, Charles M., 1956. A pure theory of local expenditures. J. Political Econ. 64 (5), 416–424.

U.S. Congress, 1983. "Nuclear Waste Policy Act of 1982. Public Law 97 (425), 10–101.

Webb, James R., 1980. Nuclear power plants: effects on property value. Apprais. J. 48 (2), 230–235.

Yamane, Fumihiro, Ohgaki, Hideaki, Asano, Kota, 2013. The immediate impact of the Fukushima Daiichi accident on local property values. Risk Anal. 33 (11), 2023–2040.

Yinger, John, Börsch-Supan, Axel, Bloom, Howard S., Ladd, Helen F., 1988. Property Taxes and House Values: The Theory and Estimation of Intrajurisdictional Property Tax Capitalization. Academic Press, Inc, Boston, MA.