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The long-run impact of nuclear waste shipments on the property market: Evidence from a quasi-experiment ☆

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ABSTRACT

We use evidence from a quasi-experiment – the shipping of radioactive spent nuclear fuel by train through South Carolina – to assess whether many years of incident-free transport of nuclear waste no longer negatively affects market valuation of properties along the route. Using Charleston County (SC) property sales data over 13 years we find, to the contrary, that the negative impact of the nuclear waste shipments on property values continues to be felt over the long run. The perception of risk from nuclear waste transport appears to be resilient. We contribute methodologically by comparing well-defined treatment and control groups of properties to estimate the average treatment effect of the nuclear waste shipment program. The results are affirmed in both a pooled cross-section sample, as well as a panel data sample of repeated property sales.

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1. Introduction

Handling highly radioactive waste has proved to be one of the most difficult parts of hazardous materials management. As the United States debates large-scale transport of spent nuclear fuel (SNF) from the 73 storage sites scattered across 33 states to more centralized interim storage sites and permanent deep-geologic repositories versus maintaining the status quo of continued on-site storage at or near reactors,[1] concerns have focused on safety and efficiency of the transport [5], National Research Council, [45]). The Obama administration's decision to withdraw the license application to construct the 77,000-ton capacity Yucca Mountain repository site, reversing the policy of former President Bush, remains controversial. The stalemate leaves in limbo the long-run solution to the current US inventory of 70,000 ton of SNF in existing sites, plus the annual output of more than 2000 ton of SNF annually produced by the country's reactors. Subsequent to its withdrawal of the license application for Yucca Mountain, the Obama administration appointed a blue-ribbon commission to advise the government on a new strategy for managing nuclear waste. In January of 2012 the commission concluded that the US

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[1] Most commercial used nuclear fuel is stored at or near operating reactors. However nine of the 73 storage sites are at shutdown reactors, often referred to as "orphan" storage sites.

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will require interim storage sites and one or more permanent, centralized geologic repositories, and recommended early preparation for transport of used nuclear fuel and high-level radioactive wastes [5].

Of interest in this paper are the economic effects that transporting spent fuel may activate, possibly resulting from beliefs about the risks posed by such transport. Experience with hazards, ranging from chemical wastes at Superfund sites to deposition of lead from smelting plants has demonstrated that property values can be sensitive to proximity to such hazards.[2] But does proximity to the route by which radioactive materials are shipped in highly resilient transport casks also affect property values? If so, by what amount do values diminish, and over what geographic scope? Finally, and most importantly, are these effects permanent or transitory?

This paper supplies answers to these questions using new methods. It is motivated by Gawande and Jenkins-Smith's [17], henceforth GJS, study of shipments of spent fuel through South Carolina in the early years after the shipments began in 1994. At that time, the shipments were beset by enormous controversy and the wide press coverage that followed was rarely positive. Into the first two years of the shipments, GJS found that in populous Charleston County, a home five miles from the shipment route was worth 3% more than a similar home located on the route. This result has been used on both sides of a fierce policy debate over Yucca Mountain.[3]

The shipments continue to this day. There has not been a single negative incident over the fifteen years, and newspaper reports of the shipments are almost negligible. This suggests that individuals' perceptions about the risk of SNF shipments may have been updated over time due to the lack of media coverage and absence of incidents. A large literature on environmental clean-ups argues that clean-ups restore property values in the long run.[4] This literature, while related, is distinct from risk revision. Cleanups entail the removal of a risk, whereas the risk may continue to be inherent in the current context, though individuals may have updated their beliefs about the risk. The time is not only apt for re-investigating the finding using long-term data, but it has critical implications for both research and policy.[5]

This paper uses the same South Carolina SNF shipment setting as Gawande and Jenkins-Smith, and improves on it in three respects. First, we appropriately view the SNF shipment as a natural experiment and use average treatment effect estimators. We use a difference-in-differences strategy to identify and estimate the average treatment effect in the treated population of properties in Charleston, South Carolina. Gawande and Jenkins-Smith [17] suffers methodologically from the same issues that Greenstone and Gallagher [21] critique in earlier studies of the impact of NPL clean-ups, namely that the methods do not control for untreated properties. We remedy this deficiency. Second, the data include property transactions over a much longer duration. We obtained records of all residential property sales in Charleston County between 1992 and 2005 (the GJS paper stopped at 1996). The transactions data permit us to estimate the effects of the spent fuel shipment program on property values over a decade of shipments without incident. Third, we are able to weigh in with panel data, while much of the literature has used pooled cross-sections. Existing studies of the effects of the environment on land and property values has largely used cross-sectional data combined with a heavy reliance on hedonic variables to control for heterogeneity. Even with the controls, doubts may remain about unobserved heterogeneity in the cross-section. Therefore, in addition to the pooled cross-section, we use repeat sales information to create panel data on a number of properties.

The paper proceeds as follows. In Section 2 we describe the foreign spent nuclear fuel shipments that began in 1996. Section 3 describes the difference-in-differences methodology using both pooled cross-section data and panel data. Section 4 explains in detail the construction of our data set. The data are unique in many respects, and add new dimensions to the environmental impact evaluation enterprise. Section 5 presents and analyzes the findings. The main finding is that the prices of properties in the most urban and populous County (Charleston) continue to be influenced negatively by SNF shipments despite the absence of any incidents that might heighten risk perceptions about the shipments. Section 6 provides our discussion and conclusions.

[2] The idea that property values will be affected by the presence of hazardous materials – including incinerators, electricity transmission lines, landfills, and nuclear power plants – has been studied, for example, by Kiel and McClain [33], Kiel [32], McClelland et al. [38], Kohlhase [34], Michaels and Smith [41], and Gamble et al. [16]. These studies use the hedonic pricing logic, viewing proximity to the environment as a characteristic of the property. The earliest efforts involved inference about the marginal value of clean air from housing prices [23,39].

[3] Board of County Commissioners Lincoln County NV [4], Clark County Department of Comprehensive Planning, Nuclear Waste Division [11], Hom et al. [25], Nuclear and Radiation Studies Board [45], O'Connor [46], State of Nevada [52,51], and US Nuclear Regulatory Commission [58].

[4] In a properly functioning market if a disamenity is transitory, it should not have permanent effects on housing prices. Stock [53], Kohlhase [34], and Ketkar [31] find this to be true about properties near cleaned-up hazardous waste sites as do Carroll et al. [7] and Dale et al. [13] in the context of chemical clean-ups. Studies by Nelson [43], Gamble and Downing [15] and Gamble et al. [16] examining incidents near nuclear power plants, specifically the Three Mile Island (TMI) accident, found no decrease in housing prices due to proximity to the TMI plant. However, since nuclear power plants produce jobs and tax revenues, they may offset the possible disamenity effects. Studies of waste sites such as the Frenald plant in Ohio (Feiertag, [60]) and Rocky Flats in Colorado (Hunsperger, [27]) indicate the effects on property values to be similar to those of Superfund sites.

[5] In a white paper, Department of Energy analysts Holm et al. [25, p. 12] write: "The numerous and complex socioeconomic analyses that attempt to quantify stigma damages for various transportation scenarios are based on a single, limited, preliminary study whose authors themselves argue that the issue requires further study. Apart from the GJS study, there appears to be no defensible empirical evidence whatsoever that stigma from transportation even exists. Their finding that there may be a statistically significant effect may be supported by further research, or it may not. What is certain is that repeated and sustained citations to this single isolated study in secondary sources and reports do not validate the findings themselves."

"Much of the research conducted to date has used polling methodologies, as opposed to empirical or real-time data. The GJS study, by contrast, used real estate sales data along with the results of systematic surveys to reach its conclusions. DOE's Appendix I of the FEIS on Yucca Mountain suggests that additional research is needed. If such analysis is undertaken …(t)he research should use actual real estate transaction data for a significant period of time…."

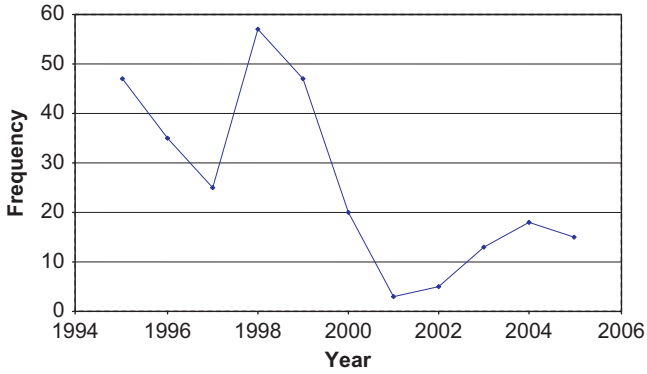


Fig. 1. Monthly reporting on nuclear issues in South Carolina.
Source: Post and Courier.

2. Theory

2.1. Background

The United States program to reclaim spent nuclear fuel from overseas reactors seeks to remove from commerce potential access to weapons-grade nuclear materials – both highly enriched uranium and the plutonium byproduct of fission in the reactor. The fuel, originally provided to many nations as part of the Atoms for Peace program, has been owned by the United States.[6] In the 1990s, a campaign to ship accumulated stocks of spent fuel back to the United States was initiated. Initial plans to return the fuel through ports in North Carolina and Contra Costa County, CA, resulted in substantial opposition. The Governor of South Carolina, the state where much of the spent fuel was to be stored, sought unsuccessfully to block the shipments in the courts. South Carolina newspapers and television news provided ample coverage of the dispute, highlighting the route and communicating the dire concerns of some state officials, anti-nuclear activists, and citizens. After a delay of nearly two years following the initial shipment in 1994, foreign spent nuclear fuel (SNF) has been transported at least once a year from the Port of Charleston to the Department of Energy's Savannah River facility in Aiken County, SC. Appendix A (available from the authors) lists the dates of each of the rail shipments between 1996 and 2003.

In contrast to the substantial initial public outcry over the shipments, there has been little negative press over subsequent years. No accidents or incidents have occurred that resulted in release of radiation. Indeed, our review of news articles in the *Charleston Post and Courier* newspaper, summarized in Fig. 1, found no articles claiming that such events had occurred. Did the lack of SNF transport incidents together with declining attention in the news lower the perceived risks from SNF shipments? Specific to nuclear waste, surveys by Slovic et al. [50], and Kunreuther and Easterling [35] have demonstrated that nuclear images of a place lower stated preferences for vacationing and residing there, suggesting long-term stigmatization of properties may occur near nuclear waste storage facilities.

2.2. Theory

A simple model of how risk perception affects property prices is developed by Gayer et al. [18]. Individuals maximize expected utility over two states of the world, U_1 when harm comes to them from exposure to radiation from spent nuclear fuel, and U_2 when they are unexposed and healthy. $U_2 > U_1$ for any given income, and marginal utility of income is greater when healthy. The consumer has income y which is spent on buying a home and a composite good a. Utility in each state is a function of characteristics of the home X, *perceived* risk of harm from exposure to the spent nuclear fuel π, and distance to the SNF route D (which measures the visual disamenity from the SNF shipment). The price of a home P is a function of characteristics X, risk perception π, and distance to the SNF route D. The consumer chooses the arguments in P and a to maximize expected utility subject to the budget constraint:

$$\text{Max EU} = \pi U_1(a,X,D) + (1-\pi)U_2(a,X,D)$$

s.t.

$$y = a + P(\pi,X,D).$$

[6] The objective of the Atoms for Peace program was to provide non-nuclear nations with peaceful means to employ nuclear technologies (usually in the form of research reactors and the reactor fuel) in return for the recipient countries' willingness to forego development of their own nuclear weapons program.

Table 1
Perceived probabilities of FSNF transport accidents and consequences as measured in cross-sectional surveys in 1994, 1995 and 2005.

	1994	1995	2005
Charleston County	1. FSNF train accident? (0=never happen; 10=certain to happen)		
	4.68, sd=0.17	4.77, sd=0.13	5.65, sd=0.13
	2. FSNG canister rupture (if accident)? (0=never happen; 10=certain to happen)		
Charleston County	5.07, sd=0.18	4.66, sd=0.15	5.74, sd=0.14
	3. Expectation of harm to area residents (if accident and canister rupture)? (percent "yes")		
Charleston County	84%, sd=0.03	80%, sd=0.02	91%, sd=0.01

Notes: 1. Sample means and standard deviations (sd).

The main result from this constrained maximization problem [18, p. 441] is the negative impact on home price P of an increase in π[7]:

$$\frac{\partial P}{\partial \pi} < 0.$$

The perceived risk of harm from SNF exposure π may be expressed as the product of three personally assessed conditional probabilities: the probability of harm given that an accident occurs and the canister carrying radioactive spent nuclear fuel ruptures, the probability of a canister rupturing given that an accident occurs, and the probability that an accident occurs:

$$\pi = \text{Prob(Harm}|\text{Accident and Rupture)} \cdot \text{Prob(Rupture}|\text{Accident)} \cdot \text{Prob(Accident)}.$$

The change in risk perception $\Delta\pi$ may come about due to new information that changes personal assessments of any of these probabilities. For example, an increase in Prob(Accident), all else constant, will update risk beliefs in the direction of greater risk perception ($\Delta\pi > 0$). Via the comparative static result above, this will lower a home's price.

To ascertain whether a change in perceived risk had indeed occurred, we conducted telephone surveys of residents in 1994 (just prior to the first shipment), 1995 (just after the first shipment), and 2005 (a decade after the first shipments).[8] The survey was designed to measure perceptions of the components of the risks posed by the shipments: Prob(Harm|Accident and Rupture),Prob(Rupture|Accident), Prob(Accident). Table 1 shows the average perception of Charleston County residents of these risk components. The experience with a decade of accident-free SNF transport has not reduced perceived risks among the public along the South Carolina rail route. Indeed, the responses to the questions (using identical wording and very similar question order) suggest that perceived risks increased over the past decade. On average, in 2005 Charleston County residents believe accidents to be more likely, the chance of a canister rupture given an accident to be higher, and the expected harm in the event of an accident and rupture to be greater than a decade before. Since perceived risks are a factor in property values, the survey data suggest a continuing negative effect from being "treated" with exposure to risk from the SNF shipments.

Since the probability components are personally assessed, they are themselves subject to uncertainty, and π is appropriately viewed as a random variable. Riddel and Shaw [48] and Riddel [47] show how the imprecision in risk perception assessment π, denoted σ_π^2, can influence a person's willingness to accept compensation for a negative environmental externality. In particular, a median-preserving increase in σ_π^2 increases the expected willingness to accept [48, p. 346]. Using evidence from a primary survey of South Nevada residents Riddel shows that, of the welfare loss from a hypothetical nuclear waste transportation program, 12.4% is attributable to the uncertainty σ_π^2. The idea that uncertainty about risk perceptions can negatively influence property prices applies naturally in our Bayesian framework. A number of events may have increased uncertainty about risk assessment in recent years, including heightened concerns about nuclear terrorism following the September 11, 2001, terror attacks in the US.

Together, the theory and the survey evidence lead to the hypothesis that the treatment effect from exposure to the SNF shipments will lower property prices in the long run. The remainder of the paper is devoted to testing this hypothesis.

[7] $$\frac{\partial P}{\partial \pi} = \frac{U_1 - U_2}{\pi \partial U_1/\partial a + (1-\pi)\partial U_2/\partial a} < 0.$$

If distance directly influences risk perception, $y = a + P(\pi(D), X)$, with $\pi'(D) < 0$, then $\partial P/\partial D > 0$.

[8] The 2005 interviews were conducted between October 7 and December 4, 2005. The samples were based on a random digit-dialing frame obtained from Survey Sampling Inc., of Fairfield Connecticut. The surveys lasted an average of 17 minutes, and resulted in a cooperation rate of 57% in 2005, in comparison to cooperation rates (using AAPOR's "COOP2" formula) of 88% in 1994 and 61% 1995 [1]. All three surveys included over 250 Charleston County respondents.

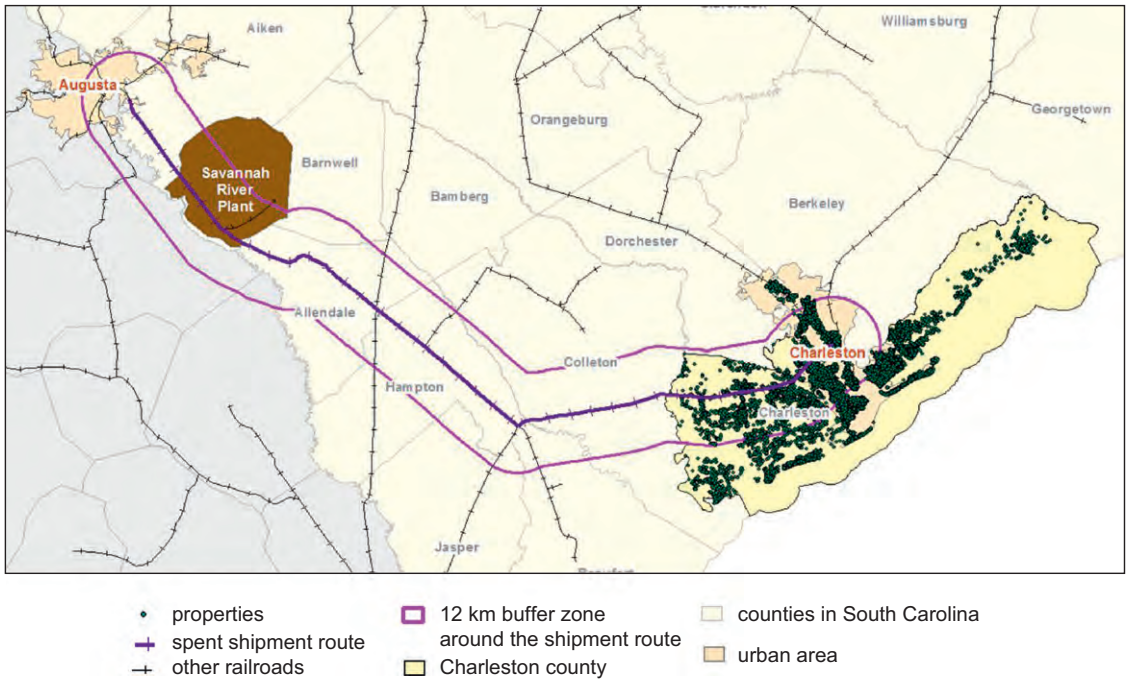


Fig. 2. SNF rail route, non-SNF rail routes, and geographic distribution of the sample of properties.

3. Data

Our data consist of the population of properties that were sold at least once during the period 1992–2005 in Charleston, South Carolina. Fig. 2 maps the South Carolina counties through which the SNF rail route runs. The SNF route is indicated by the dark line through Charleston–Colleton–Hampton–Allendale, through the Savannah River Plant, and ending in Aiken. It is enclosed by a 12 km "buffer zone", which separates the treatment and control groups of properties. Other non-SNF rail lines are also shown in Fig. 2. Each of the approximately 80,000 property sales is indicated by a dot on the map.[9] Data on sale price and date of sale were obtained from REIS, a firm that specializes in the collection and reporting of property values and transactions in South Carolina. It is the only database of its kind for the state of South Carolina. Only properties with sale price above $25,000 but less than $500,000 were considered for this study. Thus, the average treatment effect we estimate is of greatest relevance for a population of urban properties within this range of values.

Charleston County, where the Port of Charleston is located, is densely populated and 88% urban. It is the third-most populous (330,000) among the 51 South Carolina counties, and accounts for 12% of the state's GDP. The treatment group T and control group C of properties are entirely located within Charleston County. Properties within a 12-km distance from the SNF route comprise the treatment group, while properties 12 km or more from the SNF route comprise the control group. The 12-km cutoff is determined by searching over properties in distance-bands around the SNF route. The search is described in detail below. The treatment and control group together comprise the full sample of 79,560 properties. A subset of this control group that is proximate to another rail route over which no shipments were planned or occurred, may be used to control for the "placebo" effect of simply being near a rail route. The treatment group plus this sub-sample of the control group comprise the "Near Rail Routes" sample of 58,674 properties.

The distance of each property in the sample from the SNF route (DistanceSNF) is calculated as the nearest distance from the center of the property to the route. Coordinates obtained from the GIS based on the address of the property were used to calculate this distance. Housing characteristics in the REIS database include built-up square foot area (Square Feet) and the year it was built (Year Built). REIS also provided coordinates of amenities including parks, schools, bays, landmark buildings, churches, hospitals, the cape, streams and islands, which were used to compute the closest distance of each property from these amenities.[10]

[9] We also have property sales data for the four rural South Carolina counties Aiken, Berkeley, Dorchester and Orangeburg. Our focus in this paper is on urban and densely populated Charleston County. While not reported, the treatment effect estimates for these other counties is available from the authors. Perhaps not surprisingly, since proximity to a rail route is an amenity in rural areas as it reduces costs of transporting agricultural products, we find different effects for Charleston versus the rural counties.

[10] The distances were computed using Haversine's formula for spherical distances.

Census-block demographic and income data obtained from the 1990 United States Census were mapped to each property based on its address and zip code. These variables include the percent of the population in the census block who are White (% White), Black (% Black), and Hispanic (% Hispanic), and the median household income in the census block (HH Income). In sum, we have as complete a data set as possible on sale price, property characteristics, external amenities, and census block characteristics with which to investigate the effect of SNF shipments on property sale prices.

Table 2 provides descriptive statistics for the Charleston County pooled cross-section. Of the 79,650 residential properties in the full sample, 48% belong to the treatment group and 52% to the control group. 10% of the transactions in the sample preceded the shipments ($DT0$) and 90% were recorded in the shipments regime. We will distinguish the program's short-term impact (8/1994–12/1997) from its long-term impact (1/1998–2005). 21% of the sample is from the short-term regime ($DT1$) while 71% is from the long-term regime ($DT2$). The average building in the sample was 1893 square feet and was built in 1971. The distance of properties from the SNF route had a mean of 11.63 km and standard deviation equal to 6.79 km. The average distance of treated properties from the SNF route was 6.052 km.

Our panel data are constructed as three separate data sets, one comprising 46,537 properties that were sold at least twice, another comprising 17,870 properties that were sold at least thrice, and a third comprising 4926 properties that were sold at least four times during the 1990–2005 period. Appendix Table A1 provides descriptive statistics for the panels. The statistics indicate considerable within-variation in the price data.

4. Methodology

4.1. Pooled cross-section

The SNF shipment program provides a natural experiment for assessing the impact of nuclear waste shipments on residential property prices. Residential properties in Charleston, South Carolina potentially impacted by the shipments, or "treated" to the risk of exposure, are the units of analysis. We use difference-in-differences (DID) to identify and estimate the average treatment effect on this population of treated properties (ATT).[11]

The difference in differences compares the effect of SNF shipments on properties perceived to be exposed to the risk of contamination (the treated group) versus properties that were not perceived to be exposed to the risk (the control group). Specifically, the pre-shipment to post-shipment change in the selling price of properties for the treated group is compared to the pre-shipment to post-shipment change in the selling price of properties for the control group. The post-shipment phase is broken down into a two periods to enable us to contrast the short-term versus the long-term impact of the shipments. Specifically, using a pooled cross-section of property prices, we estimate parameters of the econometric model

$$\ln(P_{it}) = \gamma T_i + \tau^S (DT1_t \times T_i) + \tau^L (DT2_t \times T_i) + \beta' X_i + \text{year fixed effects} + e_{it}, \quad (1)$$

where P_{it} is the selling price of property i at in year t. The assignment to treatment group indicator $T_i = 1$ if property i is within 12 km of the SNF route, that is, perceived to be exposed to risk from the SNF shipments. Properties beyond 12 km of the shipment route are assigned to the control group. The property bands model described below is used to determine the 12 km cutoff. $DT1_t$ and $DT2_t$ are short run and long run indicators: $DT1_t = 1$ if the observation records a sale after the first SNF shipment in 8/94–12/97; $DT2_t = 1$ if the observation records a sale during 1/98–12/05.[12] The coefficient γ measures the average time-invariant difference between properties perceived to be exposed to risk versus properties that were not so perceived. The difference-in-differences estimators are the coefficients on the interaction terms: τ^S measures the short-run average treatment effect of the shipments in the 3-year period following the inception of shipments. τ^L measures the long-run average treatment effect of the SNF shipments.

4.1.1. Assumptions

Three assumptions are needed for the error term e_{it} to be independent of assignment to treatment T_i, so that the DID estimators τ^S and τ^L are identified.

4.1.1.1. Functional form. The first assumption concerns stability of functional form across treated and control units. Hedonic variables X_i described in the data section measure property-specific attributes, census block characteristics and proximity to amenities, all of which have been emphasized in the literature (e.g. [9]). The use of hedonic models in which the parameters β measure the marginal valuations of each characteristic (linearly) is standard in the large literature on property valuation. This is relevant for our estimation strategy, since DID relies on strong assumptions about stability of functional form. Specifically, the large literature on hedonics supports our assumption that β is the same for treated and

[11] Rubin's [49] potential outcomes framework motivates this analytical framework (see [28]). If the property-specific treatment effect is constant across every property, then DID estimates the Charleston county population average treatment effect (ATE). However, if the treatment effect is heterogeneous then DID estimates the average treatment effect on the treated properties (ATT). The treatment effect is heterogeneous in a specific and measurable way, as we show below.

[12] Their own effects are absorbed into the year fixed effects.

untreated properties, and is not a source of bias.[13] The log-linear specification solves the problem of skewness in the housing price, which would otherwise make the errors non-normal.[14]

4.1.1.2. Common trends. The second assumption is that in the absence of the SNF shipments, properties in both the treatment and control groups would have common trends. This assumption would be violated if, for example, the shipment route was chosen endogenously, deliberately on the basis of trends that distinguished the treatment properties from the control properties. We believe the assignment of properties to treatment from the SNF program was done independently of their value. Two reasons for this view are, first, the choice of the South Carolina SNF rail route was highly constrained by requirements associated with distance, track quality, and traffic density (DOE [57]) and second, only existing routes were utilized. No new routes were constructed. If interest groups representing high-values homes, for example, had been able to use their influence to move the route away from their homes, then assignment to treatment would not be exogenous. Or if a new route were built at a safe distance from the city of Charleston by policymakers in response to strong public opinion, the assignment to treatment of homes built around this new route would be endogenous. Neither of these occurred. The transportation corridor was chosen from routes that had existed for decades, imposing a random shock on properties along the chosen route. Quite simply, properties near the SNF route became exposed to risk, while properties located outside its range of influence were much less exposed or unexposed. In the empirical section we attempt to falsify this assumption by testing the equality of trends using pre-shipment data.

4.1.1.3. SUTVA. The third assumption needed for the error term e_{it} to be independent of assignment to treatment is the stable unit treatment value assumption (SUTVA) that the treatment has no externalities. That is, treatment of a property has no repercussions on the values of other properties. This assumption is likely to be violated because of strong spatial correlation inherent in neighboring property values. In a neighborhood, the market prices similar properties similarly. Realtors often advise sellers to set the price according to the best "comp" or comparable house in the neighborhood.

We consider two options. The first option is to ignore the externality and use (1) to estimate the treatment effect. If the price of a treated home is depressed because the comps are all selling for less, but the comps sold for less due to the treatment, then one should not control for the price of comps in the analysis. Since we are interested in the total derivative of the SNF treatment on home value, this eliminates "intermediate outcomes" such as the effect on comps. Netting out the effect on the comps underestimates the treatment effect on a home, since, in this view, the effect on the comps should be attributed to the home.

The second option is to control for the neighborhood externality directly by including a spatially lagged regressor. We do so by including the variable COMP10, constructed as

$$\text{COMP10}_i = \sum_{j=1}^{10} \left[\frac{\frac{1}{d_{ij}}}{\sum_{j=1}^{10} \frac{1}{d_{ij}}} \right] P_j,$$

where P_j's are prices of homes closest to home i, each d_{ij} kilometers from it. To avoid endogeneity, the P_j's are taken from property sales that occurred between six and twelve months prior to the sale date of property i. COMP10 limits the comps to 10 previously sold properties neighboring property i. Adding COMP10 to (1) results in the model

$$\ln(\text{P}_{it}) = \gamma T_i + \tau^S (DT1_t \times T_i) + \tau^L (DT2_t \times T_i) + \phi \ln(\text{COMP10}_{it}) + \beta' X_i + \text{year fixed effects} + e_{it}. \quad (2)$$

A reason for including COMP10 is econometric. Ignoring comps induces spatial correlations in the errors, leading to inefficient estimates of the DID and other parameters [2]. We find that including COMP10 greatly reduces spatial correlation in the errors.

Another reason for including COMP10 is that it may ameliorate the impact of the SUTVA violation. There is a possible positive externality on the price of control units, due to their lack of treatment and consequent greater demand. Thus, DID is an upper bound on the cost to homeowners in the treated units, but does reflect the total effect on the relative price of treated versus control units. COMP10 then captures some of the effect of the treatment on the decrease in price of the treated units and increase in price of control units. COMP10 also captures unobserved neighborhood attributes of individual units that may be correlated with treatment status. Even though COMP10 may not fully internalize the externality, including COMP10 may nevertheless alleviate the problem. We find a substantial difference between DIDs from the model without comps versus the model with comps, and report both, leaving the choice for the reader to make.[15]

[13] For example, X may change in response to the treatment if only smaller properties were built in the region along the route exposed to risk from the SNF shipments. Results available from the author show that there was no statistical difference in property characteristics between the treatment and control groups.

[14] Estimating the same models with a Box–Cox transformation yields results that are close to those reported here.

[15] If it is possible to satisfy no externalities across clusters defined by comps, then a neighborhood-level SUTVA, or NL-SUTVA assumption is valid [59]. However, spillovers do traverse comps-levels and even across the treatment and control groups since diminished demand for homes in the treatment group may increase demand in the control group. Still, it is worth considering the following possibility in future research. NL-SUTVA requires that there be no treatment externalities between homes in different comp groups, that is, the effect of the SNF shipments in one comp cluster does not affect the outcome in another comp cluster. Suppose any externality from the treatment, reflected in values of the comps, is confined to the treated group, and there are no cross-group spillovers (this may be tested). Then, since NL-SUTVA is satisfied, Eq. (2) may be used in a manner similar to

4.1.2. Heterogeneity

A key source of heterogeneity in the treatment effect, recognized in the theory section, and also in the GJS study, is that perceived risk from exposure decreases as distance from the SNF route increases. Two extensions of (2) are used to take this into account. In the first extension, we assign properties within three parallel 4 km distance bands, each band successively further from the SNF route:

$$\ln(P_{it}) = \gamma T_i + \sum_{j=1}^{3} \tau_j^S (DT1_t \times T_{ij}) + \sum_{j=1}^{3} \tau_j^L (DT2_t \times T_{ij}) + \phi \ln(\text{COMP10}_{it}) + \beta' X_i + \text{year fixed effects} + e_{it}. \quad (3)$$

where assignment of each property i to a band is indicated by the three dummy variables T_{ij}, $j = 1, \ldots, 3$. We expect the DIDs to follow the order $\tau_1 > \tau_2 > \tau_3$ (for both SR and LR treatment effects) since properties located further from the shipment route become less exposed to perceived risk. We use this model to search for a credible distance cutoff for defining the unexposed control group of properties. To start the search we define the treatment group indicator $T_i = 1$ if property i is within 18 km of the SNF route.[16]

In the second extension, rather than estimating constant DIDs within different bands we estimate it as a continuous function of distance from the SNF route:

$$\ln(P_{it}) = \gamma T_i + \tau^S (DT1_t \times T_i) + \tau^L (DT2_t \times T_i) + \tau_D^S (\text{DistanceSNF}_i \times DT1_t \times T_i) + \tau_D^L (\text{DistanceSNF}_i \times DT2_t \times T_i) + \phi \ln(\text{COMP10}_{it}) + \beta' X_i + \text{year fixed effects} + e_{it}. \quad (4)$$

The DID for property i is computed as $\tau + (\tau_D \times \text{DistanceSNF}_i)$, where the constant treatment effect τ is adjusted for the ameliorating effect of distance from the SNF route. From a modeling perspective, (4) captures distance from the shipment route as an essential source of heterogeneity. Since the property-specific treatment effect is not constant across every property, the DID estimates the average treatment effect on treated properties (ATT) in the Charleston county population. Specifically, the DID estimates the additional change over time in property values for the treated relative to the controls. From a policy perspective, the distance effect is critical in assessing damage valuations for individual properties.

4.2. Panel data

The availability of repeat sales data is uncommon because several years of data must be available before we can obtain a mix of properties that have been sold two, three, four, or more times. We have that luxury, and are able to estimate panel models with property-fixed effects. The panel DID model of short- and long-run ATTs is specified as

$$\ln(P_{it}) = \tau^S (DT1_t \times T_i) + \tau^L (DT2_t \times T_i) + \tau_D^S (\text{DistanceSNF}_i \times DT1_t \times T_i) + \tau_D^L (\text{DistanceSNF}_i \times DT2_t \times T_i) + \phi \ln(\text{COMP10}_{it}) + \text{year fixed effects} + u_i + \epsilon_{it}. \quad (5)$$

In (5) u_i are property fixed effects. Time-invariant regressors like property attributes, distance to amenities, and neighborhood characteristics are absorbed into the property fixed effects.[17] COMP10 is time-varying and controls for spatial errors. Bertrand et al. [3] caution about underreporting standard errors, since in panels with long durations of treatment, autocorrelation of treatment with the outcome is likely. We note that since individual properties sell at random points during the period of the sample, the autocorrelation problem in our case is not severe. Regardless, we follow their suggestion of using White's robust standard errors, which accounts for clustering on fixed effects, for computing t-values [3, fn 29].

5. Results

5.1. Pooled cross-section

5.1.1. Distance bands of properties

OLS estimates from the pooled cross-section of parameters in the distance bands model (3) are reported in Table 3. The effect of the spatial control variable COMP10 is measured extremely precisely. As expected, it is a good predictor of the change in sale prices. In the first model, for example, a 10% increase in the price of the closest 10 properties sold is associated with a 4.62% increase in the value of a home in that neighborhood. The spatial variable accomplishes its other task, namely reducing spatial correlation. While it is not possible to compute spatial statistics such as Moran's I and Getty's

(*footnote continued*)
VanderWeele's [59] two-level model for estimating neighborhood effects. In the two-level model properties are treated in clusters of comps (i.e. "neighborhood"), enabling estimation of *comps-level* ATTs.

[16] The plausibility of 18 km as a cutoff choice is based on these considerations. If a "safe" distance such as 25 km is chosen as a cutoff to determine the boundary between treated and control properties, then 99% of the Charleston properties fall in the treated group. On the other hand, a shorter cutoff, say at 5 km, may include a sizable set of properties the control group that are actually perceived to be exposed to risk from the SNF. The DID coefficient τ would then understate the actual treatment effect.

[17] In theory, improvements to properties may change their characteristics, and building new amenities can introduce time-variation. However, in our sample too few properties expanded or contracted in terms of square footage, and the stock of amenities remained constant.

Table 2
Descriptive statistics for pooled cross-section sample.

Variable	Description	Mean	sd
Ln(Sale Price)	Log of $ sale price	11.765	0.685
Ln(Comp10)	Log of average price of closest 10 properties sold in the past year	11.783	0.587
*DT*0	1 if date of sale *is prior* to onset of SNF shipment (8/1994), else 0	0.10	0.31
*DT*1	Short run: 1 if sale after onset of shipments, but before 1997.	0.22	0.42
*DT*2	Long run (post-1997): 1-*DT*0–*DT*1	0.67	0.47
T	1 if in treatment group (<12 km. from SNF route), 0 otherwise	0.48	0.50
C	1 if in control group (≥ 12 km. from SNF route), 0 otherwise	0.52	0.50
*T*0	Potential treatment group in the Pre-Shipment period=T $\times$ *DT*0	0.04	0.20
*T*1	Assignment to treatment in the short run=$T \times DT1$	0.10	0.30
*T*2	Assignment to treatment in the long run=$T \times$ *DT*2	0.34	0.47
DistanceSNF	Distance to spent nuclear shipment (SNF) rail route (km)	11.63	6.79
DistanceSNF $\times T$	DistanceSNF $\times T$ (km)	2.894	4.075
DistanceSNF $\times T1$	DistanceSNF $\times T \times DT1$ (km)	0.605	2.211
DistanceSNF $\times T2$	DistanceSNF $\times T \times DT2$ (km)	2.029	3.659
DistanceNon-SNF	Shortest distance to rail route other than the SNF rail route (km)	7.578	5.024
DistanceNon-SNF $\times T$	DistanceNon-SNF $\times T$ (km)	4.621	5.858
DistanceNon-SNF $\times T1$	DistanceNon-SNF $\times T \times DT1$ (km)	0.911	3.122
DistanceNon-SNF $\times T2$	DistanceNon-SNF $\times T \times DT2$ (km)	3.313	5.427
Square Feet	Square footage, 1000 sq. ft.	1.893	0.759
Year Built	Year Built (scaled by 1000)	1.971	0.127
HH Income	Median annual household income in census block ($ mn.)	0.054	0.019
% White	Fraction of population in the census block that is white	0.808	0.255
% Black	Fraction of population in the census block that is black	0.165	0.249
% Hispanic	Fraction of population in the census block that is Hispanic	0.015	0.035
Bay	Shortest distance to the bay (‘000 km)	0.009	0.007
Building	Shortest distance to major building (‘000 km)	0.007	0.004
Park	Shortest distance to a park (‘000 km)	0.006	0.004
Island	Shortest distance to an island (‘000 km)	0.004	0.003
Stream	Shortest distance to a stream (‘000 km)	0.002	0.001
Cape	Shortest distance to the cape (‘000 km)	0.005	0.004
School	Shortest distance to a school (‘000 km)	0.002	0.002
Church	Shortest distance to a church (‘000 km)	0.002	0.002
Hospital	Shortest distance to a hospital (‘000 km)	0.009	0.008

Note: 1. Sample of 79,650 residential properties sold at least once in Charleston County (SC) during 1992–2005.
2. DistanceNon-SNF variables based on ‘‘Near Rail Route’’ sample of 58,674 properties.

C in such a large sample, we computed them in sub-samples and found the presence of the spatial variable greatly reduced, even if it did not eliminate, spatial correlation.

Before turning to ATT estimates, it is worth noting the importance of the hedonic variables. They are very precisely estimated and have coefficients in the direction we expect. Larger square footage, for example, increases property value. Census-block characteristic measures have the expected signs on their coefficients. Higher income is associated with higher prices in that census-block. In line with a number of other studies, the greater the proportion of the census-block population that is African American or Hispanic, the lower is the property sale price. In the first model, for example, in census blocks where the percentage of black and Hispanic population is 10 percentage points higher, property price are 5.5% and 4.9% lower, respectively. The many statistically significant coefficients on the proximity-to-amenity variables indicate their usefulness as controls. Finally, year fixed-effects capture Charleston-wide annual changes in property price trends. *DT*1 and *DT*2 are absorbed into the year dummies and do not appear explicitly.

We turn to the ATTs in each property band. In the 4 km band around the SNF route, the short-run difference-in-differences (vis-a-vis the control properties beyond 18 km from the SNF route) τ^S is estimated to be -0.062. It is statistically significant at the 1% level. The long-run ATT τ^L is estimated to be -0.133, also statistically significant at 1%. ATTs for properties in the [0,4) and [4,8) km bands are larger than in the furthest band. There are two distinct reasons for this pattern. First, the further are treated properties from the SNF route the lower is the perception of risk exposure to SNF shipments. Second, the further are treated properties from the SNF route the closer they are to the control group of properties, making the difference-in-differences smaller.

Since the long-run ATT τ^L dies out in the [8, 12) km band, we choose 12 km to define the boundary between properties assigned by the SNF natural experiment to treatment and control groups. The specific cutoff used to assign treatment and control properties in Table 3 is not important for this result: it is robust to the choice of either 15 km, 18 km or 22 km In all cases, the long-run ATT disappears beyond 12 km. Finally, we note that the long-run ATT is larger than the short-run ATT. The *z*-statistic at the bottom of the table tests this hypothesis, and rejects equality of the two ATTs (except of course in the last column where both the long- and the short-run ATTs approach zero). The result that the long-run ATT significantly exceeds the short-run ATT is robust across the variety of models we estimate.

Table 3
Average treatment effect on the treated (ATT), in bands of properties. Pooled cross-section data: OLS.

		Treatment: bands around SNF route		
Variable type	Variable/Coefficient	[0, 4) km	[4, 8) km	[8, 12) km
Spatial	Ln(Comp10)	0.462***	0.464***	0.506***
		[0.009]	[0.010]	[0.008]
ATT	τ^S	−0.062***	−0.035	0.006
		[0.020]	[0.024]	[0.022]
	τ^L	−0.133***	−0.076***	−0.013
		[0.020]	[0.022]	[0.022]
	T	0.086***	0.104***	0.035
		[0.022]	[0.024]	[0.023]
Property	Square Feet	0.093***	0.102***	0.096***
		[0.005]	[0.006]	[0.006]
	Year Built	−0.098***	−0.108***	−0.138***
		[0.024]	[0.025]	[0.023]
	HH Income	4.097***	3.326***	0.44
		[0.280]	[0.399]	[0.306]
Census block	% White	−0.251***	0.102	0.026
		[0.083]	[0.099]	[0.095]
	% Black	−0.553***	−0.146	−0.303***
		[0.083]	[0.100]	[0.095]
	% Hispanic	−0.490***	0.076	−0.341***
		[0.104]	[0.114]	[0.115]
Amenities	Bay	1.804	−5.299***	−4.675***
		[1.266]	[1.371]	[1.095]
	Building	−0.43	−3.912***	−4.171***
		[1.182]	[1.306]	[1.220]
	Park	3.648**	0.371	−0.292
		[1.482]	[1.521]	[1.363]
	Island	−4.605**	−1.882	4.591*
		[2.171]	[2.550]	[2.657]
	Stream	−6.079	−15.43***	−0.904
		[3.999]	[4.570]	[4.104]
	Cape	3.284**	−0.788	−3.944*
		[1.519]	[1.595]	[2.013]
	School	10.13***	12.46***	21.66***
		[2.905]	[3.321]	[3.423]
	Church	22.47***	13.69***	4.527*
		[2.785]	[2.965]	[2.628]
	Hospital	−4.656***	−2.498***	−3.719***
		[0.837]	[0.915]	[0.882]
	Year-FE	Yes	Yes	Yes
N		27,340	20,914	27,639
Adj. R^2		0.472	0.432	0.397
# Regressors		32	32	32
z-stat. for Ho: $\tau^L = \tau^S$		4.418***	2.319***	1.183

Notes: 1. Robust standard errors. ***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively.
2. Treated properties within the distance band (above) around the SNF route; control properties lie > 18 km from the route.
3. "S" indicates short-run post-shipment period 9/94–12/97; "L" indicates long-run period 1/98–12/05.

5.1.2. Core ATT results

Table 4 presents our core ATT results from models (2) and (4). They demonstrate robustness of the results to (i) the full sample as well as the "Near Rail Routes" sample, and (ii) the model with and without the spatial control. Consider estimates with the spatial control COMP10 using the full sample of 79,650 property sales in the first column. The short-run average treatment effect of the SNF shipments is estimated to have been a 4.1% reduction in property values, while the long-run ATT of the shipments τ^L is twice this magnitude, or 8.0%. The difference between the short- and long-run ATTs is statistically significant at 1%. The long-run 8% decrease is a nontrivial reductions in property values: by these estimates, the SNF program lowers the price of a $150,000 property located within 12 km of the shipment route by $12,000 over the long run. For the hundreds of thousands of homes in Charleston County alone, the total property loss may run into billions of dollars.

As shown in the distance-band models, properties further from the route should have ATTs close to zero as the influence of the shipments diminishes, while those closer to the route experience the greatest diminution in prices. The second column produces precise, per kilometer estimates, of this distance effect. While the short run distance effect τ_D^S was statistically insignificant (which differs from the GJS finding of a statistically significant short-term effect of similar magnitude), the long-run effect τ_D^L is precisely estimated. The ATT for property i is estimated to be $(-0.117 + 0.006 \times \text{DistanceSNF}_i)$. Thus, our estimate is that a property 1 km from the route changed −11.1% in value on

Table 4
Core results: ATT w and w/o distance effects dependent variable: Ln(Sale Price).

	With spatial control				*Without spatial control*			
	Full sample		*Near Rail Routes*		*Full sample*		*Near Rail Routes*	
Ln(Comp10)	0.512***	0.506***	0.479***	0 477***				
	[0.006]	[0.006]	[0.007]	[0.007]				
τ^S	−0.041***	−0.055***	−0.027	−0.040*	−0.092***	−0.132***	−0.056***	−0.093***
	[0.012]	[0.018]	[0.018]	[0.022]	[0.013]	[0.019]	[0.019]	[0.022]
τ^L	−0.080***	−0.117***	−0.071***	−0.109***	−0.213***	−0.270***	−0.179***	−0.241***
	[0.012]	[0.017]	[0.017]	[0.020]	[0.012]	[0.017]	[0.017]	[0.020]
T	0.066***	0.040**	−0.044**	−0.041*	0.196***	0.099***	−0.028	−0.040*
	[0.0116]	[0.017]	[0.018]	[0.022]	[0.012]	[0.017]	[0.019]	[0.022]
τ_D^S		0.003		0.002		0.007***		0.006**
		[0.003]		[0.002]		[0.003]		[0.003]
τ_D^L		0.006***		0.006***		0.010***		0.010***
		[0.002]		[0.002]		[0.002]		[0.002]
$T \times D$		0.003		0.0002		0.012***		0.003
		[0.002]		[0.002]		[0.002]		[0.002]
τ_D^S (non-SNF route)			−0.003	−0.003			−0.004*	−0.003
			[0.002]	[0.002]			[0.002]	[0.002]
τ_D^L (non-SNF route)			−0.002	−0.002			0.001	0.002
			[0.002]	[0.002]			[0.002]	[0.002]
$T \times D$ (non-SNFroute)			0.015***	0.012***			0.031***	0.024***
			[0.002]	[0.002]			[0.002]	[0.002]
N	79,650	79,650	58,674	58,674	79,698	79,698	58,706	58,706
Adj. R^2	0.445	0.445	0.486	0.486	0.359	0.363	0.418	0.419
# Regressors	32	35	35	38	31	34	34	37
$ATT^{LR} - ATT^{SR}$	−0.039***	−0.039***	−0.044***	−0.045***	−0.121***	−0.117***	−0.123***	−0.122***
Non-SNF ($\tau_D^L - \tau_D^S$)			0.001	0.001			0.005***	0.005***

Notes: 1. See Notes to Table 3.
2. Models include but do not report property, census block, and amenity characteristics + year FE.
3. ATT^{SR} and ATT^{LRare} the short- and long-run ATTs, respectively. In models w/o SNF route distance effects, they are simply τ^S and τ^L, respectively. In the distance effect models, they are evaluated at the mean distance of treated properties from the SNF route.

account of the SNF program, while a property 10 km from the route diminished −5.7%. At the mean distance for treated properties of 6.052 km, the diminution in property value is the same as the ATT in the first model, or −8.0%. The (homogeneous) ATT is therefore interpreted as the treatment effect on a property located at the "average" distance from the route among treated properties.

The "Near Rail Routes" sample has the same treatment group as the full sample, but includes only the subset of control group properties that are less than 12 km away from a non-SNF rail route. The control group therefore also picks up the disamenity (the negative placebo effect) of being near a rail route per se. The third column indicates that the ATT continues to be both statistically and economically significant: the long-run ATT of the SNF program is −7.1%. Thus, the program's long-run impact is robust to placebo control. The fourth column shows that this sample produces almost the same distance-from-the-SNF-route effect and the impact of the program on each property that was found using the full sample. This sample also informs us whether the distance effects observed with respect to the SNF route are also observed for the non-SNF route. The estimates on the non-SNF route τ_D^S and τ_D^L are both statistically no different from zero. Unlike the post-shipment distance effect from the SNF route, the distance effect from the non-SNF route remained unchanged from that which existed before the shipments started.

The models with COMP10 included do not suffer from spatial correlation in the data, and provide our preferred estimates for the ATTs. However, as we have mentioned, controlling for COMP10 may absorb some of the "true" treatment effect. Owners may argue that their home price is depressed because the comps are all selling for less, and that the comps sold for less due to the treatment. The correct ATT then requires dropping the price of comps in the analysis. The last four columns mirror the first four columns, but without the spatial control COMP10. The magnitudes of the ATT estimates without the comps are sharply higher than the ATTs with the spatial control. The long run ATT of the SNF program is estimated to be −21.3% in the full sample and −17.9% in the "Near Rail Routes" sample, depressing prices by two to three times as much as the diminution estimated by the comps models. On the other hand, omitting COMP10 produces spatial correlation in the error term. Perhaps the real value of reporting the (possibly biased) estimates without the comps is to indicate that the true ATT is probably higher than in the model with the comps, but lower than without.

In sum, the pooled cross-section evidence overwhelmingly rejects the null hypothesis of no treatment effect from the SNF shipments over the long run. The negative quantitative impact of the SNF shipments is striking, especially for

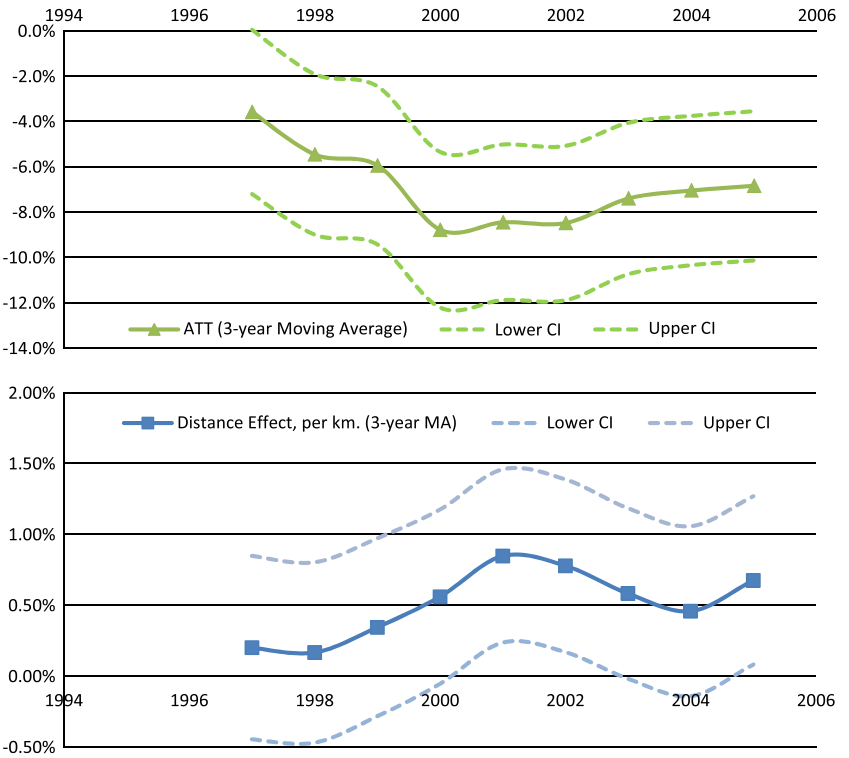


Fig. 3. Annual average treatment effects (ATT) and two-standard deviation confidence intervals: 3-year (sample-weighted) moving average. Top panel: average treatment effect for treated properties (% of sale price). Bottom panel: distance effect in ATT: % increase in sale price of treated properties per km away from SNF route.

properties closer to the SNF route. Regardless of the sample or specification to which one subscribes, the estimated impact on property prices is nontrivial.

5.1.3. *ATT evolution*

How did the ATTs evolve over time, and have they reached a steady state? Whether the ATT has converged after more than ten years of experience with the SNF shipments is an important policy question, and also an essential ingredient into any valuation exercise. We answer this question by interacting T with the full set of year dummies from 1995 to 2005 to see how the treatment effect varies over time. In Fig. 3 the result is plotted as a three-year moving average of the coefficients on the interactions with the year dummies, along with their two-standard deviation confidence intervals.[18] The top panel indicates that the ATT dipped from -3.6% in 1997 to almost -9% in 2000. Since 2003 it appears to have settled at around -7%.

The bottom panel of Fig. 3 traces the evolution of the distance effect, expressed here per kilometer a property is located from the shipment route. The graph indicates three phases: an increasing price premium on locating away from the route peaking at 0.85% per km in 2001, a decrease in that premium bottoming out at 0.46% per km in 2004 and an increase in 2005. The long-run effect seems to be converging to around 0.6% per km, similar to our core Table 3 result. The smaller annual samples lead to less precise estimates of the distance effect than the full-sample estimates in Table 3—the confidence intervals include zero for more than half the years. Still, the results appear to describe learning in the property market about risk perceptions from the SNF shipments over this period. A possible conclusion about the periods for which the confidence intervals included zero is that learning about the distance premium was itself imprecise. We note that the annual distance effects estimated in models without the spatial control COMP10 are all statistically significantly greater than zero, and approximately twice the magnitude of the effects reported in Fig. 3. Those results are available from the authors.

5.1.4. *Falsification test*

A key assumption needed for the difference-in-differences method to identify the treatment effect is that the treatment and control groups both have common time trends in the absence of treatment. We use a falsification test to affirm that this is indeed true. Since we have multiple years of data prior to the start of the SNF shipments, we can estimate model (2)

[18] These are sample-weighted averages, where the DID for year t is weighted by the number of properties in the sample in year t. The confidence interval are similarly constructed.

Table 5
Identification: falsification test with pre-shipment data dependent variable: Ln(Sale Price).

	W/spatial	*W/o spatial*
Ln(Comp10)	0.422***	
	[0.0173]	
$d^{\text{"PRE"}}$	−0.033	−0.041
	[0.040]	[0.040]
T	−0.059	0.097***
	[0.038]	[0.037]
$d^{\text{"POST"}} \times T$	0.137***	0.034
	[0.036]	[0.035]
Square Feet	0.171***	0.216***
	[0.011]	[0.011]
Year Built	−0.877**	−0.863*
	[0.445]	[0.479]
HH Income	2.048***	5.046***
	[0.528]	[0.541]
% White	0.227	0.277*
	[0.159]	[0.161]
% Black	−0.128	−0.222
	[0.162]	[0.164]
% Hispanic	−0.206	−0.149
	[0.168]	[0.178]
Amenities	Yes	Yes
Year-FE	Yes	Yes
N	7867	7915
Adj. R^2	0.293	0.225
# regressors	21	20

Note: 1. OLS, robust errors. See Notes 1 and 2 to Table 3.
2. Pre-shipment sample: from 1992 through 8/1994. $d^{\text{"POST"}}=1$ if property sold after 1/1993.
3. Treated properties ($T=1$) within 12 km, of the SNF route; 41% "treated" and 59% "control".

using only data before the start of the shipments (8/1994), with 1/1993 as a "placebo" treatment cutoff. If the assumption about common trends is valid, there should be no significant treatment effect using only this data (see e.g. [36]).

Table 5 reports results from the falsification test. In the model without spatial controls the ATT is statistically not significant, suggesting no important differences in the time trends of control and to-be-treated properties prior to knowledge of the SNF shipments. The model with comps shows a statistically significant ATT but in the *opposite* direction to our core ATT results. If there were differences in the time trends of control and to-be-treated properties prior to the shipments, then the shipments reversed these trends. It is possible that the difference in the ATT estimates in the models with and without comps is due to this difference in pre-treatment trends. Subsequent reporting of our results are from the model with comps. We note that in every case the models without comps produce the same contrast as we have seen in Tables 4 and 5.

5.1.5. *ATTs for quantiles*

Are ATTs different for properties in different price ranges? We investigate this source of ATT heterogeneity using quantile regressions, and report the results in Table 6. For brevity, results with the shorter sample are omitted here and available from the authors. The short run ATTs are statistically insignificant except for properties priced in the third quartile. The long-run ATTs are statistically significant, and large. At the mean distance of treated properties, the ATT of the SNF program is an expected loss of 10.2% over the long run for properties at the 25th quartile, of 5.0% for properties at the median, and of 3.1% for properties at the third quartile. Higher-priced properties appear to be a bit more resilient, but not by much. A 3.1% price decline for properties priced above $300,000 is a significant reduction in value.

5.2. *Panel data*

Data on repeated sales of properties are not easy to find. Even in the rare instance that they are available, the absence of identifying information about the property such as address or cross-streets-plus-zip-codes makes them less useful. Hence the tradition in the literature assessing the impact of environmental disamenities is to use a (pooled, if possible) cross-section of properties and available hedonic variables as controls, as we do above. However, even an extended list of controls cannot fully account for the heterogeneity in the cross-section. A feature that distinguishes this from other studies is that we have available detailed identifying information on the properties. We use that to construct three panel data sets: one consisting of properties that were sold at least twice during the 1992–2005 period (sample size=46,632 with 19,940 distinct units); another consisting of properties that were sold at least thrice ($N=17,877$ with 5523 units); and a third consisting of properties that were sold at least four times during this period ($N=4926$ with 1191 units). The panels

Table 6
Robustness: quantile regressions dependent variable: Ln(Sale Price).

	Quantiles		
	0.25	0.5	0.75
Ln(Comp10)	0.633***	0.597***	0.473***
	[0.007]	[0.004]	[0.004]
τ^S	−0.047	−0.027	−0.049***
	[0.030]	[0.017]	[0.017]
τ^L	−0.155***	−0.079***	−0.054***
	[0.026]	[0.016]	[0.016]
T	0.085***	0.012	−0.051***
	[0.026]	[0.016]	[0.015]
τ_D^S	0.004	−0.0001	0.001
	[0.004]	[0.002]	[0.002]
τ_D^L	0.009***	0.005**	0.004*
	[0.003]	[0.002]	[0.002]
$T \times D$	−0.006*	0.004**	0.012***
	[0.003]	[0.002]	[0.002]
N	79,650	79,650	79,650
# Regressors	35	35	35
Pseudo R^2	0.292	0.362	0.383
ATT^{SR} at mean DistSNF	−0.021	−0.028***	−0.043***
ATT^{LR} at mean DistSNF	−0.102***	−0.050***	−0.032***
$ATT^{LR} - ATT^{SR}$	−0.081***	−0.022***	0.011**

Notes: 1. ***, **, * indicate statistical significance at 1%, 5%, and 10%.
2. Models include but do not report property, census block, and amenity characteristics + year FE.

Table 7
ATT from panel data sets full sample. Dependent variable: Ln(Sale Price).

	# Repeated sales ≥ 3					
	≥ 2		≥ 3		≥ 4	
Ln(Comp10)	0.464***	0.460***	0.487***	0.483***	0.525***	0.522***
	[0.012]	[0.012]	[0.018]	[0.018]	[0.034]	[0.034]
τ^S	−0.092***	−0.127***	−0.0094***	−0.139***	−0.077*	−0.11
	[0.0168]	[0.026]	[0.025]	[0.039]	[0.044]	[0.074]
τ^L	−0.187***	−0.289***	−0.174***	−0.288***	−0.166***	−0.263***
	[0.016]	[0.023]	[0.023]	[0.035]	[0.043]	[0.070]
τ_D^S		0.006*		0.007		0.005
		[0.003]		[0.005]		[0.008]
τ_D^L		0.016***		0.018***		0.014*
		[0.003]		[0.004]		[0.008]
N	46,632	46,537	17,877	17,870	4926	4926
# Homes	19,940	19,889	5523	5520	1191	1191
Max # sales	6	6	6	6	6	6
Within R^2	0.470	0.471	0.520	0.521	0.565	0.565
% var due to FE	0.492	0.490	0.453	0.451	0.404	0.401
$ATT^{LR} - ATT^{SR}$	−0.095***	−0.096***	−0.086***	−0.081***	−0.089***	−0.088***

Notes: 1. OLS with property-fixed effects and year dummies.
2. Robust standard errors. ***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively.
3. Treated properties are < 12 km from SNF route; control properties ≥ 12 km.
"S" indicates short-run post-shipment period 9/94–12/97; "L" indicates long-run period 1/98–12/05.
4. See Note 3 to Table 4 regarding SR and LR ATTS.

overcome concerns about time-invariant effects not captured by observed hedonic variables. The pooled model removes variables that do not vary over time or across properties within the treatment or control groups. The panel model removes time invariant attributes, regardless of whether these attributes differ within the treatment or control groups. For example, if building grade is time invariant, correlated with T, but varies across properties even conditional on T, then this is an unobservable that is removed in the panel model but not the pooled cross-section model.

Property fixed effects estimates of the ATT from both samples are presented in Table 7. The long-run estimates of the negative impact of the SNF shipments are larger than their pooled cross-sectional counterparts in Table 4. In the first column the long-run ATT is estimated to be −18.7%, twice the short-term effect here, and more than twice the long-run

ATT (of −8%) from the pooled data. The distance effect τ_D^L is also more than double that from the pooled data, indicating a stronger influence of the shipments on homes proximate to the route. The total effect on home i is estimated to be $(-0.289+0.016 \times \text{DistanceSNF}_i)$. A home located at the mean treatment distance (of 6.233 km) from the route has a long-term treatment effect equal to that in the first column, or −18.7%.

A possible reason for why the panel ATTs differ markedly from the pooled ATTs is omitted variables bias in the pooled data. Property-fixed effects in the panel data control for *all* variables that are time-invariant, while the set of hedonic variables in the pooled cross-section only capture time-invariant influences that are measurable. In particular, in (2) if an omitted time-invariant regressor has a theoretically positive (negative) coefficient, and is positively (negatively) correlated with the assignment to long-run treatment variable $DT2_t \times T_i$, then the absolute size of the coefficient τ^L is diminished. Examples of omitted property-specific variables include number of bedrooms or bathrooms, swimming pool, condition of the building, and building grade. If building grade, for example, is time invariant, correlated with T, but varies across properties even conditional on T, then this is an unobservable that is removed in the panel model but not the pooled cross-section model. Specifically, suppose treated properties are of higher grade than control properties. Since this omitted variable is positively correlated with T, the absolute value of the OLS estimate of τ^L is attenuated in the pooled cross-section.

A second reason is that the panel data includes only those properties that have been sold more than once. If the propensity to re-sell increased after the inception of the SNF shipments, then it provides a new explanation for how the shipments negatively influenced prices for the treated properties. Suppose the distribution of risk aversion among owners is heterogeneous, but the distributions are the same in the treatment and control groups. Exposure to the risk from the SNF shipments induces especially risk-averse owners of treated properties to sell at whatever price they can get, even if this means taking a loss on the property in order to move to a safer location. Owners in the pre-shipment era or owners of control properties in the post-shipment era, on the other hand, do not perceive the same risk and do not need to sell their property on unfavorable terms. Since the onset of the SNF shipments makes this channel of influence salient, the causal mechanism is clearly identified. Perceived risk from the shipment reduces the bargaining power of sellers assigned to treatment but leaves unaltered the bargaining power of other potential sellers. Therefore, the sample consisting of repeat sales produces a larger negative average treatment effect than a sample in which a predominance of single-sale homes mutes this mechanism. The predominance of single-sale properties in the pooled cross-section is evident in the much smaller samples in Table 7 in which they are dropped, as compared with Table 4.

This finds support in Riddel and Shaw's [48] survey of Southern Nevada residents about their perceived mortality risk and willingness to accept the risks related to nuclear waste transportation. Riddel [47] reports that willingness to accept risk varied significantly across population characteristics. Women perceived more risk than men, higher education was correlated with lower risk perception, and older persons perceived greater risk. The pooled cross-section does not include information about the gender and age of the homeowner, and their relation to risk perception. To the extent these characteristics are time-invariant, the DIDs from the panel reflect the disparate attitudes.

The results from the three panel samples produce remarkably similar inferences about the magnitudes of the short- and long-run ATTs. The long-run ATTs are greater by about 8–10 percentage points. As a further robustness check we estimate the models using the "near Rail Routes" panel samples. They produces ATTs similar in magnitude to those reported in Table 7, showing the results are driven by the proximity to the shipment route, not a non-shipment rail route. Finally, the panel allow us to take account of autocorrelation in repeat-sale prices. An AR(1) model of (5) produces estimates of the AR(1) coefficient of over 0.55, which indicate that dynamics may be important.[19] The long-run ATTs from the AR(1) models are estimated to be between −6% and −15.8%.

6. Conclusion

Modern industrial societies produce and manage many types of hazardous materials that may impose risks on those who live near their storage sites and transport routes. While the benefits from industrial and commercial activities that generate hazardous materials may be of sufficient social value to justify those perceived risks, important equity concerns are raised when those perceived risks are involuntary and the potential losses are geographically concentrated. In such cases, fixed values in property may come to reflect lower market valuation attributable to proximity to the hazardous materials. From a property rights perspective, if the imposition of such a cost was verified, then it could be perceived as a "taking" by those who experience the reduced property values. The policy implications of studies that weigh in on this issue are of major consequence.

This paper quantifies the cost of transporting radioactive spent nuclear fuel (SNF), based on property sales data from Charleston, South Carolina over the 1992–2005 period. The SNF shipments began in 1994 and are ongoing. The impact on housing values in the early years of these shipments was studied by Gawande and Jenkins-Smith [17], GJS. We reconsider the evidence in that study. First, the GJS study estimates only the distance gradient – the effect of the distance from the SNF route on the price of a property – but not the absolute effect of the shipment program on the property price, or the treatment effect. We are able to estimate the average treatment effect of the SNF shipment program using appropriate program evaluation methods [22]. Second, the treatment effect measured by GJS ignored trends in prices of comparable properties that were

[19] Due to the differencing, properties that sold twice are dropped, reducing the effective sample considerably.

unaffected by the SNF shipments. We use difference-in-differences comparing affected properties with a carefully chosen control group. Third, we bring to bear both pooled cross-sectional data as well as panel data evidence.

In populous Charleston County we find evidence of a reduction in property prices due to the SNF shipments. Both the pooled cross-section and the panel provide compelling evidence of a negative average treatment effect in properties that experienced heightened risk perception from the SNF shipments program. This treatment effect is long-lived even in the absence of any accident involving the SNF shipments. For properties located within 18 km from the SNF route, the pooled cross-sectional data indicates average treatment effects of between 2.5% and 5% declines in long run property price due to the SNF shipment program. There is strong distance-heterogeneity, so that properties located further from the route are less affected by the shipments. Our estimates may be used to obtain precise estimates of the ATT for specific properties.

Our finding implies that policymakers should evaluate how to mitigate that effect and, when it can be clearly demonstrated, consider compensation for those who bear these costs. The estimate of the total property loss due to the shipments is likely to run into billions of dollars in urban Charleston County. As the nation debates how to store its nuclear waste, at Yucca Mountain or elsewhere, substantial concerns about damages are sure to be raised. Because the policy implications of the findings are enormous, quantitative assessments of environmental impacts need to be carefully developed. Our study contributes methodologically to that end.

We note some limitations applicable to our findings. The effects identified in this study apply to Charleston County, but did not appear to affect other counties on the rail route (GJS [17]). While we can speculate that offsetting amenities may be responsible for these differences, it is possible that effects of SNF transport are not uniform. Some regions may experience negative property price effects, while others may not. We leave this an open question for further research.

Finally, from the point of view of policy, it is not surprising that programs (such as the SNF return program) that generate clear and substantial benefits to society also impose localized costs. In such cases, considerations of both justice and practicality dictate a need to understand the effects and find appropriate policies to address them. Effective policy design thus seems to require a willingness to carefully evaluate and then respond to inadvertent transfers of wealth that result from otherwise sound programs. What policies might the government use to address such concerns? The default might be to argue that under eminent domain, the government need not pay anything. It is not certain that the courts would uphold this claim [25,19,10,54]. Moreover, opposition to transport policies would almost certainly find expression; for example, the state of California has explicitly forbidden a similar transport through that state into Nevada. Therefore, it is not only practical for the government to find a solution before a possible incident triggers claims, but ex ante policy is very likely to make it less onerous for the government and taxpayers. A range of mechanisms from mitigation through insurance and compensation [37,30] in order to address this problem are important areas of further research. In our view, the time for consideration of such policies is before rather than after the large-scale transport of SNF commences within the US. The recent call by President Obama's Blue Ribbon Commission to undertake "Prompt efforts to prepare for eventual large-scale transport of spent fuel and high-level wastes to consolidated storage facilities…" [5]: vii makes this an opportune time to do so.

Appendix A

See Table A1.

Table A1
Descriptive statistics for panel data sample.

	>2 sales			$\geq$ sales			>4 sales		
	mean	sd	within-sd	mean	sd	within-sd	mean	sd	within-sd
Ln(Sale Price)	11.806	0.672	0.431	11.833	0.658	0.476	11.834	0.662	0.510
Ln(Comp10)	11.830	0.577	0.325	11.853	0.561	0.365	11.866	0.570	0.393
*DT*0	0.095	0.294	0.224	0.098	0.298	0.251	0.111	0.314	0.280
*DT*1	0.216	0.412	0.312	0.223	0.417	0.352	0.228	0.420	0.378
*DT*2	0.688	0.463	0.340	0.678	0.467	0.390	0.661	0.473	0.421
T	0.456	0.498	0	0.439	0.496	0	0.398	0.489	0
C	0.544	0.498	0	0.560	0.496	0	0.601	0.489	0
*T*0	0.039	0.193	0.143	0.038	0.157	0.234	0.038	0.189	0.162
*T*1	0.092	0.290	0.205	0.092	0.290	0.227	0.088	0.284	0.236
*T*2	0.324	0.469	0.227	0.308	0.461	0.252	0.272	0.445	0.259
DistanceSNF	11.854	6.576	0	11.947	6.285	0	12.300	5.686	0
DistanceNon-SNF	10.990	7.557	0	10.971	7.237	0	10.863	6.876	0
N	46,537			17,870			4926		

Note: 1. Charleston County (SC) residential properties sold between 1992 and 2005.
2. *N* is the sample size.
3. See Table 1 for definitions of variables and their units.

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EFFECTS OF NUCLEAR POWER PLANTS ON RESIDENTIAL PROPERTY VALUES*

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1. INTRODUCTION

Over the past several decades there has been growing opposition to nuclear power plants, intensified by the March, 1979, accident at the Three Mile Island (TMI) plant near Harrisburg, PA. If many people are genuinely concerned over the health and safety aspects of nuclear power, logic suggests that when confronted with a choice for residential location, they would not choose to live (purchase property) near a nuclear power plant unless they expect some form of compensation. Compensation could arise when long-term locational or site disamenities, such as those arising because of proximity to a nuclear power plant, are capitalized negatively into property values, or when there are expectations of payments for possible property damages.[1]

This paper presents the results of two studies: the first examines the effects on residential property values of four nuclear power plants in the Northeastern United States before the March, 1979, TMI accident; the second examines the effects on property values in the vicinity of the TMI plant following that accident.

Valuing locational disamenities by examining their negatively capitalized effects on property values has been widely applied in recent years to environmental intrusions such as air and noise pollutants.[2] These studies are based on the hedonic price model developed by Freeman (1974), Griliches (1971), and Rosen (1974), whereby sale prices are regressed on a set of explanatory variables.[3] Specifically,

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[1]The expectation of future damage awards from federal, state, and/or private insurance sources should be positively capitalized into property values, thus partially or fully offsetting negative effects. In the absence of any historical precedence for awards for property value effects, including (as of this date) the TMI accident, it would seem that such expectations would be very low. Moreover, if awards are tied to a property and not an owner, new purchasers after an accident would not be eligible and no positive capitalization would occur. For a more detailed discussion of these points, including the transitional gains trap elaborated by Tullock, see Nelson (1981).

[2]For a review of the rather extensive literature on this subject see Freeman (1979a, 1979b).

[3]Nelson (1975) provides a good summary of the conceptual economic framework and the development of the basic theoretical model of housing markets.

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the various attributes or characteristics of a house serve as surrogates for the flow of services provided by that house (and its location) when attempts are made to relate housing price to service flows. This follows from the belief that people, in choosing their house and its location, reveal their preferences by their willingness to pay for certain housing and locational characteristics. If people value quiet, nearness to employment, or relief from a potential hazard, the real estate market should reveal these preferences.

An economic relationship must therefore exist between market price and the quality and quantity of housing service that any given dwelling provides the occupant. Location is one attribute that can provide a number of such services: nearness (accessibility) to employment, schools, and shopping; as well as distance or remoteness from undesirable environmental variables such as noise, congestion, odors, or perceived hazards from a nuclear power plant. This relationship implies that for consumer equilibrium in the housing market, price differentials must arise among various locations which compensate consumers for the differences in housing services associated with specific locations. Otherwise, consumers would not remain at particular locations and locational choice for new entrants would be restricted. Because of mobility and the ability to buy and sell in the housing market, consumer equilibrium requires that for identical housing in all respects at two different locations, except that location 1 is near a nuclear plant and location 2 is well removed, the price of housing at location 1 must be less than that at location 2 by an amount which will just compensate buyers for the additional hazards they perceive at location 1. Otherwise, the consumer would be better off at location 2. Hedonic prices represent compensating price differentials, since individuals are assumed to choose locations such that price differences among different housing and site characteristics are equalized at the margin (equilibrium willingness to pay).[4]

We used hedonic price equations to test the hypothesis that residential property values are directly related to distance from nuclear power plants (the closer to a plant the lower the values, ceteris paribus). Multivariate regression analyses were used to obtain estimates of the implicit or hedonic prices of housing characteristics. A simplified linear economic relationship would take the form

$$(1) \qquad V_i = b_0 + b_1X_{1i} + b_2X_{2i} + \cdots + b_nX_{ni} + u_i \qquad (i = 1, \ldots, N)$$

where V is selling price of the ith house in dollars; $X_1, \ldots, X_n$ are the variable amounts of the housing characteristics, including distance from the nuclear plant or other plant related variables; $b_1, \ldots, b_n$ are the implicit prices to be estimated; b_0 is a constant term; and u is a stochastic error term reflecting possible omitted variables, measurement errors, and market variations.

In order to show the effect, if any, of proximity to a nuclear plant on the value of housing, it is important to include in the analysis as many variables as possible among those that a priori are known to affect housing prices. The method depends on a causal relationship, not merely one of association. Potentially, a large number

[4]There is some controversy over the basic assumptions underlying the hedonic price model, which we will not discuss here. For elaboration see Freeman (1979a) and Pearce (1978).

of variables contribute to housing price differences within any market area. These variables include characteristics of the house and lot, such as floor area and size of lot; indicators of accessibility such as distance to employment centers and major highways; locational variables such as land use mix and neighborhood characteristics; and public sector descriptors such as availability of utilities, tax ratios, and land use controls.[5]

The authors are aware of only one study which statistically examines the effect of nuclear power plants on property values.[6] Two studies examined the effects of fossil-fueled power plants on property values, both of which reported positive results.[7] Webb (1980) surveyed 26 residents within five miles of a nuclear plant in the Midwest following the TMI accident. Fifteen *thought* their property has sustained a loss in value. Using equalized assessed real property values as a proxy for growth, Gamble (1980) studied 64 communities near four nuclear power plants in the Northeast. There was no adverse impact on growth; after the plants became operational the rates of growth in the communities nearest the plants exceeded the rates for the more distant communities, a reversal of the growth rate trends before the plants were constructed.

Section 2 of this article discusses the method used to determine property value effects. Section 3 reports on a study completed prior to the TMI accident of March, 1979, which examined property value effects of four nuclear power plants in the Northeastern U.S. Section 4 presents the findings of a second study that was carried out to determine the effects of the TMI accident on residential property values. Section 5 presents the conclusions and a discussion of the results.

2. METHOD

The linear and log-log functional forms of the multiple regression model were used to explain variation in the selling price of housing, expressed as follows:

$$V_i = b_0 + \sum_{j=1}^{n} b_j X_{ij} + \mu \tag{2}$$

$$\ln V_i = \ln b_0 + \sum_{j=1}^{n} b_j \ln X_{ij} + \mu \tag{3}$$

where

V_i = the deflated selling price of the ith residential property,
b_0 = constant term,
X_{ij} = independent variables from 1 to n associated with the ith property, and
μ = an error term, assumed to be randomly distributed, reflecting all other unexplained variations.

[5]Characteristics of the occupants, such as income, should not be used in hedonic price equations.

[6]Nelson (1981) examines the effects of the TMI accident on housing prices in two small residential communities.

[7]Blomquist (1974) studied a plant in Chicago and Jack Faucett Associates (1976) studied a plant in a rural section of Maryland.

The dependent variable is the actual market selling price of houses corrected for inflation.[8] The California Statistical Procedures Computer Programming Package (1977), using the Breaux (1968) modification of the Effroymson (1960) algorithm and developed specifically for property value analysis, was used to screen and select the independent variables. Data were gathered on all those variables which the literature and property value effects studies have shown as having likely important causal effects on property values. We could have specified some or all of these variables in a regression equation, but for some variables there was either not enough variation or enough observations for the coefficient estimate to be reliable based on the degrees of freedom for each variable. We specified a minimum of six observations for each variable. Multicollinearity is another specification problem that is reduced by use of the algorithm. Further, using the algorithm avoids specifying an equation which may contain bias by including variables that the researcher feels are important in explaining property value effects.

In this algorithm each variable, as entered, is tested against all variables. The test is the reduction in the standard error of the estimate, variables with the greatest reduction being entered first. All variables are tested to assure that the t-value for that variable exceeds 2, a value that was chosen so as to obtain a significance level of at least 5 percent for all variables in the final regression equation. A variable is removed by the algorithm if it fails this test. The search continues for new variables from among all variables, including those previously removed. Thus, the final equation resulting from the algorithm is one in which all variables are significant. The significant variables were then used in the Statistical Analysis System (SAS) regression package (GLM) for the remainder of the analysis to test the hypothesis that property values are directly related to distance from the plant; i.e., properties close to a nuclear plant have lower values than more distant properties, all other factors being equal. When nuclear plant related variables were not selected by the algorithm as being significant in explaining property value differences, we forced them into an equation using the SAS package to see what their levels of significance were and to see what effects their introduction had on the other independent variables.

3. PROPERTY VALUE EFFECTS OF FOUR NUCLEAR PLANTS

The four plants are: Pilgrim, near Plymouth, MA; Millstone, near Waterford, CN, on Long Island Sound; Oyster Creek in Lacey Township, NJ, along the

[8]Because sales do not occur at the same time, a deflation index was computed to correct for inflationary effects over the sampling period. An initial deflation index, reflecting the average monthly price changes, was used to correct actual sales prices. The month of sale was entered in the regression equation as an independent variable, and the initial deflation index adjusted until the month of sale was no longer significant. The final deflation indexes selected were monthly rates of 0.5 and 0.7 for the two studies, respectively. We feel that this approach provides a more accurate measure of inflationary effects in specific real estate markets than does the use of national average data. In addition, the month of sale variable was entered in all equations as an independent variable.

Atlantic coast; and R. E. Ginna near Rochester, NY on Lake Ontario.[9] Regression analyses are applied to a sample of 540 observations for the four plants. The dependent variable is the actual market selling price of houses that sold between 1975 and 1977 within selected housing developments, corrected by a deflation factor of 0.5 percent per month (see footnote 8). Housing developments that reflected a high degree of homogeneity of lot and house characteristics over the 20-mile distance from each plant were selected; therefore, not all sales during the time period were included.[10]

Sales and property characteristics data were obtained from county or township tax assessment offices or from multiple listing services. Each property in the sample was site inspected and the property descriptors recorded. In total, 76 property, sale, and community characteristics were a priori identified as possibly affecting the sale prices of houses.[11] These characteristics were then used to structure the independent variables for use in the regression equations. The California statistical procedures package selected the significant variables (at a 5 percent or better level).

We used two variables to indicate possible effects of the nuclear plants on property values: variable 33, nuclear plant visible (a binary variable to account for any price discrimination that might have arisen when the nuclear plant was directly visible from the property), and variable 34, distance to plant in miles. These two variables should be negatively and positively significant, respectively, to uphold our hypothesis that nearness to the plant is negatively capitalized into property values.

The results of the separate linear regressions for each plant are shown in Table 1, where all variables significant at the 5 percent or better level are included.[12] The signs of the coefficients are as predicted, except for variable 4, corner lot, in the Oyster Creek equation. Corner lots were common in only two developments in this study area, both of which were older developments containing lower priced homes. This variable probably reflects the lower values associated with these two developments rather than the usually higher values associated with corner lots. The magnitudes of all the remaining coefficients are close to what one would expect.

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[9]These plants were not randomly selected, but were selected from those plants in the Northeast around which we felt property value effects would most likely be evident and around which residential development was quite homogeneous. The results, therefore, cannot be used for predictive purposes.

[10]All plants were fully operational by mid-1972, so any market adjustments to the presence of the plants should have occurred.

[11]For a thorough discussion of the variables including their method of construction, data source, means, and ranges, as well as a more detailed presentation of the data analyses and results see Gamble et al. (1979).

[12]A few of the variables may need further explanation. Variable 5, outstanding view, is 1 if there is a particularly striking unobstructed view of natural features from the lot; 0 if otherwise. Variable 6, view from house, is 1 if there is any view of natural features from the lot; 0 if the lot is surrounded by housing or other developments. House grade refers to the relative quality of materials and design of the house at the time of construction. House condition refers to the level of maintenance given the house over the years. The remaining variables are commonly used in property value regression models and should need no further elaboration.

TABLE 1: Regression Results: Separate Analyses of Four Nuclear Plant Sites in the Northeast

Variable	Predicted Sign	Regression Coefficients (F Value)			
		Pilgrim	Millstone	Oyster Creek	R. E. Ginna
Constant		9,013	14,903	8,863	31,162
2. Built 1969–1977 (b)[a]	+	2,856***		2,435**	
		(11.52)		(9.26)	
3. Lot Depth (ft)	+			55.88***	
				(11.16)	
4. Corner Lot (b)	+			−1,602**	
				(−6.09)	
5. Outstanding View (b)	+		3,796**		10,198***
			(5.08)		(20.00)
6. View from House (b)	+			2,176***	
				(16.71)	
7. House Grade good (b) × Area of Second Floor (ft^2)	+		11.701***		
			(10.03)		
8. House Grade Good (b) × Area of First Floor (ft^2)	+	8.230***	4.801**		
		(32.33)	(5.23)		
9. House Condition Poor (b)	−		−4,589**	−2,650***	
			(−6.55)	(−7.82)	
10. House Condition Good (b)	+			3,446***	
				15.86)	
14. Distance to Major Employer (miles)	−			−244.43***	−956.46***
				(−42.24)	(−64.37)
17. Month of Sale (Month)	±			103.43***	
				(17.35)	
18. Area of First Floor (ft^2)	+	11.128***	15.217***	9.714***	8.702***
		(20.88)	(47.84)	(95.15)	(14.14)
19. Area of Second Floor (ft^2)	+	5.126***	13.523***	12.872***	6.240***
		(15.40)	(46.32)	(26.92)	(8.76)
20. Area of Finished Basement (ft^2)	+			5.346***	
				(8.05)	
21. House on Slab (b)	−		−2.558**		−5,627***
			(−6.00)		(−6.09)
22. Attach Garage (Number of Cars)	+	3,960***		1,164***	
		(28.92)		(4.32)	
23. Detached Garage (Number of Cars)	+	2,024**		2,951***	
		(4.61)		(9.07)	
24. Internal Garage (b)	+	3,009***			
		(7.12)			
25. Fireplaces (Number)	+	3,015***	4,111***	2,764***	7,128***
		(17.56)	(19.32)	(18.03)	(18.14)
27. Stone exterior (b)	+			2,211**	
				(4.71)	
28. Bedrooms (Number)	+	1,543***			
		(7.40)			
29. Lot Area (ft^2)	+		0.1718***		
			(10.18)		
30. Water Frontage (b)	+		10,162***	7,927***	
			(20.52)	(182.36)	
R^2		.809	.761	.874	.706
F		54.131***	55.858***	64.004***	22.778***
SEE		4,311	6,633	2,999	5,075
Residual Degrees of Freedom		115	175	148	57

Notes:
**Significant at the 1–5 percent level.
***Significant at the 1 percent or better level.
[a](b) refers to a binary variable.

Differences in the magnitudes of a coefficient among study areas reflect the housing and community characteristics associated with each area plus the fact that the same variables are not important in each equation.

All the equations are significant at the 1 percent or better level, and they explain between 70 and 87 percent of the variation in housing prices. As is to be expected, the same variables do not explain variations in housing prices in all four areas (only if the housing and community characteristics in all four areas were almost exactly alike would the equations be similar). There are several reasons for this variation. First, there are study area differences in the basic housing stock. For example, there are very few seasonal homes near the R. E. Ginna plant as compared to the three other plants. Second, there may not be enough observations for a particular variable within a study area for that variable to become significant. For example, in the Pilgrim, Millstone, and Ginna study areas there were only three, five, and two houses, respectively, with stone exteriors (variable 27), whereas in Oyster Creek there were 15 such houses. Third, there may not be enough variation in the measurement of a given variable within a study area for that variable to influence price. For example, in the Pilgrim, Oyster Creek, and Ginna study areas, lot sizes (variable 29) were apparently too uniform to explain differences in housing prices.

The two most important variables to the study, 33 (plant visible) and 34 (distance to plant), are not significant in any of the four study area equations. Based on these results, there is no evidence to indicate that the nuclear plants have any measureable effects, positive or negative, on single family housing prices. The fact that there were different significant variables in the four separate equations does not detract from these findings.

Table 2 presents the regression results when the data from all four study areas are combined,[13] all equations being linear.[14] All variables except numbers 33 and 34 that are significant at the 5 percent or better level (those originally selected by the California statistical procedures program) are included.[15]

The two variables indicating nuclear plant effects on property values (number 33, plant visible, and number 34, distance to plant) are not significant in the regular equation (the first column of data in Table 2). In separate subsequent regressions we forced in these two variables to see: (1) their level of significance, (2) the sign and value of their coefficients, and (3) the effects they had on other coefficients.

When variable 33, plant visible, is forced in it has a positive coefficient of 1,189, a sign that is opposite to that predicted to support the hypothesis and is significant at the 5–10 percent level. The coefficients of only two other variables are

[13]Some researchers have questioned the combining of two or more distinct housing market areas into a common data set to analyze hedonic price relationships. A recent study by Butler (1980) points out that the hedonic relationships of different metropolitan areas are considerably more alike than has generally been thought. We assume this to be true for our areas as well.

[14]The log-log form of the equation for the pooled data was specified, but the results did not improve the explanatory ability of the variables over the linear form. Both the R^2 and F values for the log-log form were slightly lower than those for the linear form.

[15]Variables 31 and 32 refer to subjective evaluations of the quality of community beach associations which have made certain kinds of improvements, membership in which is contingent upon owning property within a certain development.

TABLE 2: Regression Results: Combined Analyses of Four Northeastern Nuclear Plants

Variable	Predicted Sign	Regression Coefficients (F values) Regular	Variable 33 Forced In	Variable 34 Forced In
Constant		19,509	19,363	19,588
1. Built Before 1914 (b)[a]	–	−3,462***	−3.604***	−3.498***
		(−7.95)	(−8.63)	(−8.06)
2. Built 1969–1977 (b)	+	2,233***	2,236***	2,229***
		(14.72)	(14.83)	(14.63)
6. View from House (b)	+	1,346***	1,151*	1,324**
		(4.86)	(3.47)	(4.65)
7. House Grade Good (b) × Area of Second Floor (ft^2)	+	7,797***	7,706***	7,756***
		(11.58)	(11.36)	(11.42)
8. House Grade Good (b) × Area of First Floor (ft^2)	+	6,139***	6,256***	6,220***
		(22.51)	(23.43)	(22.43)
9. House Condition Poor (b)	–	−2,368***	−2,216**	−2,320**
		(−6.85)	(−5.98)	(−6.43)
11. On Unpaved Road (b)	–	−1,437**	−1,392**	−1,427**
		(−5.18)	(−4.87)	(−5.09)
12. On Major Highway (b)	–	−2,118**	−2,093**	−2,111**
		(−5.68)	(−5.57)	(−5.64)
13. Distance to Swim Area (Miles)	–	−241.00**	−253.15***	−240.29***
		(−20.13)	(−22.00)	(−19.95)
14. Distance to Major Employer (Miles)	–	−195.96***	−188.02***	−191.54***
		(−38.49)	(−34.96)	(−32.16)
15. Distance to Limited Access Highway (Miles)	–	−532.41***	−534.54***	−527.46***
		(−59.81)	(−60.56)	(−56.50)
16. Distance to State Park (Miles)	–	−350.37***	−357.90***	−362..74***
		(−18.04)	(−18.87)	(−16.61)
18. Area of First Floor (ft^2)	+	11.436***	11.409***	11.396***
		(151.72)	(151.719)	(148.448)
19. Area of Second Floor (ft^2)	+	10.333***	10.236***	10.318***
		(110.59)	(108.72)	(109.89)
20. Area of Finished Basement (ft^2)	+	3.574***	3.671***	3.589***
		(9.86)	(10.433)	(9.915)
21. House on Slab (b)	–	−1,466**	−1,508**	−1,448*
		(−5.18)	(−5.50)	(−5.01)
22. Attached Garage (Number of Cars)	+	2,257***	2,279***	2,283***
		(29.37)	(30.07)	(29.16)
23. Detached Garage (Number of Cars)	+	2,230***	2,201***	2,224***
		(17.92)	(17.52)	(17.77)
24. Internal Garage (b)	+	2,107***	2,147***	2,113***
		(10.34)	(10.78)	(10.38)
25. Fireplaces (Number)	+	2,509***	2,495***	2,500***
		(26.31)	(26.16)	(26.03)
26. Central Heating (b)	+	1,688**	1,849**	1,704**
		(4.58)	(5.46)	(4.65)
29. Lot Area (ft^2)	+	0.0571***	0.0551***	0.0571***
		(7.51)	(7.01)	(7.49)
30. Water Frontage (b)	+	8,104***	7,950***	8,104***
		(114.43)	(109.37)	(114.26)

TABLE 2: Continued

Variable	Predicted Sign	Regression Coefficients (F values) Regular	Variable 33 Forced In	Variable 34 Forced In
31. Average Beach Association (b)	+	2,577***	1,917*	2,517***
		(7.31)	(3.57)	(6.77)
32. Good Beach Association (b)	+	3,696***	3,642***	3,682***
		(8.40)	(8.19)	(8.31)
33. Plant Visible (b)	−		1,189*	
			(3.48)	
34. Distance to Plant (Miles)	+			−20.296
				(−0.14)
R^2		.8055	.8068	.8056
F		85.166***	82.419***	81.759***
SEE		5,295	5,282	5,299
Residual Degrees of Freedom		514	513	513

Notes:
*Significant at the 5–10 percent level.
**Significant at the 1–5 percent level.
***Significant at the 1 percent or better level.
°(b) refers to a binary variable.

simultaneously affected to a significant degree: view from house (Number 6) decreases in value about $200 and in significance from the 1–5 percent to 5–10 percent level, and average beach association (Number 31) decreases $660 in value and in significance from the 1 percent or better level to the 5–10 percent level. It is quite obvious that variable 33 is strongly related to variables 6 and 31, because of the change in sign from that hypothesized for variable 33 and the simultaneous decrease in values of the coefficients for variables 6 and 31.

The third column shows the results when variable 34, distance to plant, is forced in. Its coefficient is not significant and is also negative, a sign opposite to that expected. None of the other coefficients in the equation are strongly affected.

The hypothesized negative effects of the plants on property values were not revealed by variables 33 and 34. The conclusion of the regression analysis, based on sales data for 540 single family homes near the four nuclear power plants, is that no evidence exists to support the hypothesis that these nuclear power plants had an adverse effect on residential property values.

4. EFFECTS OF THE TMI ACCIDENT

Following the March 28, 1979, accident at the TMI nuclear plant near Harrisburg, PA, a concern frequently mentioned was a decrease in real property values in the vicinity of the plant. Our purpose now is to measure this effect. Here we use a sampling approach different from that used in Section 3. Sales of 583 single family homes within 25 miles of the plant, and of 112 homes in a control area

TABLE 3: Effects of TMI Accidents on Property Values

Variable	Expected Sign	Regression Coefficients (t value)			
		Before Accident (Linear)	After Accident (Linear)	Before and After Accident (Linear)	Before and After Accident (Log-Log)
Constant		−435	8,964	2,053	3.3937
1. House Built Before 1915 (b)[a]	−	−6,135*** (−4.43)	−5,012* (−1.89)	−6,295*** (−5.18)	−0.0720*** (−3.84)
2. House Built 1915–1933 (b)	−	−4,603*** (−3.36)	—	−4,610*** (−3.77)	−0.0402** (−2.15)
3. House Built 1934–1946 (b)	−	−3,426* (−1.86)	−6,573** (−2.00)	−4,191*** (−2.65)	−0.0705*** (−2.93)
4. House Built After 1968 (b)	+	2,564*** (2.14)	—	1,761* (1.69)	—
5. Lot Frontage (ft)	+	48.54*** (5.78)	—	36.99*** (5.28)	0.1394*** (5.82)
6. Lot on Paved Road (b)	+	—	—	3,865** (2.16)	0.0493* (1.82)
7. House Grade Poor (b)	−	−6,833*** (−3.60)	−10,075*** (−3.75)	−7,475*** (−4.32)	−0.2683*** (−11.35)
8. Public Sewer (b)	+	3,493*** (3.42)	—	2,863*** (3.35)	0.0407*** (3.04)
9. House Grade Good (b)	+	9,380*** (4.19)	6,891* (1.89)	8,563*** (4.62)	0.0684** (2.46)
10. Airport Noise (b)	−	−2,571* (−1.80)	—	—	—
11. Trees on Lot (b)	+	—	3,598** (2.31)	—	—
12. Two Family House (b)	+	6,330** (2.51)	−5,726* (−1.71)	—	−.0585* (1.92)
13. Flood Plain (b)	−	—	−8.257*** (−2.68)	−3,202* (−1.84)	−0.0447* (−1.68)
14. House Condition Poor (b)	−	−3.646*** (−3.01)	−4,033* (−1.89)	−3,691*** (−3.52)	−0.1249*** (−7.84)
15. House Condition Good (b)	+	3,815*** (2.78)	4,782** (2.09)	3,349*** (2.88)	—
16. Floors (Number)	+	4,169** (2.31)	—	3,254** (2.25)	—
17. Bathrooms (Number)	+	2,330*** (3.00)	—+	2,210*** (3.28)	0.1854*** (3.19)
18. Area of First Floor (ft^2)	+	11.26*** (5.92)	10.02*** (3.45)	10.34*** (6.66)	0.2914** (6.33)
19. Area of Second Floor (ft^2)	+	—	—	—	0.0211* (1.99)
20. Attached garage (Number of Spaces)	+	2,298*** (3.20)	3,361** (2.35)	2,845*** (4.52)	0.0894** (2.34)
21. Detached Garage (Number of Spaces)	+	—	3,290** (2.62)	1,289** (2.10)	0.0631* (1.66)
22. Internal Garage (b)	+	—	5,433*** (2.91)	2,341*** (2.66)	—
23. Fireplaces (Number)	+	3,571*** (3.87)	4,447*** (2.84)	4,044*** (5.14)	0.0166*** (3.04)
24. Central Air Conditioning (b)	+	5,684*** (3.02)	—	5,146*** (3.28)	0.0406* (1.66)
25. Modern Kitchen (b)	+	2,739*** (2.69)	—	2,142** (2.45)	0.0423*** (3.21)
26. Stone Front Exterior (b)	+	—	2,864** (2.15)	—	0.0218** (2.04)
27. Tax Rate (per $1,000)	−	−168*** (−2.84)	204* (−1.93)	−196*** (−3.83)	−0.2317*** (−4.56)
28. Bedrooms (number)	+	—	—	1,007** (2.19)	0.0137** (1.97)
29. Distance to TMI (Miles)	+	163*** (2.84)	105† (1.07)	163*** (3.02)	0.0385** (2.27)
30. After Accident (b)	−			924† (0.78)	(−0.0081† (−0.24)

TABLE 3: Continued

Variable	Expected Sign	Regression Coefficients (t value)			
		Before Accident (Linear)	After Accident (Linear)	Before and After Accident (Linear)	Before and After Accident (Log-Log)
31. (Var. 29) × (Var. 30)	-			−74† (−0.76)	0.0102† (0.30)
R^2		.767	.833	.766	.787
F		46.42	19.50	58.14	65.83
Standard Deviation		7,360	6,590	7,276	.1107
Residual Degrees of Freedom		410	113	551	551

Notes:
†Not significant.
*Significant at the 5–10 percent level.
**Significant at the 1–5 percent level.
***Signifcant at the 1 percent or better level.
— Variables entered but have t values less than 1.00.
"(b) denotes a binary variable.

around Williamsport, PA, about 75 miles north of TMI, form the data base.[16] Two time periods were specified from which valid sales were selected: (1) before the accident, from January, 1977, through March, 1979; and (2) after the accident, the last nine months of 1979. Several distance zones around the TMI plant were also specified.[17] Sales were recorded by months, but the actual values were converted to real values (corrected for inflation) by a deflation factor of 0.7 percent per month as determined by an earlier regression (see footnote 8).

The sampling of house sales in the TMI study differed from the method used in the previous four-plant study because of basic spatial differences in growth patterns. The four nuclear plants studied earlier were all located along or very near the coasts of major water bodies (the Atlantic Ocean and Lake Ontario). Growth primarily occurred in a strip fashion along the coasts, with only minor development inland from the plants. In the case of TMI, growth in the Harrisburg SMSA area spread out in all directions from the central city. A time sampling difference in the two studies (one time period in the four-plant study, 1975–1977, and two time periods in the TMI study) was necessary in order to isolate correctly the effects due solely to the accident. We did not assume, just because of the findings from our earlier four-plant study, that the TMI plant before the accident had no effects, positive or negative, on housing prices. To measure properly the accident-induced effects, we would have to take into account the pre-accident effects on prices. Thus

[16]The Williamsport, PA area was selected because of its remoteness from any nuclear power plant and because of its similarity to the TMI area in terms of population growth and density, per capita income, land use mix, and location along the Susquehanna River.

[17]All valid sales in both time periods within three miles of the plant were used. Because of the large volume of sales in the more distant zones, sampling was done. Within 3–5 miles of the plant a random sample of 20 percent of all valid sales was used; from 6–25 miles a random sample of 1 percent was used; and a 5 percent sample was used in the control area. Before the accident sales totaled 505; after the accident sales totaled 190. There were 272 sales within five miles of the plant, of which 70 occurred after the accident.

house sales data were gathered from two time periods, one before and one after the March, 1979, accident.

The analytic procedures used in this study are the same as those used in the earlier study. From the initial list of independent variables, the California statistical procedures package identified those that were significant in explaining variations in house prices either before or after the accident and over the entire time period.

The regression results are shown in Table 3. Before interpreting the results, three variables need further explanation. Airport noise (Number 10), a binary variable, was inserted to account for any price effects by nearness to one of two airports serving the Harrisburg area, one of which, Harrisburg International, almost abuts the TMI plant. All property sales that fall within the NEF 30 noise contour interval for each airport were assigned 1, otherwise 0. There were 41 such sales before the accident, 10 after.

Property sales located on the flood plain (variable 13) were identified from flood plain maps, and were assigned 1, otherwise 0. There were 15 such properties before the accident, seven after. A troublesome fact is that much of the flood plain and the area within the NEF 30 noise contour coincide; also, they are in close proximity to TMI.

Variable 12, two family house, refers to a house which has rooms for rent. There were 17 such observations in the study area assigned a value of 1, otherwise 0.

The variables important for the purpose of this study, those related to the TMI plant and the accident, are numbers 29, 30, and 31. The first column shows the regression results for all property sales occurring before the accident. The variables in this equation all have the anticipated signs, and the magnitudes of the coefficients are reasonable. The important variable in this equation, distance to TMI (Number 29), is highly significant, which means that property values are expected to increase by $163 for each mile that a property is located from the plant; i.e., property values near the plant are lower than values for more distant properties. Whether this is TMI related or not is an important question that will be discussed shortly.

Column 2 gives the results of the regression on property sales that occurred during the nine months following the accident. For all variables except Number 12 (two family house) the signs are as predicted and, in general, the magnitudes of the coefficients are reasonable. The reasons why this variable became negative after the accident may be that: (1) rapidly rising mortgage interest rates during this period may have made people reluctant to invest in such properties for fear that rental income would not cover their costs, and (2) of the six sales of such properties after the accident, the majority may have been in poor condition, thus commanding lower prices. Whatever the reason, it is not accident related, nor are the other differences in the first 28 variables between these two equations explained by the accident.

Variable 29, distance to TMI, is not significant in the after accident data set, leading us to conclude that the accident itself had no apparent effects on housing prices.

Columns 3 and 4 contain results for the linear and log-log functional forms,

TABLE 4: Mean Annual Residential Prices and Number of Sales by Areas, Selected Years 1966–1979

Areas	1966	1970	1973	1975	1976	1977	1978	1979
0–5 miles								
Mean price	10,399	11,298	20,564	25,644	28,588	31,375	34,224	36,473
Number of Sales	296	374	388	351	561	597	415	406
5–25 Miles								
Mean price	13,030	15,970	25,087	28,041	31,420	34,143	37,424	41,463
Number of Sales	11,673	11,267	13,243	8,489	11,529	12,831	12,400	11,111
Control								
Mean price	13,233	17,981	22,832	29,537	30,956	33,111	37,933	40,247
Number of Sales	705	514	715	525	546	749	779	576

respectively, of the regressions run on the complete data set (property sales both before and after the accident). These regressions were run to substantiate further the effects, if any, on house prices. The signs of all the significant variables are in the direction anticipated and magnitudes are reasonable. The log-log form explains somewhat more the variation in selling prices than does the linear form.

Variable 29, distance to TMI, is significant and positive in both equations. Variable 30, after accident (a binary variable), is not significant in either equation, meaning that there were no significant differences in real housing prices in the two time periods. When variable 30 is interacted with variable 29 (after accident $\times$ distance to TMI) to produce variable 31, its coefficient is not significant in either equation.[18]

Based on the significance of the distance to TMI variable in several of the previous equations, it appears that our hypothesis is supported and that the presence of the plant did have an adverse effect on the price of single family homes. Regression coefficients, however, only depict relationships; they do not explain cause and effect. Is the relationship between property values and distance from TMI due to the plant, or is it due to some other phenomenon?

Because of our familiarity with the area, we know that the housing market in the area within a few miles of the plant contains old industrial communities in which older homes on small lots predominate. Mean annual residential sales data from 1966 (the first year in which State Tax Equalization Board data are available) through 1979 show that residential prices within five miles of TMI have traditionally been lower than those in the greater Harrisburg and control areas. These data are given in Table 4 and shown in Figure 1, where the number of sales are all valid sales of single family homes in the respective areas for the indicated year. There appears to be no noticeable effect resulting from the plant opening or from the accident on any of the curves.

Our sample sales data reflect the somewhat lower quality housing in communities near the plant as compared to the more distant communities. Table 5 shows

[18]See McClave and Benson (1979) for an excellent discussion of the use and interpretation of interacting two or more variables in multiple regression.

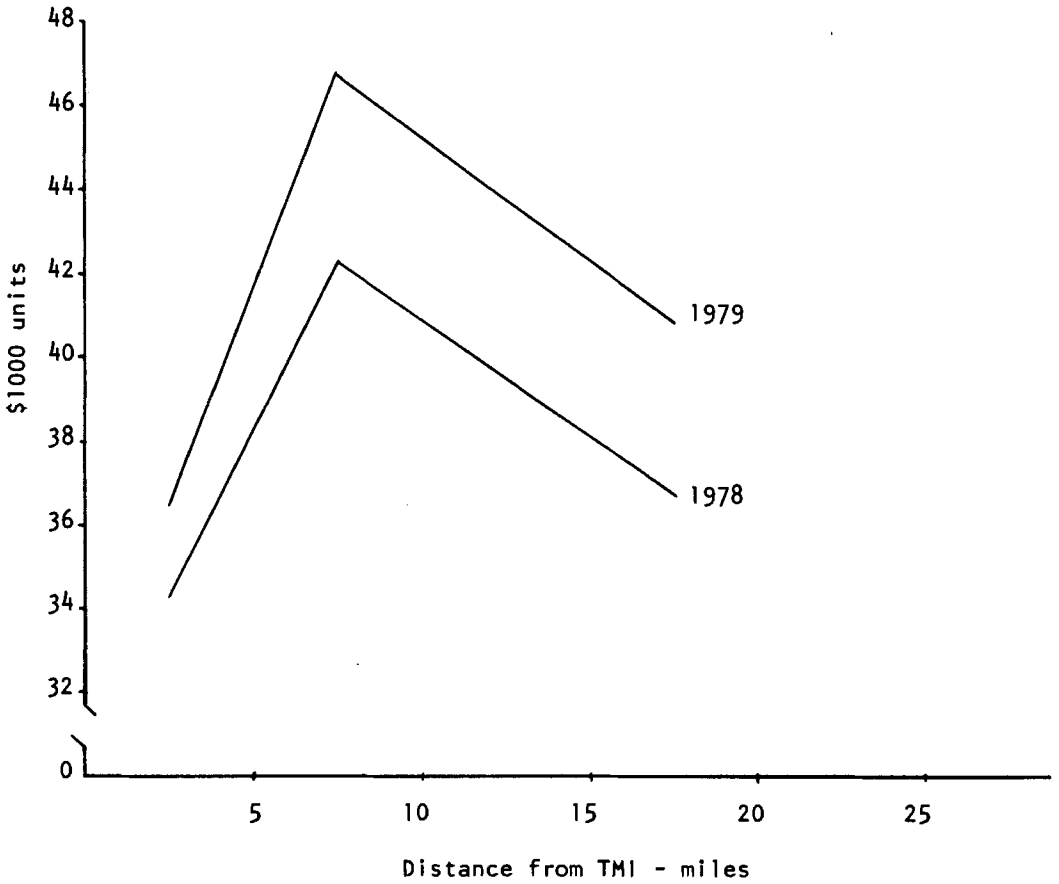


FIGURE 1: Mean Residential Prices, Selected Years, 1966–1979, By Areas.

the proportion of housing in our samples in poor condition and of lower grade by distance zones from TMI, and the average year built.

If community quality characteristics are reflected in the positive and significant distance to plant coefficient, might there be some objective measure of these which could resolve this problem? Data on two variables, available from the 1970 census, might reflect quality: the proportion of houses constructed on or before

TABLE 5: Proportion of Poor Condition and Low Grade Housing in Sample Data by Distance Zones from TMI, and Average Year Built

	Poor Condition (Percent)			Low Grade (Percent)			Average Year Built		
	Before	After	Before & After	Before	After	Before & After	Before	After	Before & After
0–5 miles	19.3	21.4	19.9	6.9	8.6	7.4	1932	1933	1933
5–10 miles	15.7	7.1	13.9	3.9	0.0	3.1	1951	1959	1953
10–25 miles	11.8	17.0	13.0	2.7	6.8	3.7	1937	1940	1938

1939 and the proportion of houses lacking all or some plumbing. When introduced into the regression equations, however, neither affected the magnitude or significance of the distance to plant variable, due to the fact that they were too closely related to existing variables that already depicted these housing characteristics.

Another possibility is that the distance to plant variable is not a linear or logarithmic function and is therefore misspecified in our equations. Computing and plotting the annual sales means for 1978 and 1979 for three distance zones around TMI using the complete STEB data set, we get Figure 2. These curves show that the distance to plant variable may be misspecified, and thus no interpretation of the meaning of the coefficient is possible. Further evidence of misspecification of

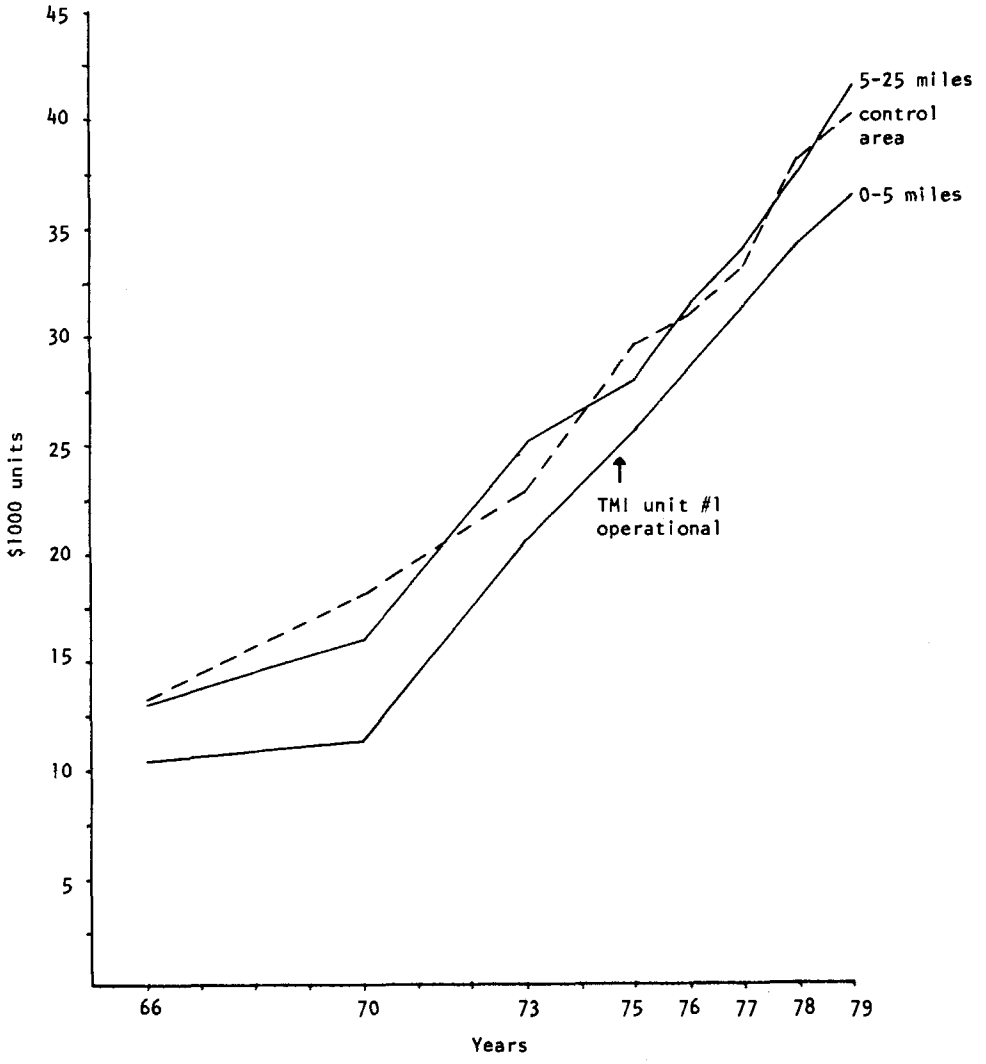


FIGURE 2: Annual Mean Sales Values By Distance Zones Around TMI, 1978 and 1979.

this variable was revealed when the coefficient for distance to TMI variable using the complete data set (including the control 80 miles away) was much smaller than the value shown in Table 3.

We next substituted the binary variable, close to TMI, for the distance to TMI variable in the before, after, and before and after accident data sets that included the entire study and control areas. In these runs, close to TMI was defined in two ways: 0–5 miles and then 0–2 miles. The results are shown in Table 6, omitting the nonplant related variables that changed little in magnitude and none in sign from those shown in Table 3. Within five miles of TMI, the price of housing is significantly lower (at the 1-3 percent level of significance) in the full data set (column 3), with no evidence that the accident had an effect on prices. However, there was no significant difference in the price of housing within two miles of TMI (column 4), indicating that whatever factors are influencing price close to TMI, they must exist beyond two miles from the plant. We have not been able to identify these factors. Logic suggests, however, that TMI is not one of them, for one would certainly expect that if the plant was adversely affecting housing prices, this effect would be felt most strongly on housing nearest the plant, a situation not supported by the regression results just discussed.

In summary, the results of our first TMI regression equations, which tested the hypothesis that housing prices were directly related to distance from TMI, indicated that the plant had a significant adverse affect on prices, but we presented

TABLE 6: Regression Results, TMI Related Variables, Substituting "Close to TMI" for "Distance to TMI" Variable in Full Data Set[a]

Variable	Before	After	Before & After	Before & After
	1	2	3	4
30. After Accident (b)			−323†	331†
			(−0.42)	(0.51)
36. Close to TMI (b)	−1,559*	−1,534†	−1,915**	
0–5 miles	(−1.89)	(−1.28)	(−2.50)	
37. After × Close (30 × 36)			1,167†	
			(0.92)	
39. Close to TMI (b)				−1,556†
0–2 Miles				(−1.44)
40. After × Close (30 × 39)				−2,730†
				(−1.15)
R^2	.772	.819	.770	.768
F	57.52	26.60	65.29	70.95
Standard Deviation	7,210	6,339	7,068	7,089
Residual Degrees of Freedom	474	161	662	662

Notes:
†Not significant.
*Significant at the 5–10 percent level.
**Significant at the 1–5 percent level.
[a]The significant variables describing house and lost characteristics are not included.

evidence that the distance variable was misspecified. The historical trends in mean annual residential prices by distance zones reveal that housing prices within five miles of TMI have been consistently below those farther away, going back eight years before the plant became operational. Further regression analysis indicates that housing prices in a zone within two miles of the plant are not significantly different from the total sample, but within a 0–5 mile zone they are significantly lower. Our inclination is to suspect that some factor, not identifiable, is responsible for this variation in housing prices.

In subsequent regressions we analyzed the data to see if there might be distributional effects in terms of (1) direction from the TMI plant, and (2) value classes of residential property. Four quadrants, North, East, South, and West, were delineated and entered as binary variables. Close to TMI (0–5 miles) was also entered as a binary variable and, as before, the data were structured into three time periods: before, after, and before and after the accident.

The results, shown in Table 7, report only those variables that contribute to an understanding of the quadrant effects, omitting the other variables that were very similar in most respects to those shown in Table 3. In the after accident data set, one coefficient is weakly significant, that for the south quadrant for variable 33 in which close to plant is interacted with the quadrant variable. There were only eight observations after the accident in this 0–5 mile area south of the plant, concentrated in a community lacking sewers and containing low value properties, many of which are converted small vacation homes. We do not believe this coefficient reflects the accident, particularly since the coefficient for the interactive variable 34 (close to TMI × quadrant × after) has a t value of only 0.04 for the south quadrant in the before and after accident data set.

In the before and after accident data set, two coefficients are significant for the quadrant binary variable (32); the north quadrant with a negative coefficient of −$3,026 and the south quadrant with a positive coefficient of $2,321. The positive coefficient is opposite to that which we would predict from the accident. The negative coefficient for the north quadrant, we suspect, reflects the unidentifiable factors discussed previously. None of the coefficients in this data set for variable 33 (close to plant × quadrant) and variable 34 (close to plant × quadrant × after accident) are significant. We conclude that there is not sufficient evidence to indicate that the accident had significant adverse effects on residential property values when examined in terms of their direction from the plant. Apparently prospective buyers did not discriminate against properties located downwind of the TMI plant.

We also used regression analyses to determine if the accident had any effects among three value classes of residential properties: low, medium, and high. The parameters for the value classes were selected by use of a histogram for the 1977 sales, and then deflators were applied to subsequent sales values through 1979. Significant independent variables for each value class were ascertained by using the California statistical procedures program. Three regression equations were specified for each value class (before, after, and before and after accident) and three binary variables relating to the accident were entered into the regressions

TABLE 7: Relevant Regression Results to Determine Quadrant Effects

Variables	Regression Coefficients (t values)							
	North Quadrant		East Quadrant		South Quadrant		West Quadrant	
	After	Before & After	After	Before & After	After	Before & After	After	Before & After
32. Quadrant	−1,794†	−3,026***	572†	520†	1,758†	2,321**	−257†	742†
	(−0.88)	(−3.15)	(0.29)	(0.53)	(0.84)	2.11	(−0.10)	(0.66)
33. Close[a] × quadrant	3,888†	1,267†	−663†	1,918†	−6,682*	−4,231†	766†	−1,592†
	(1.40)	(0.77)	(0.21)	(1.12)	(−1.88)	(−1.17)	(0.22)	(−0.87)
34. Close × quadrant × after		−34†		751†		174†		505†
		(−0.02)		(0.29)		(0.04)		(0.20)
R^2	.84	.77	.84	.77	.84	.77	.84	.77
F	18.79	53.77	18.41	53.01	19.10	53.04	18.40	52.48
Standard Deviation	6,519	7,241	6,575	7,281	6,474	7,279	6,576	7,309
Degrees of Freedom	111	548	111	548	111	548	111	548

Notes:
†Not significant.
*Significant at the 5–10 percent level.
**Significant at the 1–5 percent level.
***Significant at the 1 percent or better level.
[a]Within 0–5 miles of TMI plant.

TABLE 8: Regression Results, TMI and Accident Related Variables, Comparing Control Area to TMI Area[a]

Variable	Regression Coefficients (t values)			
	0–5 Mile Area			10–25 Mile Area
	Before	After	Before & After	Before & After
30. After Accident (b)			−368†	−374†
			(−0.33)	(−0.32)
35. Lycoming Control (b)	1,592*	276†		−1,649†
	(1.77)	(0.20)		(−1.26)
36. Close to TMI (b)			−1,804**	
			(−2.03)	
37. After × Close (30 × 36)			1,177†	
			(0.86)	
38. After × Lycoming (30 × 35)				492†
				(0.25)
R^2	.818	.816	.801	.773
F	45.26	16.97	55.10	34.89
Standard Deviation	5,511	5,649	5,608	7,883
Residual Degrees of Freedom	242	92	357	349

Notes:
†Not significant.
*Significant at the 5–10 percent level.
**Significant at the 1–5 percent level.
[a]The significant independent variables describing house and lot characteristics are not shown.

(close to TMI, after accident, and close × after). The results of the regressions, not reproduced here, show that the accident had no effects on the prices of residential properties when considered in terms of low, medium, or high value classes.

A final step was to compare the TMI area to the control area, in Lycoming County, PA. If property value effects were rather evenly dispersed over more than a 25-mile radius around the plant, then our previous analyses would not uncover them. The same three time periods (before, after, and before and after accident) were specified and separate regression equations were constructed for the 0–5 mile and 10–25 mile areas surrounding TMI.[19] The independent variables relevant to this analysis (all binary) were, after accident (30), Lycoming Control (35), and close to TMI (36).[20] Variables 35 and 36 were interacted with variable 30 in separate regression runs in the before and after data set.

Table 8 presents the results of several regression equations, showing the coefficients for the independent variables relevant to the accident and areas involved. The signs and magnitudes of the coefficients for the house and property

[19]It was felt that if no significant differences existed in the 0–5 or 10–25 mile zones, there would not likely be any differences in the 5–10 mile zone around TMI.

[20]Close to TMI is the same as the 0–5 mile zone around the plant.

selected variables followed the same general pattern as shown in the regression results in Table 3, and thus are not repeated here.

Before the accident, housing prices were somewhat higher in the Lycoming control area than prices in the 0–5 miles zone around the plant. After the accident, however, there was no significant difference in the price of housing in the two areas. In the before and after data set (column 3) housing prices were lower in the 0–5 mile zone, which follows the earlier findings and supports the positive but weakly significant coefficient for variable 35 in the first equation. The significance of the lower values for housing in the 0–5 mile zone disappears after the accident (variable 37). In the 10–25 mile area (Column 4), neither the Lycoming control area nor the 10–25 mile zone show significant differences in explaining variations in the selling price of houses. We conclude that after the accident there were no significant housing price differences between the control and TMI areas.

5. CONCLUSIONS AND DISCUSSION

Regression analyses using actual sales values for 540 single family properties in the vicinity of four nuclear power plants in the Northeast before the March, 1979, accident at the Three Mile Island plant found no significant positive or negative effects on property values. The same analytic approach, with 695 observations of property sales around the TMI plant, uncovered no evidence that the accident had adverse effects on property values through 1979. As part of the TMI investigation, differential effects were sought for three value classes of residential property, distance zones from the TMI plant, and direction from the plant, but no effects attributable to the accident could be identified.

Records of residential sales show that immediately following the accident there was a sharp decline in the number of sales within about ten miles of the plant. Some of the realtors we talked to characterized this period as a virtual collapse of the market. However, within 4–8 weeks of the accident the real estate market returned to near normal conditions, considering the coincidental effects of high interest rates and scarcity of mortgage funds at that time. This does not imply that, even today, there may not be an occasional buyer who will refuse to purchase a particular property because of its proximity to TMI. Apparently there were too few such people in the market during 1979 to affect measurably the demand for and consequently the price of housing in the area. However, this means that some properties may remain on the market for a longer time before being sold, thus increasing the holding costs for some sellers. This situation was not investigated.

Shortly after the accident the utility employed a large number of clean-up workers and nuclear technicians. These people should have little aversion to living near a nuclear plant, and they may have had a positive effect on the real estate market, counteracting an actual negative effect and thus resulting in a near zero net effect. It is the net effect of course, that our data measure. In terms of the concern of current property owners over the effects of the accident on property values, it is the net effects that are relevant, not the individual effects. We are inclined to believe that neither positive nor negative individual effects exist. Our rationale for this view is based on our conviction that very few, if any, clean-up workers would locate west of the plant, across the Susquehanna River, where the

only access to the plant requires driving northward to the bridge crossings at Harrisburg. If this is the case, then no positive effect from the clean-up workers would occur here to balance any negative effects, and the results of our analyses for areas to the west of TMI must reflect, therefore, the singular negative effect of the accident. The results for this area showed no effects on prices. To accept the existence of counteracting effects, all negative effects must have been concentrated to the north or east of the plant (most of the area to the south of the plant is also across the Susquehanna River with even more difficult access to TMI). We find it difficult to believe that potential buyers would discriminate against properties close to TMI only when they were located north or east of the plant. However, if the influx of clean-up workers did have a positive influence on the housing market east of the plant, then the possibility exists that after clean-up operations are complete their exodus from the area might have a depressing effect—a long delayed reaction to the accident.

There is also a possibility that shortly after the accident most people realized that the nuclear contaminants were contained and that there was no imminent danger of massive spill or release of radioactive materials; therefore, no capitalization effect occurred once the market returned to normal within a few weeks. However, as the immense difficulties associated with the clean-up have become known, and the longer the plant remains closed with the contaminants contained therein, there may appear long-term capitalization effects. In addition, sharply rising electric power costs for the utility's customers, due to clean-up costs and to the cost of purchasing replacement power, may over time inhibit growth and development in the utility's service area, thus indirectly affecting property values.

Another possible explanation for the lack of capitalization effects in the nine months following the accident is that buyers anticipate federal or state compensation for any possible losses that may be identified, and that the expected value of such compensation is positively capitalized into property values. If it turns out that the seller receives the compensation (assistance tied to the property and not the owner) then the seller receives a windfall gain.[21] If the buyer receives the compensation, then he or she is no better off, since the compensation will be equal to the premium paid for the property. In such a case there remains the very difficult task of estimating from market sales data only the negative effects of the accident.

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[21]If the buyer knows in advance that compensation would be paid to the seller, no capitalization of the TMI accident would occur. There could be capitalization of anticipated future accidents.

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RECRUITMENT AS DIFFUSION AND THE SPATIAL STRUCTURE OF OCCUPATIONS

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1. INTRODUCTION

It is a remarkable fact that in spite of the large amount of attention devoted to modeling diffusion in recent years, little has been directed to the geographical differentiation which results. This may have been because it has proved necessary to invoke a grossly over-simplified fundament on which diffusion unrolls in order to discern the resulting patterns. Hägerstrand (1967) made this claim and included a complex underlying geography, yet the measurements used to validate his simulation could have been applied equally well to a mathematical model for a uniform plain. Even Hudson's excellent studies in geographical diffusion theory (1972) concentrate on flows and only aspatial results are displayed. Yet it is abundantly clear that when only the fortuities of random choice and of dispersion are operative in a homogeneous environment, the geographical differentiation which results is entirely dependent on these factors. Extra factors can no doubt be added at some later date: degrees of selectivity of the diffusing phenomenon according to areal contents or to biased paths, for example. But until we appreciate the geography which results from random drift, further elaboration is premature.

This is a study of recruitment processes in the labor market and the geographical differentiation in occupations which develops under various assumptions about them. These spatial patterns should also be mirrored in associated variables such as wage changes because they all respond to labor supply conditions. Assume the spread of information about the vacancies in a factory is by word of mouth as a $2D$ random walk with a normal density function of path ends resulting at a specific time. The applicants and indeed those who are successful will also conform to this distribution. If one considers a number of job changes and especially if one considers a family over a few generations, it is apparent that the selection of workers is occurring as a diffusion process in the same way as the information spread. It is evident that the limited local horizons of job search will have profound effects on economic geographical structures and, of course, there will be reciprocal influences.

The micro-theory of job search which drives the diffusion process has information of a job vacancy moving in an acquaintance network. The basic mechanism of spatial movements and their concomitant spatial differentiation is

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the characteristic weekly round of activities of individuals. In an important sense it is a fundamental primitive concept which cannot be derived from simpler postulates. It is affected by and affects so many different activities, attitudes, and values of a person and his relations to others and is such an incredibly complex integration of past, present, and future conditions that it is difficult to see what sort of explanation of it could be offered. Perhaps some stochastic entrainment process on the lines of the time-space periodicities conjectured for the existence of towns [Curry (1978b)] is possible. We shall here regard it, however, as given naively. The weekly round defines the usual allocation of time to different activities and locations, the probability distribution in space of a person's presence, the things he sees, and the people he meets habitually. The field of acquaintance will be determined by the weekly round and the network of contacts by the intersection of such fields. It is because of the constraints that one activity places on another for an individual that we have an inherent conservatism of an individual's action space, and the constraints between individuals provide long-lasting areal differences.

Given continuous radially symmetric personal search fields and a uniformly distributed expectation of vacancies, it is possible to generate a spatial process of job change and the geographical differentiation in occupations which results. The dissemination of information and indeed of job changes can be represented as a succession of convolutions which are closely spaced in time. If the initial distribution was independently random, say, then characteristic spatial correlations would develop. Although we shall only be concerned with occupations, other economic distributions should be linked because they are produced by the same mechanism. In the labor market this includes wage differences, wage changes, or unemployment ratios. Equally, similarities should exist with preference structures or some technological innovations and even with church or club membership, residences of marriage partners, and the spread of diseases.

A convenient point of entry to the subject is Holt's discussion [Holt (1970), Holt et al. (1971)] which uses extremely crude geographical considerations. In regard to segmentation in the labor market, he makes the point that the possibility of matching workers and jobs is reduced if most vacancies are in some regions and most of the unemployed workers are in others. He attempts to demonstrate this by appeal to rigidly separated compartments, asserting that if an economy is split into N compartments, the vacancy and unemployment rates are each increased by the square root of N, and that the degree of imbalance between these two rates in each region is also a factor. It is also noted that the strength of dependence between the unemployment rates and wage inflation rates for a single economy will go up if it is split into two noninteracting regions of equal size. This is due to the nonlinear, concave upwards relation between the rates. The postulated regional compartmentalization of the labor market is unnecessarily rigid, and it is more reasonable to allow degrees of interaction between regions in regard to search, advertising, and the winning of jobs. Better still we shall later introduce continuous space and limited information flows acting as a friction of distance on movement: this affords a much more penetrating geographical analysis.

2. ISLAND MODEL

In the simplest form of diffusion, as in the island model, proximity is ignored [Wright (1931, 1970); Crow and Kimura (1970); Kimura and Ohta (1971)]. Each of a number of places of equal size N exchange individuals at the same rate with a random sample from the entire area. The object is to exclude geographical differentiation due to any distance control of migration and to any selection of destination by emigrants. Thus only random drift is possible from the two processes in operation, sampling and dispersion, neither of which is related to the existing occupational structure. The amount of differentiation can be measured by the variance of the frequencies of an occupation among islands. Immigration, with rate of m, will tend to pull an island's frequency of a particular occupation q towards the general mean $\bar{q}$ of the total population with $\Delta q = -m(q - \bar{q})$. A steady state will occur for the total area when the net probability flux is zero and

$$\sigma^2 = \bar{q}(1 - \bar{q})/(4Nm + 1)$$

if m, the immigration rate, is small. Frequencies will be beta distributed

$$\phi(q) = C(q(1 - q))^{2Nm-1}$$

$$C = \Gamma(4Nm)/\Gamma(4Nm\bar{q})\Gamma(4Nm(1 - \bar{q}))$$

If islands are completely isolated

$$\phi(q) = C/q(1 - q)$$

Values are diagrammed in Figure 1 where the abscissa represents the probability of occupation A being on an island against the density function corresponding to a particular value of Nm. If migration is small and the total population is small the curve is U-shaped, so that A is likely to be present on an island or is likely to be absent. Thus differentiation is most marked. With migration at all significant, probabilities of occupations being present will vary only slightly between islands, clustering around the general mean.

A neighborhood can be defined as an area from which the progenitors and successors may be treated as if drawn at random. Since areas are likely to become differentiated from each other, a correlation between the status of contacting parties can be expected [Wright (1970)]. The correlation between such occupations for the receiver I, relative to those of the total population, can be represented by F_{IT}. F may be considered as a coefficient of "inbreeding" in subdivided populations, an index of specialization in the broad sense. The correlation between the occupations of contacting individuals from within their own neighborhood is F_{IS}. The correlation between the occupations of random individuals without regard to area, i.e., relative to the occupations of the total population, is F_{ST}

$$F_{ST} = (F_{IT} - F_{IS})/(1 - F_{IS})$$

or, using $P = (1 - F)$ to represent self containment

$$P_{IT} = P_{IS} P_{ST}$$

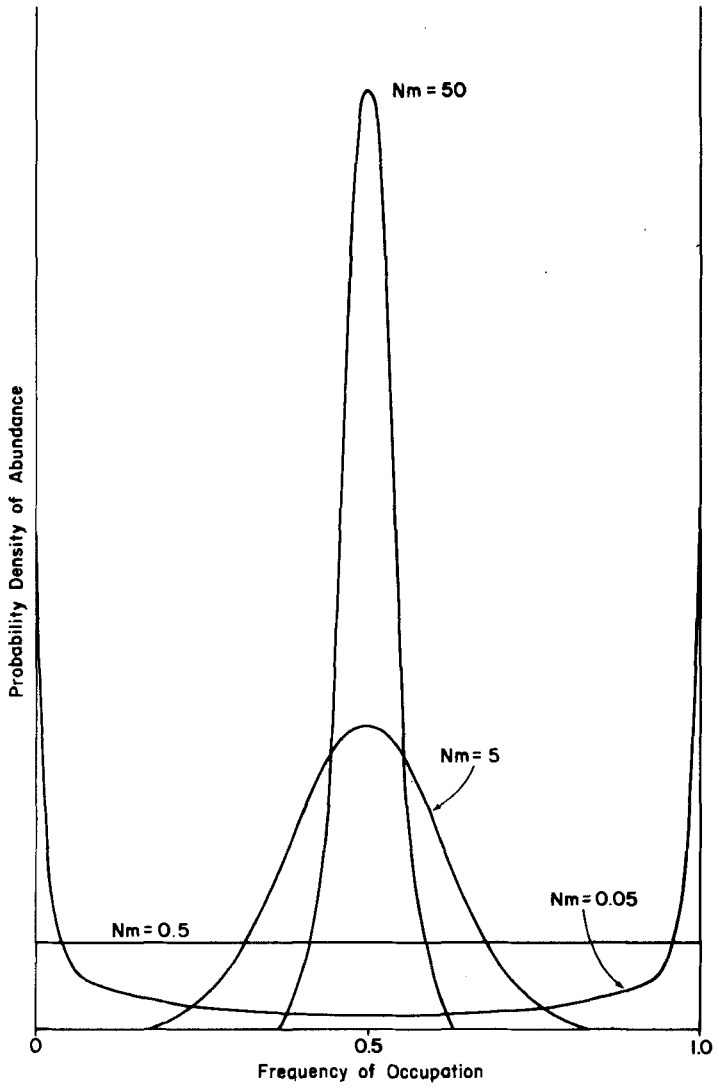


FIGURE 1: Distribution of Occupation Frequencies Among Sub-groups for Various Values of Nm.

F_{IS} thus represents the effect of local "inbreeding" while F_{ST} measures the degree of differentiation among subpopulations due to random drift. The latter may be calculated from the mean $\bar{q}$ and the variance σ_q^2 of the frequencies of a particular occupation among subgroups

$$F_{ST} = \sigma_q^2/(\bar{q}(1 - \bar{q}))$$

and similarly for the other indices.

Using the covariance between the frequencies of the ith and jth occupations,

σ_{jk}, and their mean frequencies $\bar{q}_j, \bar{q}_k$, Nei (1971) obtains the inbreeding coefficient as

$$F_{ST} = -\sigma_{jk}/\bar{q}_j\bar{q}_k$$

It seems clear that areal differentiation will be marked only for very small areas. This gives

$$F = (4Nm + 1)^{-1}$$

Define the coefficient of kinship ϕ_{kj} as the probability that an occupation taken at random in area k is identical with one taken in area j [Courgeau (1974)]. Let X_{ky} (= 1,0) denote whether the sampled occupation, out of $2N_k$ present, which is occupation y in the kth island, is a match or not

$$q_k = \sum_y X_{ky}/2N_k \qquad q_j = \sum_z X_{jz}/2N_j$$

In equilibrium $E(q_k) = E(q_j) = q$ and

$$\text{Cov}\,(q_k, q_j) = (4N_k N_j)^{-1}\Sigma_{yz}E[(X_{ky} - q)(X_{jz} - q)]$$

Since squaring X_{ky} can make no difference, the two possibilities are

$$E[(X_{ky} - q)^2] = q - q^2 \text{ and } E[(X_{ky} - q)(X_{jz} - q)] = 0$$

with probabilities ϕ_{kj} and $1 - \phi_{kj}$, whether the two occupations drawn from k and j are identical by "descent" or they are not. Consequently

$$\text{Cov}\,(q_k,q_j) = (q - q^2)\phi_{kk}$$

and

$$\sigma^2(q_k) = (q - q^2)\phi_{kk} + (q - q^2)(1 - \phi_{kk})/2N_k \simeq (q - q^2)\phi_{kk}$$

Thus coefficients of kinship and second moments are related.

3. STEPPING-STONE MODEL

After the nonspatial island model, the effects of distance are most easily introduced by the stepping-stone model [Crow and Kimura (1970)]. Differentiation by islands yields to a geographical differentiation. In this case only nearest neighbors exchange migrants, with m_1 being the proportion of individuals exchanged each period between a pair of areas. However, it is an easy matter to retain the independently random exchange of the island model as a sort of long distance migration at the rate $\bar{m}_\infty$. It turns out, as might be expected, that the dimensions of the space considered affect the results.

In the case of one dimension and isotropic space, let r_j be the correlation coefficient of occupation frequencies between two places which are j steps apart

$$r_j = E(q_i q_{i+j})/\sigma_q^2$$

Writing $r_j = \lambda^j$, and using

$$\alpha = (1 - m_1)(1 - \bar{m}_\infty)$$

$$\beta = 0.5m_1(1 - \bar{m}_\infty)$$

$$R_1 = ((1 + \alpha)^2 - 4\beta^2)^{0.5}$$
$$R_2 = ((1 - \alpha)^2 - 4\beta^2)^{0.5}$$
$$K = R_1/(R_1 + R_2)$$
$$\lambda_2 = ((1 - \alpha) - R_2)/2\beta$$
$$\lambda_4 = ((1 + \alpha) - R_1)/2\beta$$

then

$$r_j = K\lambda_2^j + (1 - K)\lambda_4^j$$

The degree of differentiation is measured by the variance

$$\sigma_q^2 = \bar{q}(1 - \bar{q})/\{2N - (2N - 1)\,[1 - 2R_1R_2(R_1 + R_2)^{-1}]\}$$

When $m_1 = 0$, i.e., no short-range migration, the island model is obtained. On the other hand, if $\bar{m}_x \ll m_1 \ll 1$, then

$$\sigma_q^2 = \bar{q}(1 - \bar{q})/[1 + 4N(2m_1\bar{m}_x)^{0.5}]$$

and

$$r_j = \exp\,[-j(2\bar{m}_x/m_1)^{0.5}]$$

so that

$$r_1 \simeq 1 - (2\bar{m}_x/m_1)^{0.5}]$$

In two dimensions and isotropic space

$$r(\rho) \simeq \exp\,[-\rho(4\bar{m}_x/m_1)^{0.5}]/\rho^{0.5}$$

where σ is the direct distance between two places in Cartesian space. It may be seen that, while in one dimension autocorrelation declines negative exponentially as a direct function of distance, in two dimensions the decline is more rapid since this same rate is itself now a function of the square root of distance.

4. ISOLATION BY DISTANCE

We must always remember that these models all involve the assumption that the traits in question—occupations, skills, etc.—are neutral as to place and that nothing is involved in trait frequency but the fortuities of sampling and dispersion. Consider a population uniformly distributed in an area continuum in which the distances between the locations of senders and the corresponding receivers have the same normal pattern through time. We shall consider the steady state. N_X is the population of a neighborhood from which the progenitors of a central individual in generation X may be considered to have been drawn at random. F_{1S}, F_{2S}, . . . , F_{XS} are the correlations between random drawings within the areas 1, 2, . . . , X relative to the area of population N_S. The distribution of senders in the previous generation X would be compounded of X sender-receiver distributions and would thus be normal with variance X times that of the latter. The effective population number of the population at X would be X times that in a neighborhood [Wright (1970)]

$$N_X = XN_1 \qquad N_S = SN_1$$

where S is the number of subdivisions. In the steady state

$$F_{1S} = 0.5(1 + F_{1S})\ (\Sigma t)$$

where

$$\Sigma t = \frac{1}{N_1} + \frac{1}{N_2}\left(1 - \frac{1}{N_1}\right) + \frac{1}{N_3}\left(1 - \frac{1}{N_1}\right)\left(1 - \frac{1}{N_2}\right) + \ldots + \frac{1}{N_S}\prod_{X=1}^{S-1}\left(1 - \frac{1}{N_X}\right)$$

$$= t_1 + t_2 + t_3 + \ldots + t_s$$

and

$$F_{1S} = \Sigma t/(2 - \Sigma t)$$

But

$$\sum_{X=1}^{S-1} t_X = 1 - N_S t_S$$

and therefore

$$F_{1S} = (1 - N_S t_S)(1 + N_S t_S)$$

Figure 2 shows the values of F_{IS} for neighborhoods of various sizes in relation to larger populations N_S. It is difficult to interpret because both denominator and numerator of the equation change together. The degree of differentiation among

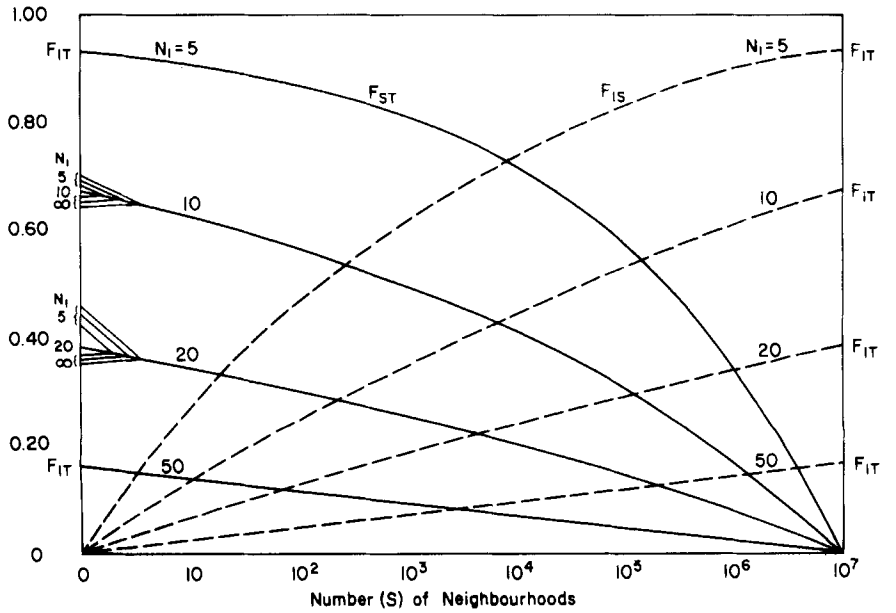


FIGURE 2: F_{IS} and F_{ST} in Relation to Number of Neighborhoods within a Total of 10^7.

areas of any effective population number within some constant large total, F_{ST}, is more interesting. Figure 2 shows that there is much differentiation due to random drift if N_1 is 20 or less but relative variabilities are not negligible up to $N_1 = 200$.

When considerable neighborhood differentiation occurs from accidents of sampling, differentiation of much larger areas is built up but only slowly. Consider the effect of an abrupt change in effective size of neighborhood on F_{ST}, a reduction of N_1 from 10 or 20 to 5 for three successive periods. An abrupt rise at the left-hand side of the curve occurs which both continues and spreads to the right, but very slowly, until the curve is raised to a new equilibrium. The number of periods required is about the same as the number of neighborhoods. S is the area before the rise begins to affect the variance of such areas in the total. Increases in both dispersion and density of population increase N_1 and vice-versa.

N_1 can be defined in terms of the degree of inbreeding. Let n be the number of potential sources in a square 2σ on the side. The area occupied by an individual is the reciprocal of density $d = 4\sigma^2/n$; y is a normal distribution of distances between source and destination. The chance that a given job arose from a particular source X_i is y_i/d. The chance that two jobs in a "neighborhood" arose from that source is $\Sigma(y_i/d)^2$, where the summation applies to all sources. N_1 is defined to equal this. For the normal distribution

$$N_1 = n\pi = 4\pi\sigma^2 d$$

The effective size of neighborhood is equivalent to the effective population number in a circle of radius 2σ which would include 86.5 percent of senders to a central individual.

Let us turn now to specifying the relation between effective size of neighborhood and the dispersion pattern of contacts. In a population of uniform density in area, let the distance X of a sender from a receiver be represented by

$$y = y_0 \exp(-bX^{1/a})$$

This is a normal distribution if the exponent $1/a$ is 2 but leptokurtic if less

$$y_0 = b^a/2\Gamma(a+1)$$

$$\sigma^2 = b^{-2a}\Gamma(3a)/\Gamma(a)$$

$$\text{kurtosis: } \gamma_2 = [\Gamma(a)\Gamma(5a)/(\Gamma(3a))^2] - 3$$

$$N_1 = 2^{2a}(\Gamma(3a+1)\,\Gamma(a)/\Gamma(3a))\pi\sigma^2 d$$

Table 1 shows some results including the case of zero dispersion, $a = 0$, and of the normal distribution, $a = 0.5$. N_1 changes very little with increasing kurtosis, i.e., peakedness or concentration around the mean [Wright (1970)]. It might seem that a leptokurtic mixing distribution would imply a large population number for given variance. Figure 3 shows the distribution of frequencies of senders in concentric rings around a receiver in terms of the radius R of the neighborhood as the unit. Kurtosis seems to have relatively little effect within the range of moderate values. In calculating what fraction the quartile distance (which includes half the senders) forms of the radius of the neighborhood, values are obtained of $0.689R$ ($a = 2$),

TABLE 1: Midordinate (y_0), Variance (σ^2), γ_2, Size of Neighborhood (N_1), in an Area Continuum for Different Values of a in the Distribution $y = y_0 \exp(-bx^{1/a})$

a	y_0	σ^2	γ_2	N_1 ($\times\pi\sigma^2 d$)
0	$0.5000/L$	$0.333L^2$	−1.20	3
0.5	$.5642b^{0.50}$	$0.5000b^{-1}$	0	4
1.0	$.5000b$	$2.0000b^{-2}$	+3	4
2.0	$.2500b^2$	$120.\ b^{-4}$	+22.20	3.20
3.0	$0.0833b^2$	$20{,}160\ b^{-6}$	+104.25	2.286

$0.589R$ ($a = 1$), $0.594R$ ($a = 0.5$) and $0.707R$ ($a = 0$). The radius of the neighborhood can be taken as about 1.7 times the range of the mixing operator that includes half the senders or about 2.0 times the distance which includes 40 percent of the senders.

Instead of uniform density, let there be a pattern of randomly distributed clusters each exchanging a little with those that are closest. Let origins be drawn from a cluster of effective size M, and in the next period the increase is $N < M$, because of the very low densities between clusters. If $M = kN$, then $N_X = (k + X - 1)N$

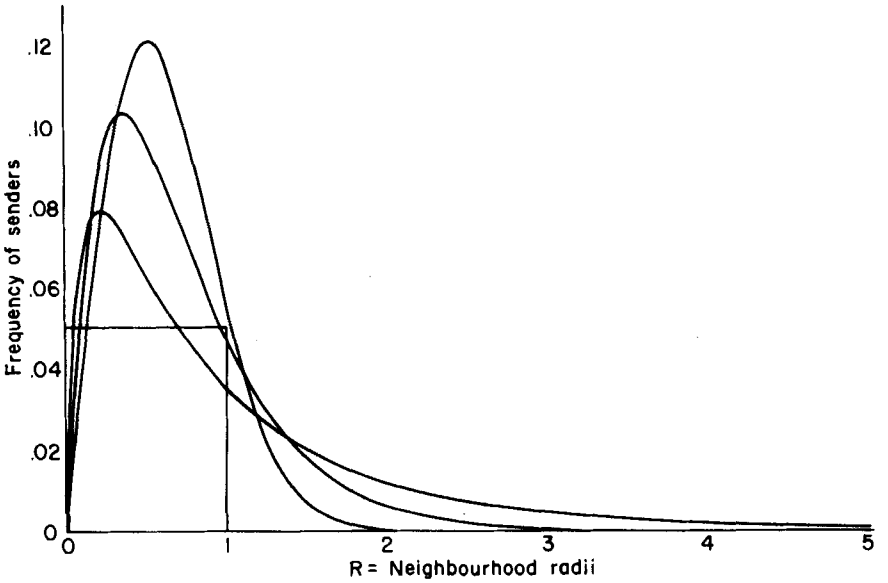


FIGURE 3: Distribution of Senders in Concentric Rings about Receivers when the Unidirectional Distribution is, on a Scale of Neighborhood Radii.

(1) Rectangular; $a = 0$, $\gamma_2 = -1.2$
(2) Normal; $a = 0.5$, $\gamma_2 = 0$
(3) Moderately leptokurtic; $a = 1.0$, $\gamma_2 = 3.0$
(4) Strongly leptokurtic; $a = 2.0$, $\gamma_2 = 22.2$

for the xth period back. In the steady state.

$$F_{1S} = \frac{1 + F_{1S}}{2}\left[\frac{1}{kN} + \frac{1}{(k+1)N}\left(1 - \frac{1}{kN}\right) + \right.$$

$$\left. \cdots + \frac{1}{(k+S-1)N}\prod_{X=2}^{S}\left(1 - \frac{1}{(k+X-2)N}\right)\right]$$

which may be written concisely [Wright (1970)] as

$$F_{1S} = \sum t'_S/(2 - \sum t'_S) \qquad \text{where } \sum t'_S = \sum_{X=1}^{S-1} t'_X$$

$$t'_X = \frac{(k+X-2)N - 1}{(k+X-1)N}\, t'_{X-1} \qquad X > 1;\ t'_1 = 1/kN$$

so that

$$\sum t'_S = 1 - (k + S - 1)\, Nt'_S$$

and

$$F_{1S} = [1 - (k + S - 1)\, Nt'_S] \,/\, [1 + (k + S - 1)Nt'_S]$$

These equations are comparable with those for the uniform case by substituting $t'_X = t_{k+X-1}/kNt_k$.

Figure 4 shows the values of F_{1S}, i.e., F_{IS} and F_{ST}, obtained for $N = 20$ and $k = 1$ to 10^4 and S0 to 10^8. General conclusions are (1) that the differentiation of clusters of size 200,000 is about half that of neighborhoods of size 20 and (2) differentiation of large populations ($S > 10^4$) does not occur for values of k from 1 to 10^4.

5. MALÉCOT'S MODEL

Malécot (1969) has treated the same case of a population continuously distributed over a two-dimensional plane. His use of the autocovariance function provides a natural means of handling a complex problem to produce a beautifully simple solution. Again the topic is the effect of migration on the evolution of the structure of a population. We are concerned to relate the receiving of job information (and the subsequent changes) to the acquaintance net: only one way flows from work place to the eventual recruit are considered.

Let X be a two-state (1,0) random variable recording whether a person has news of a vacancy or not. He can learn of it by two means: (1) through non-distance related mechanisms such as the media or in the opposite direction, by forgetting—call this media change; (2) through personal encounters which are distance related. With regard to (1), write U and V for the probabilities in each period of outside random change from 1 into 0 and of 0 into 1 respectively, e.g., of X changing via media influence. The expectation of a person having knowledge or not, conditional on the person who encounters him knowing, is

$$E(X)' = (1-U)X + V(1-X)$$

or

$$E(X)' = (1-k)\mathrm{X} + kc$$

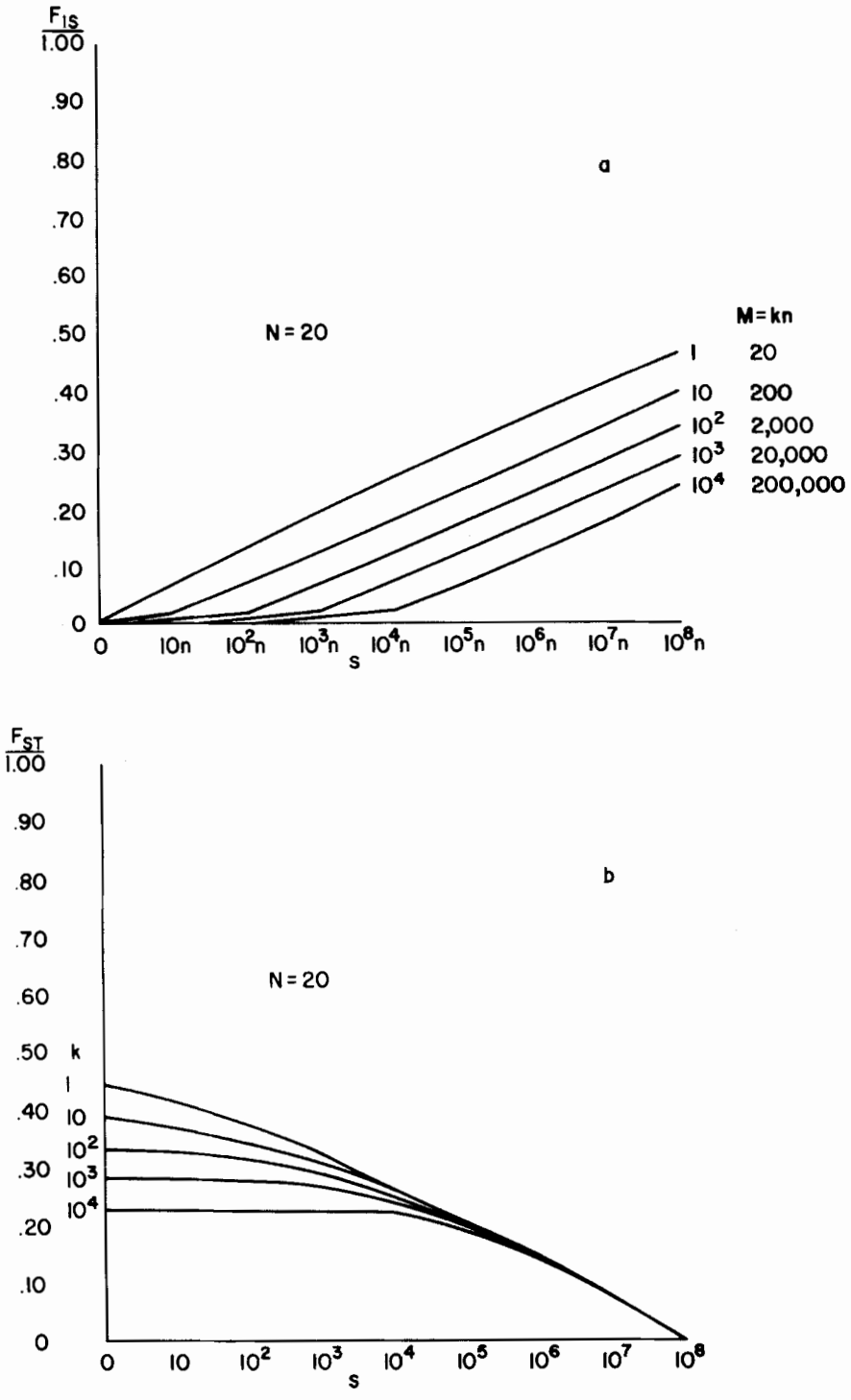


FIGURE 4: F_{IS} (above) and F_{ST} (below), where $N = 20$ is the Increment Per Period and $M = kN$ is the Neighborhood Size.

where $c = V/(U + V)$ and $k = (U + V)$, the intensity of media-induced change. If $X = 0, E(X' = 1) = V$; if $X = 1, E(X' = 1) = 1 - U$. More specifically $X_n(C)$ is a two-state (1,0) random variable characterizing an individual of the nth period at point C with specific probabilities of its being in one or the other state, depending on n and the position of C.

For mechanism (2), let $g(C, D)dA_c$ be the probability of an individual at D, i.e., within the small area dA_d, encountering a person from C, i.e., within dA_c. Because there is no relation between those informed other than the eventual relation among their tellers, the joint moments $E[X'(C)\,X'(D)]$ of random variables X' of the $(n + 1)$st period will be linear combinations of expectations of the products of the X's of the tellers, i.e., of the joint moments of the nth period. Using a bar for expectations

$$\overline{X(D)} = \int_A [\overline{X(C)}(1 - k) + kc]g(C, D)dA_c$$

This equation has only one solution if $k > 0$, i.e., if media change occurs

$$\overline{X(C)} = c = V/(U + V)$$

a constant, so that first moments are independent of position. Given that a media change has occurred, the probability of it being $0 \rightarrow 1$ is C. For $Y = |X - c|$, Y is read as: given that a person has a 1 and given that a media change has occurred, this is the probability that he learned of it through personal contacts. For example $|1 - 0.4| = 0.6$, or given that he has a 0 and given that a media change has occurred this is the probability that he got it by direct contact, for example $|0 - 0.4| = 0.4$. Thus it is the probability of (0,1) in a person occurring via the acquaintance net, given that media contacts are occurring.

$$\overline{Y} = 0 \qquad \overline{Y'} = (1 - k)Y$$

The variance of Y, $S^2 = c(1 - c)$, for a binomial distribution. To describe the probability ϕ_n of $X(C)$ being identical to $X(D)$, or of $Y(C)$ being identical to $Y(D)$, and $1 - \phi$ the probability of their being independent, the correlation coefficient $\phi(C, D)$ can be used. It also describes the coefficient of "coancestry" between individuals located at C and D. The first joint moment of $Y(C)$ and $Y(D)$ in the same period is

$$\overline{Y(C)\,Y(D)} = S^2\,\phi(C, D)$$

$Y_{n+1}(C)$ and $Y_{n+1}(D)$ for two individuals in the $(n + 1)$st period at C and D: (1) have the probability $g(E,C)\,g(F, D)dA_E dA_F$ of coming from tellers who learned at E and F and (2) have the probability $g(E,C)\,g(F, D)dA_E^2$ of coming from tellers who learned at the same site E. The latter can be split into: (2a) the probability of coming from the identical teller, $0.5\delta\,(E)dA_E$, with $\delta(E)$ as the population density at E and 2(b) the probability of not coming from the identical teller, i.e., without involving common "ancestry" and thus by public media, $1 - [0.5\delta(E)dA_E]$. The first joint moment is

$$\overline{Y_{n+1}(C)\,Y_{n+1}(D)} = (1 - k)^2 \int\int_A \int\int_A \overline{Y_n(E)Y_n(F)}\; g(E,C)g(F, D)\; dA_E dA_F$$

i.e., it is equal to the joint moment of the teller's location in the nth period times the probability of their contacting the sites being discussed, with a term included to take account of common media change probabilities in both areas. These terms can be written out and the general form of the correlation coefficient for the $(n + 1)$st generation obtained on dividing throughout by S^2, but there is little point in repeating Malécot's mathematics. Assume stationarity so that $\phi(C, D)$ does not change with time and let the total area be infinite, population density δ be uniform in space and time and $g(P,Q)$ depend only on the distance $PQ = r$; migration probabilities and common ancestry probabilities are equal. Assume the acquaintanceship contacts and thus the information flows are described by an isotropic Gaussian distribution

$$G(\sigma^2)dA = \frac{\exp(-r^2/2\sigma^2)}{2\pi\sigma^2}\,dA$$

This is a convolution operator which may be substituted for $g_n(EC)\ g_n(ED)$ where

$$g_n(E, C) = \int\int_A g_{n-1}(E, F)g(F,C)dA_F$$

By moving in and out of Fourier transforms, the autocovariance function is obtained [Malécot (1969)]

$$\phi(r) = \frac{1 - \phi_0}{2\delta}\sum_{p=1}^{\infty}(1 - k)^{2p}G(2p\sigma^2)$$

with variance

$$\phi_0 = 1\left(\frac{1 - 8\pi\sigma^2\delta}{\log(2k - k^2)}\right)$$

Finally the autocorrelation is

$$\frac{\phi(r)}{\phi_0} = \frac{\sum_{p=1}^{\infty}(1 - k)^{2p}(1/4\pi p\sigma^2)\ e^{-r^2/4p\sigma^2}}{\sum_{p=1}^{\infty}(1 - k)^{2p}(1/4\pi p\sigma^2)}$$

Malécot points out that this exact approach may be approximated by a partial differential equation involving the partial derivatives of $\phi_n(C, D)$ with their coefficients being the moments calculated from C and D. It is assumed that moments are negligible above some order and equilibrium is reached. Then if σ, the argument of the normal distribution, is small compared to $r\sqrt{k}$ (the argument of the correlation coefficient multiplied by the square root of the media intensity)

$$\phi(r) \simeq ar^{-0.5}\exp\left[-(2kr)^{0.5}\sigma^{-1}\right]$$

with a constant and $r \gg \sigma$. This result is independent of the particular migration operator chosen and the exponential term is independent of the number of dimensions. He also remarks that if an individual has a probability α of making a small displacement with variance ϵ^2 and a probability $(1 - \alpha)$ of making a long

migration with variance σ^2 then $\phi(r)$ remains as above but the variance changes to $\alpha\epsilon^2 + (1 - \alpha)\sigma^2$. This corresponds to individuals existing in colonies.

6. OCCUPATIONAL DISTANCE

Various measures of the distance between populations in terms of occupations have been proposed, and we follow here the exposition of Nei (1971). Let x_i and y_i be the frequencies of i employment in populations X and Y, respectively. The probability of identity of two randomly chosen jobs in X is $j_x = \Sigma x_i x_i$, in Y is $j_y = \Sigma y_i y_i$ and of the identity of a job from X and one from Y is $j_{xy} = \Sigma x_i y_i$. If there was a common ancestral structure and subsequent areal differentiation has not involved environmental selection, j_x and j_y are coefficients of inbreeding [Wright (1931)] while j_{xy} is a coefficient of kinship (Malécot). A normalized measure of the identity of jobs in X and Y is

$$I = (J_{XY}/J_X J_Y)^{0.5}$$

where the J's are arithmetic means of the j's and $0 \leq I \leq 1$. The occupational distance between X and Y is

$$D = -\log_e I$$

A population has split into two isolated populations. Let α be the rate of job substitution per year. In the tth year

$$I = I_0 e^{-2\alpha t}$$

and

$$D = 2\alpha t - \log_e I_0$$

I_0 would normally equal one so that the second term is zero. If there is interaction between the two populations, the relation between occupational differentiation and interaction can be calculated for particular diffusion models, assuming no selection.

(a) In the case of the island model, let N be the size of a sub-population, n the number of sub-populations, m the migration rate and u the innovation rate per generation. For $u \ll m$

$$I \simeq \frac{m(2 - m)}{m(2 - m) + 2nu(1 - m)^2}$$

I is independent of N and is unity when $u = 0$ or when $m = 1$

$$D = \log_e \left[1 + \frac{nu(1 - m)^2}{m(1 - (m/2))}\right]$$

or

$$D = nu(1 - m)^2/m(1 - m/2) \text{ when } D < 0.3$$

In this latter case, D is linearly related to n and thus to size or area in all likelihood.

(b) In the stepping-stone model, between sub-populations which are k steps apart and which are numerous

$$I(k) = \exp[-k(2u/m)^{0.5}]$$

m is the migration rate such that in every generation a proportion $m/2$ of the occupations in a population is exchanged with its two neighboring sub-populations

$$D(k) = k(2u/m)^{0.5}$$

so that D is linearly related to geographical distance.

(c) In the continuous model, for one dimension, m is replaced by σ^2, the variance of migration distance in a generation (Malécot). In $2D$, D is no longer linear with distance. The coefficient of kinship, ϕ, and distance, k, are related as

$$\phi = ae^{-bk}/k^c$$

with a, b, c constants and $c = 0$ for $1D$ and $C = 0.5$ for $2D$. Morton (1971) proposes a direct comparison between occupational distance and distance on the ground. Recall that Malécot's coefficient of kinship ϕ_{ij} describes the probability that a pair of occupations drawn from two locations i and j will be identical by descent. Its measurement requires a symmetric matrix Φ whose i, jth element is ϕ_{ij}. If the geographic distance between i and j is d, Malécot's expectation is

$$\phi_{ij} = ae^{-bd}$$

Let V_i be the ith eigenvector of the kinship matrix where V_1 measures the occupational dispersion among populations. Let the geographic coordinates (X, Y) be regressed stepwise on the set of V_i to select the pair of most significant independent variables for each coordinate of the form

$$X^* = A + BV_i + CV_j$$

$$Y^* = A' + B'V_m + C'V_n$$

These specify the occupational location which may be compared to the geographic location X, Y. Discrepancy

$$D = [(X - X_i^*)^2 + (Y_i - Y_i^*)^2]^{0.5}$$

and the occupational distance between two populations r and s is

$$G = [(X_r^* - X_s^*)^2 + (Y_r^* - Y_s^*)^2]^{0.5}$$

A population recently migrated into a region will have G displaced towards its origin, an unusually inbred population will be located more peripherally in the occupation space than in geographical space and populations with high intermigration will be closer together in occupation space than geographically.

7. HIERARCHICAL DIFFUSION

We have so far let items of job news move out from source as a random walk and the degrees of similarity or differentiation of people which result are described

in terms of the degree of coancestry in the acquaintance net and therefore the relative distances from source. This can be done because of the extreme simplicity of the notion of interaction between contiguous partners. The distance operator which gives us our results can be applied anywhere on the map. In its most elementary form the map is uniform but even if it is quite complex, one can still conceive the same operator being applied à la Hägerstrand (1967). But if movement is very much dependent on population concentrations and particularly if the concentrations are functionally specialized according to size, as are central places, then clearly the operator needs to change depending on where it is being applied.

Is it likely that movement to procure central goods will be distributed identically with movement to obtain jobs? We have assumed that the obtaining of a job is a function of uniform acquaintance nets (up to a frontier) with probabilities of information spread declining with distance. If we make the probability of having an acquaintance result from central place interaction, then each acquaintance field will be hierarchical, and the spread process will match the spatial structure of the central places. The difference between shopping behavior and commuting to jobs will then be due to the extent to which an individual discounts by distance jobs of which hears, a factor which we are consistently rejecting. Of course it is only partly true that the spatial structure of shops, including their hierarchical functions, will match that of jobs. For theory, there is no correspondence to the underlying uniformity in incomes and utilities as for example skills, and while native abilities could be postulated to be so, there is no mechanism to exhaust their use. Mute inglorious Miltons and puffed up favorites both abound. However, it seems likely that acquaintanceships and job locations will follow central place distributions and circulations to some extent.

A parable may be excused perhaps. Let two messages be released in the air. Initially they will float along together; even if they are moving in a strong wind, the currents which will separate them are generally very small. There will come a time however, when the small scale turbulence will have separated their messages sufficiently that they come under the influence of larger atmospheric eddies having winds moving in different directions so that separation increases considerably. And so the process goes on in an upwards cascade to eddies of continental proportions. The efficiency of separation depends on the extent of separation and these are both likely to increase with time for two messages released together. Now note the difficulties of describing this process in conventional terms. We can no longer describe the mechanism produced by the spatial structure as spatially invariant. Nor can we regard increases in time as only involving so many more convolution operations to increase the spread. If we wish to retain spatial invariance and thus continue to regard the process as independent of structure, then we must introduce a new datum, namely another message. By keeping note only of the distance apart of the messages we specify the scale of the interactions which are relevant and therefore the efficiency of separation. Time has no relevance and the structure is invariant. This process has been used to describe the structure and operation of a central place system [Curry (1967)]. Carrying over the same ideas to labor markets we can consider information flows as moving down the settlement hierarchy, while

movement to jobs will be upwards. In terms of personal contact fields, we are saying that because of the hierarchical arrangement of many central institutions, it may be best to conceive the probability of acquaintanceships as not declining with distance in such a direct manner as in the Gaussian field mentioned earlier. The likelihood of interaction increases in proportion to some power of the distance apart of the partners because functional specialization is hierarchical to the same degree. Peoples' willingness to move longer distances does not decrease linearly with distance because more attractive destinations (because of higher-order functions and more vigorous contacts) are spaced further apart.

It was argued purely dimensionally that diffusion within a hierarchical central place system could be expressed in terms of the Richardson equation

$$\delta\sigma/\delta t = A(\delta/\delta\ell)[\ell^{1.5}(\delta\sigma/\delta\ell)]$$

In words, the degree of spread through time depends on the grad-grad of concentration and the 1.5 power of a characteristic distance apart of the items moving. The process of separating items such as dollar bills a certain distance apart must be via income flows of the same spatial order of magnitude. Smaller cellular movements could provide different tracks for the bills but would not alter separation much; larger cells would move bills in the same orbit and thus not affect separation. It is only between cells of sizes comparable to the distance separation of bills that the process of separation is really effective and diffusive efficiency increases as the 1.5 power of the distances apart. If the probabilities of travelling to centers of various orders are equal and the relative distances between centers of neighboring rank are as $r_n = r_{n-1}^{1.5}$ then efficiency of diffusion is in the same proportion.

These results are compatible with a spatial autocorrelation function (in closed space) for interaction between two points d units apart which varies linearly with distance

$$R(\delta) = \sigma^2[1 - (d/D)] \qquad (d < D)$$

The corresponding spectral density function

$$F(w) = (2/\pi)\sigma^2[(1 - \cos wd)/w^2D]$$

shows a series of regularly-spaced waves the peaks of which decrease exponentially with wavelength. This decline is due to the spectrum varying inversely as the square of wavelength or directly as the square of frequency. The suppression of some wavebands in this regular manner is consistent with locally-imbedded hierarchical structures which, although incorporating random variations, retain ordering at the macro-level because of the limited closed space postulated.

8. SOME IMPLICATIONS

Consider the previous models as referring to wages and that the government wishes to control the degree of areal differences occurring. It is unduly facile to say that efficiency would require easy substitution between people in jobs. Certainly this would allow the smallest differentiation in supply/demand relationships and thus repress the development of differences which could spread. But it is not ever

realistic to think of information spread as possibly instantaneous and universal. One must accept that personal acquaintanceship fields will always play a part in the working of labor markets. Consequently local wage differences will always be present even if only due to the differences or even the main forms of these differences are locally generated. Selection processes have been excluded in this paper and thus regional differences due to special resource inequalities which might justify large scale differentiation are not present.

What criteria should be used in assessing the control of such differentiation? Certainly from an equity viewpoint and probably on efficiency grounds, reducing the total spatial variance is to be recommended. Our present models point only to real time control of the transient processes: for example, the use of feedback from futures markets designed for the purpose [Curry (1976)] would be effective here since areas of either increasing or decreasing wages would be affected. The continuous space models do emphasize the arbitrariness of the boundaries used to define areas of operation and the necessity of administrative flexibility. The hierarchical model demonstrates this even more strongly with its leakages from any one town. Anything which stimulates greater mixing would also be important, especially at the primary level of labor such as better commuting facilities, migration incentives, education and re-education to improve job choice, improved information of the extensive type. At the secondary level, mixing via fiscal transfers can be of some assistance. Finally what shape of the areal spectrum is to be recommended? It certainly appears that differences occurring between large regions would be longer lasting than those at a small scale and thus be more inequitable over a long term. In these circumstances, measures to promote long-distance mixing should be especially useful. It does seem likely, however, given the nature of the processes in operation, that a spatial variance spectrum will always be with us. In our context it does not represent the field of choice of where to live for a well-informed, unconstrained individual à la Tiebout (1956). Rather it is imposed on the individual due to his limited information and the constraints on his repertoire of skills.

In this paper we have ignored any sort of selective process. In our context, where the environment is specified only in terms of the senders and receivers of job information, selection would occur as bias in the communication net among acquaintances as well as bias in the opportunity range among generations. This is not capitalist apologetics but rather recognition of the analytical difficulties involved; in any case the simpler situation needs to be examined to appreciate the more complicated and realistic. A small amount of work has been done on biased random walks [Montroll and West (1973)].

Lösch has argued that relative wages perform the same function regionally that rates of exchange do nationally [Lösch (1954)]. However, in both cases economic efficiency depends on good information. A shift in the rate of exchange does not induce changes in exports/imports without the necessary information flows and organizational flexibility. Thus in the absence of information there would be no restructuring of production so that sustaining of the change in exchange rates is due to lack of information. The equivalent case can be made for wage changes as the interregional adjustment process. Assuming capital can be

shifted at will and rent is regionally noninteractive, then the textbook argument for restablishment of equilibrium after switches in imports/exports is for wage rates to change and production to change accordingly. But as we have seen, supply and demand in labor markets cannot even be discussed without regard to information flows. A long-lasting change in the areal differentiation of wages must be due to insufficient information spread.

Nothing new is being said here since we know that labor is not homogeneous and the geographical differentiation in occupations has arisen under the same constraining information spreads as occurred before the areal differences developed. Areas are somewhat specialized, migration is not immediately possible, so that wage changes can last a long time. Nevertheless, information is the basis of labor market mechanics and any major improvements in the intensive forms of search will have large effects on the economy.

The author has begun to attempt the writing of articulated geographical theory in terms of the notion of potential [Curry (1978a, 1979)]. It is interesting to note that most of the present models could probably be treated in this mode. Beckmann (1957) has argued that "Migration may be regarded as the net outcome of the random movements of many persons subject to an external field force, derived from a potential. In the absence of a force, pure diffusion occurs from areas of high density to low densities; the vectors of net flow are a fixed proportion of the gradient of concentration." Since he wrote, it has been established that many diffusion processes also have a potential interpretation [Kemeny, Snell, and Knapp (1966)]. For instance, the information about a job might execute a two-dimensional random walk which would lead to a symmetrical bell-shaped potential operator for the location of a successful applicant. This operator convolutes the map of workers in a particular occupation so that this map itself denotes potential. However, this generalization via potential does not, at first glance, lead to fresh insights and so is not pursued further here. The virtue of a general theoretical formulation is not in the formal connections which can be made but rather in the facility with which various parts can be seen to be operating together.

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A REPLY TO "NUCLEAR POWER PLANTS AND RESIDENTIAL PROPERTY VALUES: A COMMENT ON SHORT-RUN vs. LONG-RUN CONSIDERATIONS"

Hays B. Gamble and Roger H. Downing*

In his comment about our earlier article in this journal, Galster suggests that there may be significant short-run negative effects on property values following a public announcement of the intended construction of a nuclear power plant, effects that we were unable to account for in our analysis. On theoretical grounds, we do not argue with this position. Nonindifferent households within the externality zone could place enough houses on the market to disrupt the normal market supply-demand relationships. If, at the same time, outside nonindifferent buyers shied away from the externality zone then further strain would be put on the housing market. On the other hand, one might argue that a nuclear power plant could have a positive short-run effect on local property values, (1) because of the large number of construction workers involved over a period of years, and/or (2) through the capitalization of lower real property taxes into land values due to the very large local tax contribution made by nuclear power plants in some states. We did recognize the possibility of some kind of short-run effects in our article, where we stated: "all plants were fully operational by mid-1972, so any market adjustments to the presence of the plants should have occurred" [Gamble and Downing (1982, footnote 10, p. 461)].

In fact, there were very severe short-run market effects immediately following the TMI accident, where for several weeks, the real-estate market virtually collapsed in the vicinity of the plant (remember, thousands of households temporarily fled the area). This was briefly discussed on page 476 of our article.

To support his argument, Galster places too much emphasis on a slightly slower rate of increase of property values between 1966 and 1970 within a 5-mile zone of TMI as compared to more distant properties. There is no factual basis by which one can claim that this slow rate of increase is due or not due to the announcement of the TMI plant. Other factors, of course, influence housing markets, one of the most important being employment in the area. Middletown, which abuts TMI, is an old industrial town which economically was strongly tied to the steel industry and to Olmstead Air Force Base which closed in the mid-1960s. At one time, about 12,000 civilians were employed at the air base. Harrisburg-area realtors all comment that for years the housing market in the Steelton-Middletown

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area has been considerably lower than in the greater Harrisburg area. To us the loss of 12,000 jobs seems a more plausible explanation for both lower property values and a slower rate of property value increase in the vicinity of TMI.

In conclusion, we agree with Galster that the case for short-run impacts "must be left to further investigations which collect data on property values soon after a plant location is announced" [Galster (1986, p. 805)].

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The Effect of Decisions About Spent Nuclear Fuel Storage on Residential Property Values

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National, regional, state, and local surveys have revealed that people have intensely negative images of "nuclear" and "radioactive" technologies, activities, and facilities, as well as associated fears of stigmatization. In light of these perceptions, the debate over where to temporarily store or permanently dispose of spent nuclear fuel (at the reactor site, an interim storage facility, or a permanent repository) provokes immense concern among possible host jurisdictions. To address these concerns, one needs to know if people's subjective opinions conform with the choices they make and are therefore reflected in their economic behavior. Argonne National Laboratory researchers used a hedonic model to complete a study of residential property value dynamics over a 5-year period within a 15-mile radius of two California nuclear power plants. They tracked the economic ramifications of decisions about the spent nuclear fuel stored at those reactors. The study revealed that no significant negative effects on residential property values resulted from a decision to move spent nuclear fuel from wet storage to a dry-cask storage facility or from a request to extend the reactor operating permit (given future changes in the type of nuclear fuel storage facility that would accompany such an extension).

KEY WORDS: Risk; perceptions; spent nuclear fuel; residential property; behavior.

1. INTRODUCTION

Congress continues to try to resolve the contentious problem posed by the increasing number of spent nuclear fuel rods that are accumulating at this nation's 73 commercial reactor sites in 34 states. In 1982, Congress enacted the Nuclear Waste Policy Act, assigning the U.S. Department of Energy (DOE) the responsibility for selecting a suitable site and constructing a mined, geologic repository to isolate spent nuclear fuel, which is considered high-level radioactive waste (HLW), for at least 10,000 years. In 1987, Congress redirected DOE to focus its site characterization activities only at Yucca Mountain, Nevada. In 1996, Congress tried to redirect the program again, but was unable to pass legislation for an interim storage facility on the Nevada Test Site. Now, in 1997, Congress is trying once more to redirect the $12 billion program to quickly "do something," because 23 reactors will run out of space in their on-site, water-filled storage pools in 1998. January 1998 is the mandated, court-reaffirmed date when DOE is supposed to begin accepting spent fuel from commercial reactors, but at present DOE is unable to do so.

A lack of public acceptance, fueled by perceptions of risk and a fear of stigmatization, have resulted in political opposition, a major obstacle to finding a logical, practical, and necessary solution to the problem of storing and disposing of spent nuclear fuel. In 1995, the Nevada legislature passed a joint resolution that verified the State's vehement opposition to the interim storage and permanent disposal of HLW in Nevada, stating it has "studied the economic, social, public health and safety and environmental impacts that are likely to result

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from the transportation and storage of high-level radioactive waste and spent nuclear fuel and has conclusively determined that transforming this beautiful state into a nuclear waste disposal area would pose a severe threat to the health and safety of the current and future generations of Nevadans and have devastating consequences on the tourist-based economy of the State of Nevada. . . ."[1] A Western governor expressed concern that possible negative stigma from an interim storage facility could "alter our image as a state, our environment or our tourism industry."[2] Utilities attempting to construct temporary independent spent fuel storage installations are encountering strong resistance from area residents, who often express concerns "about crops and property values, and whether the children will be able to farm or even live in the area."[3]

In this study, we examine changes in residential property values to provide evidence of whether (1) the public's perception of risk and fear of stigmatization, which are claimed to accompany decisions about spent nuclear fuel facilities, do exist, and (2) there is a link between these fears and the actual economic behavior of individuals. Two California nuclear reactor sites (Rancho Seco and Diablo Canyon) were selected to conduct research on this relationship with recent, quality data available on residential properties that were sold while spent nuclear fuel storage decisions and announcements were being made. The economic impact findings should be transferrable for estimating the economic effects of implementing two other siting alternatives—interim storage and permanent disposal—unless it can be shown that images and concerns about spent fuel differ depending on the specific location and siting alternative.

2. RESIDENTIAL PROPERTY VALUE CHANGE AS AN INDICATOR OF CONCERN

Property values are dynamic and very sensitive to surrounding land uses, especially when new land uses are unwanted and considered hazardous to the environment and population. Changes in residential property values can serve as behavioral indicators or a barometer of people's concern during the process of building an unwanted and hazardous facility—from the rumor of its possible siting through its construction and into its operation. Results of research on the property value effect of transmission lines,[4] incinerators,[5] landfills,[6,7] airports,[8] earthquake hazards,[9] and nuclear facilities,[10] as well as actual lawsuits that address the stigmatization and fear associated with Nuclear Weapons Complex facilities,[11] have generally revealed that the perceived risk concern is very localized; any economic effects that occur begin to taper off within 3 miles.

Researchers have studied residential property values in the vicinity of nuclear reactors as a proxy to assess people's concern over the health and safety aspects of nuclear power, their perception of risk, their fear of stigmatization, and the potential for economic impacts. Gamble[12] conducted a study of single-family properties in the vicinity of four nuclear power plants in the Northeast before the March 1979 Three Mile Island (TMI) accident, in which equalized assessed real property values and the hedonic approach were used. His research revealed "no evidence to indicate that nuclear plants have any measurable effects, positive or negative, on single-family housing prices."[12] The same analytic approach was used by Gamble and Downing[13] in examining property sales around the TMI plant after the accident; again, no adverse effects on property values were apparent through 1979. A study of TMI effects by Nelson,[14] which used a hedonic approach, revealed similar results: neither an absolute decline in prices nor a slower appreciation rate for housing sales recorded during May–December 1979. Critics maintain that these findings of no negative capitalization into land values could have been caused by the omission of variables that consider the impact of the public sector on property values.[15]

Recent surveys suggest that residents in the vicinity of operational and closed nuclear reactors are concerned about at-reactor storage of HLW. For example, when the issue of storage of spent fuel was receiving public attention, residents around three nuclear facilities (the Zion plant in Illinois and the Cook and Palisades plants in Michigan) were surveyed to determine their overall perceptions, imagery, sensitivities, and perceived risks concerning on-site storage at those facilities.[16] Residents were asked if it became widely known that a nuclear power plant within 50 miles of their home were to become a storage site for HLW for the foreseeable future, the effect that this knowledge would have on the value of their homes and their likelihood of moving. The responses were similar to those obtained in surveys about reactor sites, transportation routes for radioactive waste, and potential interim storage and permanent disposal facility locations. Of those who responded, most people believed home values would decrease; the average drop in home values expected by those projecting a decline was 25%. Twenty-one percent of the respondents said their chance of moving would greatly increase.

A heightened perception of risk and apprehension about stored spent fuel was confirmed in a random survey of households within an 8-km radius of the Hum-

boldt Bay plant in 1993.[17] In rating the risk levels of various decommissioning options for the plant, the greatest concern centered on whether spent fuel would be left on-site in casks or storage pools. The issue of on-site storage of HLW dominated public perceptions of risk; 27% of the respondents were "very concerned" about the prospect of maintaining the plant for 30–50 years in a state of dormancy with spent fuel kept on site.

People's economic decisions may not always correlate with their images and perceptions of risk; there appear to be paradoxes between thought and action.[18] While the public may possess intensely negative images of nuclear reactors and HLW, the actual economic choices of individuals appear to be made more on the basis of a pragmatic logic that relies on practical knowledge, experience, and the personal context of their attitudes and values.[19] Predictions of possible adverse economic impacts from perceptions and images must be reconciled with actual economic behavior before policy decisions can be made.

3. REACTORS, SPENT FUEL, AND PROPERTY VALUES IN CALIFORNIA

In this study, researchers used a hedonic model to investigate potential influences on residential property values over a 5-year period (1990–1994) in the vicinity of two California nuclear reactor sites offering different scenarios. Pacific Gas and Electric Company's Diablo Canyon nuclear power plant, operational since 1985, is a major employer in the San Luis Obispo area, with a work force averaging 1800. The utility also contributes to the local property tax base. Sacramento Municipal Utility District's Rancho Seco nuclear power plant near Sacramento, closed since 1989, employs fewer than 150 workers and pays no property taxes because it is owned by a local municipal utility.

The two utilities have been involved in making decisions about the storage of their current and future spent fuel, and this information has been disseminated to the public through the local newspapers. In October 1991, it was reported that Rancho Seco operators applied for a Nuclear Regulatory Commission (NRC) license to construct and operate a dry-cask storage facility at the reactor for its spent fuel.[20] After permits were received, facility construction began at the end of 1994, and the first storage module was delivered in March 1996. The idea of dry-cask storage at Diablo Canyon first appeared in the local newspaper in July 1992, as part of a story on DOE's announced position that the agency did not have an obligation to begin receipt of spent fuel in 1998, as congressionally mandated.[21] During the October 1992 NRC Atomic Safety and Licensing Board public hearings for a 15-year license extension (to 2025), the public expressed concern about what would happen to the plant's HLW after 2007; the pools could no longer accept new spent fuel and the federal government would not take it. The long-range alternative for Diablo Canyon would be to use dry-cask storage.

3.1. The Hedonic Model

The hedonic model views housing as a differentiated bundle of attributes, z_i, which collectively determine the value of a particular residential property. Attributes include the structural characteristics of the property (e.g., bedrooms, bathrooms, fireplace), features of the neighborhood (e.g., proximity to amenities and disamenities, fiscal conditions in the community, sociodemographic traits, accessibility to the workplace), time (which primarily influences prices through the effect of business cycles), and other defining variables (e.g., announcements, information dissemination, distance). Extensive descriptions of the hedonic price theory and the housing price model are discussed elsewhere,[10,22,23] and those discussions are not reproduced in this article.

3.2. Model Specifications

Because we were interested in determining the extent to which proximity to a nuclear power plant and its spent nuclear fuel storage activities influence sale prices of residences in the vicinity of the plant, we developed a hedonic model that controls for as many influences as possible. To avoid the bias from excluded variables in estimates of the implicit valuation of characteristics of nuclear plants, the model had to include attributes that vary spatially and could be correlated with proximity to the Rancho Seco or Diablo Canyon nuclear plants.

For this study, we employed four different hedonic models representing two separate residential property submarkets (above- and below-median sales price) for both Rancho Seco and Diablo Canyon by using multivariate regression analysis. The models include the following categories of variables: $\ln\text{RPRICE}_k = f$ (Structure, Neighborhood, Nuclear, Time). The real sale price of housing (measured in logarithmic form) in submarket k is a function of four vectors of determinants: Structure, Neighborhood, Nuclear, and Time. The submarkets are defined by the median price of housing in

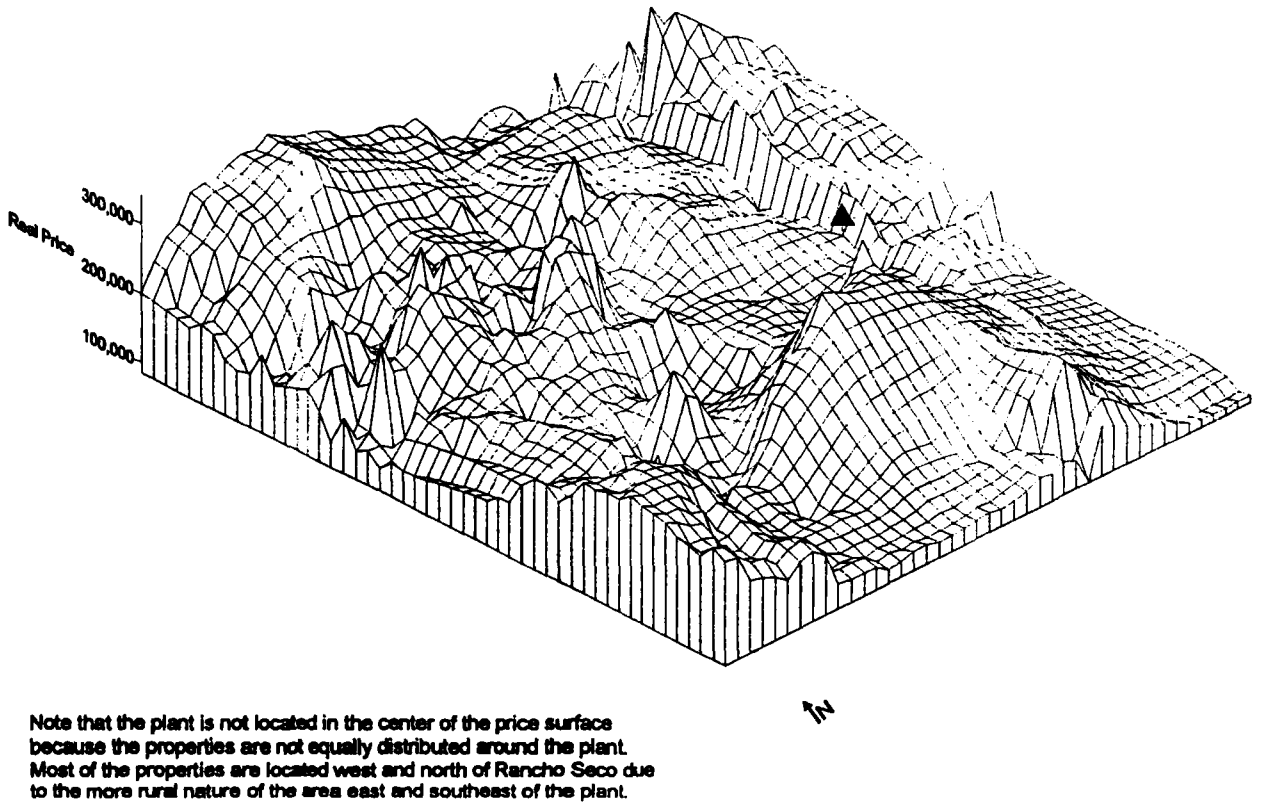


Fig. 1. Real estate price surface for all properties in sales sample (1990–1994) around Rancho Seco (15-mile radius).

the Rancho Seco sample ($134,836) and the Diablo Canyon sample ($162,677).

Residential property sales data were obtained from TRW REDI-Property and represent individual single-family residential property sales that took place between 1990 and 1994 within 15 miles of the Rancho Seco and Diablo Canyon nuclear plants.[3] The TRW sales price data were also screened to eliminate residences for which sales price and address data were incomplete and for which the real sales price was less than $10,000. This screening was done to reduce the likelihood that the transaction was not at arm's length (not market price) or that the quality of the structure was not adequately reflected in the structural characteristics. We also screened out 10 residences that sold for more than $400,000, again because of the likelihood that residences in this price range have unmeasured qualities. The screening yielded a sample of 765 residences in the vicinity of the Rancho Seco plant and 400 residences surrounding the Diablo Canyon plant.

Advanced geostatistical tools were used to graphically display the actual real sale price of residential properties over the 5-year period for 15 miles around each of the plants (Figs. 1 and 2). While there was no obvious pattern, these price surfaces did indicate that many factors influence residential property values. The hedonic model allowed researchers to distinguish among the various factors that affect sales prices.

Geographic Information System (GIS) software was used to precisely match *Neighborhood* and *Nuclear* variables to each residence. Because all residential property sales data are assigned latitude and longitude values, the distance to a specific neighborhood or nuclear characteristic can be readily computed as long as the location of the activity is also geocoded. This method was used for most of the variables. When data were defined by areal units (e.g., census tract and school district data), matching was based on those characteristics.

[3] An earlier paper by Clark *et al.* (1997)[22] estimated the housing price gradient for a 25-mile radius around the plant. Those findings suggest that when the gradient was statistically significant, a premium was associated with *proximity* to the plant for residences selling within approximately 15 miles of the plant. Given that much of the sample was composed of residences beyond 15 miles (the city of Sacramento is approximately 20 miles northwest of the Rancho Seco plant), we restricted this sample to the smaller radius to focus on residences closer to the plant.

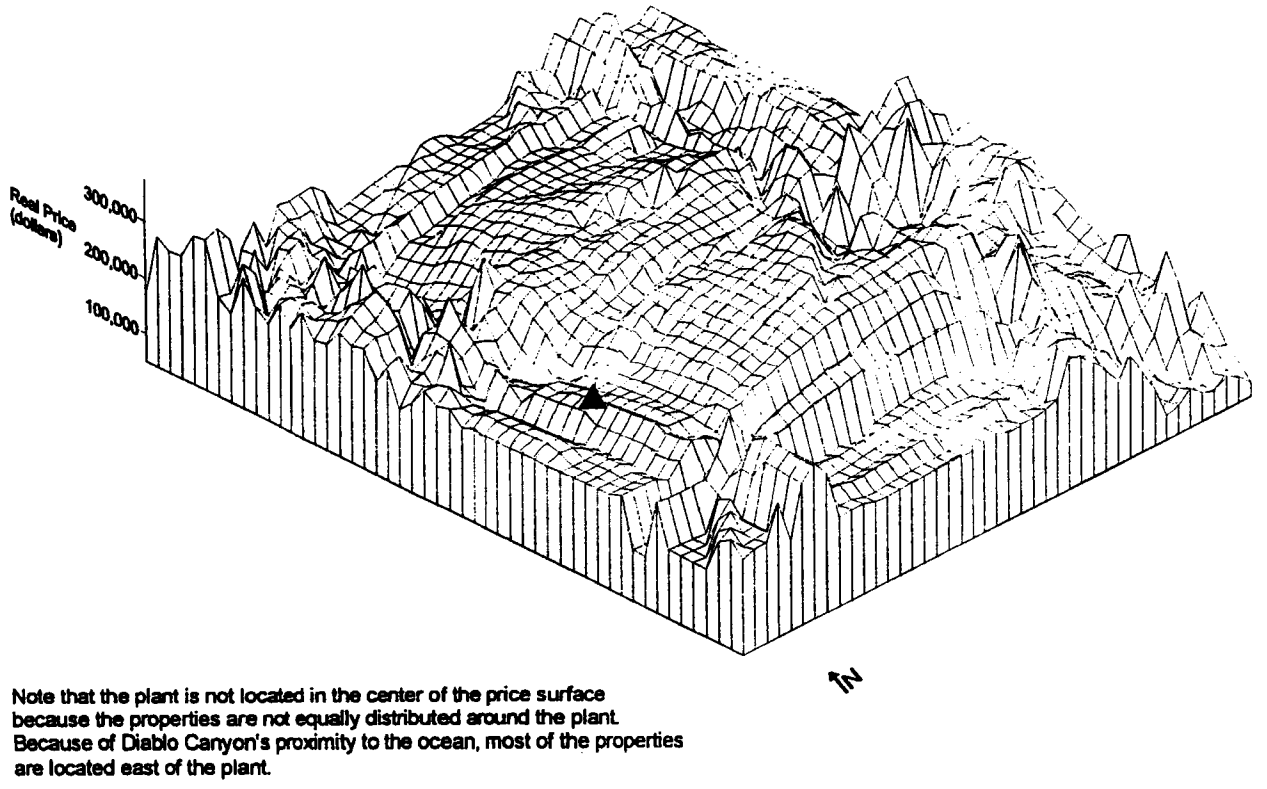


Fig. 2. Real estate price surface for all properties in sales sample (1990–1994) around Diablo Canyon plant (15-mile radius).

3.3. Independent Variables

A complete list of the variables used in the regressions, their definitions, and their descriptive statistics is provided in Table I. The *Structure* category contains characteristics of the residence. Among the selected variables are the age[4] of the residence; number of bedrooms, full bathrooms and half bathrooms, and fireplaces; stories in the structure; presence of central air conditioning (for the Rancho Seco sample only); and size of the lot on which the residence is located.

The *Neighborhood* category includes attributes that account for the influence of locational phenomena on residential housing markets. The variables include demographic measures characterizing the racial and ethnic mix in the neighborhood and poverty rates, as proxied by the percent of households receiving public assistance. Another neighborhood variable is the composition of the local housing stock. To capture the influence of local hazards and annoyance factors, we included variables of ozone pollution and proximity to interstate highways, railroads, airports and manufacturing facilities on the Toxic Release Inventory (TRI). We also determined the distance of residences from a coal-fired power plant in Morro Bay, north of Diablo Canyon.[5] The average travel time to work in the neighborhood was included to proxy access to jobs. The fiscal influences were measured by the effective property tax rate and the teacher/student ratio in the local public school district. Proximity to the ocean (Diablo Canyon), lakes, rivers, and streams was included to capture access to scenic vistas and recreational opportunities. Finally, a suburban variable was employed to capture unmeasured influences, both positive and negative, that are correlated with a suburban residence as compared with a central city residence. Population density proxies unmeasured density-related factors.

There are two selected variables in the *Time* category. Because the California economy experienced a significant recession beginning in 1992, we accounted for

[4] For the Diablo Canyon properties, when data for the AGEHOUSE variable were missing, we substituted the average value for the variable in the census tract in which the residence is located.

[5] We also had data on earthquake risks within the zip code in which the residence is located. The Federal Home Loan Mortgage Corporation conducted a study that ranked these risks as either low, moderate, or high. However, within the geographic region considered, these rankings did not vary.

Table I. Variable Description, Sign Expectation, Mean Value, and Standard Deviation

Variable name	Definition	Source	Sign	Mean Values		σ	
		Dependent variable and *Structure* variables					
LRPRICE	Natural log of the real sale price of the residential property (1990 dollars)	TRW REDI-property data nominal price divided by the national Consumer Price Index for residential properties	—	$Rancho_{above}$ = $191,292 $Rancho_{below}$ = $106,720 $Diablo_{above}$ = $220,004 $Diablo_{below}$ = $131,238 Mean values are actual real sale prices. Note: Ra = Rancho Seco above median Rb = Rancho Seco below median Da = Diablo Canyon above median Db = Diablo Canyon below median		Ra = 49,982 Rb = 16,716 Da = 50,261 Db = 24,018	
AGEHOUSE	Age of residence in years	TRW	?	Ra= 9.305 Rb= 14.675	Da= 23.150 Db= 25.205	Ra= 10.100 Rb= 14.321	Da= 14.149 Db= 14.561
BEDROOM	Number of bedrooms in the residence	TRW	+	Ra= 3.504 Rb= 3.068	Da= 2.945 Db= 2.580	Ra= 0.647 Rb= 0.589	Da= 0.674 Db= 0.668
CNTRLAIR	1 = central air conditioning, 0 otherwise	TRW (Rancho Seco only)	+	Ra = 0.864 Rb= 0.715	Da= ------- Db= -------	Ra= 0.343 Rb= 0.452	Da= ------- Db= -------
FIREPLACE	Number of fireplaces in the residence	TRW	+	Ra= 0.958 Rb= 0.749	Da= 0.875 Db= 0.525	Ra= 0.456 Rb= 0.480	Da= 0.875 Db= 0.520
FULLBATH	Number of full bathrooms in the residence	TRW	+	Ra= 2.248 Rb= 1.872	Da= 1.930 Db= 1.595	Ra= 0.505 Rb= 0.412	Da= 0.465 Db= 0.512
HALFBATH	Number of half bathrooms in the residence	TRW	+	Ra= 0.305 Rb= 0.076	Da= 0.145 Db= 0.110	Ra= 0.461 Rb= 0.265	Da= 0.353 Db= 0.329
LOTSIZE	Square feet of lot area	TRW	+	Ra= 0.305 Rb= 0.076	Da= 8847.9 Db= 5815.2	Ra= 0.305 Rb= 0.076	Da= 10006.3 Db= 5030.1
NUMSTORY	Number of stories in the residence	TRW	?	Ra= 1.253 Rb= 1.055	Da= 1.060 Db= 1.020	Ra= 0.459 Rb= 0.250	Da= 0.581 Db= 0.480
		Neighborhood variables					
OZONE	Distance-weighted value of nearest ozone monitor, computed as concentration divided by distance of monitor to residence	EPA-AIRS AQS database	—	Ra= 0.453 Rb= 0.460	Da= 1.369 Db= 1.359	Ra= 0.157 Rb= 0.181	Da= 1.005 Db= 1.303
AIRPORT	1 = airport within 2 miles of residence, 0 otherwise	FAA, MapInfo computed	—	Ra= 0.292 Rb= 0.212	Da= 0.010 Db= 0.070	Ra= 0.455 Rb= 0.409	Da= 0.100 Db= 0.256
INTRSTATE	1 = interstate highway within 0.25 mile of residence, 0 otherwise	Census TIGER database (1992) MapInfo computed	—	Ra= 0.044 Rb= 0.092	Da= 0.225 Db= 0.185	Ra= 0.206 Rb= 0.289	Da= 0.419 Db= 0.389
RAILROAD	1 = railroad tracks within 0.25 mile of residence, 0 otherwise	Census TIGER database (1992) MapInfo computed	—	Ra= 0.217 Rb= 0.249	Da= 0.050 Db= 0.070	Ra= 0.413 Rb= 0.433	Da= 0.218 Db= 0.256
%HISPANIC	Percent of census tract population of Hispanic origin	Census STF-3A 1990	?	Ra= 10.200 Rb= 14.101	Da= 7.439 Db= 8.482	Ra= 4.553 Rb= 6.890	Da= 2.481 Db= 3.529
%AFRAMER	Percent of census tract population of African-American origin	Census STF-3A 1990	?	Ra= 2.131 Rb= 1.440	Da= 1.148 Db= 1.006	Ra= 4.553 Rb= 1.143	Da= 0.859 Db= 0.814
%ASIAN	Percent of census tract population of Asian or Pacific Islander origin	Census STF-3A 1990	?	Ra= 3.461 Rb= 3.220	Da= 3.660 Db= 4.370	Ra= 1.899 Rb= 1.355	Da= 2.436 Db= 2.189
%OWNEROC	Percent of census tract occupied housing units - owner occupied	Census STF-3A 1990	+	Ra= 80.289 Rb= 75.038	Da= 51.660 Db= 54.210	Ra= 9.908 Rb= 7.101	Da= 13.425 Db= 11.923
TRI	1 = Rancho Seco property within 1 mile and Diablo Canyon property within 5 miles of TAI facility, 0 otherwise	EPA-AIRS AQS database	—	Ra = 0.089 Rb = 0.024	Da = ------- Db = 0.050	Ra = 0.286 Rb = 0.411	Da = ------- Db = 0.313
POPDENSITY	Population density of census tract	Census STF-3A 1990	?	Ra = 583.7 Rb = 1313.3	Da = 2176.7 Db = 3076.0	Ra = 1010.1 Rb = 1538.7	Da = 5822.4 Db = 7447.0

Table I. Continued

Variable name	Definition	Source	Sign	Mean Values		σ	
%OCCUNIT	Percent of census tract occupied housing units - occupied	Census STF-3A 1990	+	Ra= 94.470 Rb= 95.718	Da= 89.446 Db= 91.411	Ra= 3.738 Rb= 3.415	Da= 8.083 Db= 7.458
%WELFARE	Percent of census tract population that is on public assistance	Census STF-3A 1990	—	Ra= 6.707 Rb= 9.420	Da= 4.917 Db= 6.239	Ra= 3.133 Rb= 3.744	Da= 2.042 Db= 2.600
TAXRATE	1994 tax payment divided by 1994 assessed valuation	TRW	?	Ra= 0.011 Rb= 0.011	Da= 0.011 Db= 0.011	Ra= 0.001 Rb= 0.002	Da= 0.001 Db= 0.001
COMMUTE	Average travel time of households living in that census tract	Census STF-3A 1990	—	Ra= 27.921 Rb= 26.117	Da= 18.175 Db= 19.612	Ra= 2.870 Rb= 1.894	Da= 2.670 Db= 2.165
MORROBAY	1 = Morro Bay Power Plant within 5 miles, 0 otherwise	MapExpert and MapInfo computed	?	Ra= ------- Rb= -------	Da= 0.030 Db= 0.035	Ra= ------- Rb= -------	Da= 0.171 Db= 0.184
SUBURB	1 = suburb address, 0 otherwise	TRW	?	Ra= 0.945 Rb= 0.976	Da= 0.570 Db= 0.760	Ra= 0.228 Rb= 0.160	Da= 0.496 Db= 0.428
TSRATIO	Teacher/student ratio for the secondary or unified school district in which residence is located	CA State Department of Education Online Data Service	?	Ra= 0.039 Rb= 0.035	Da= 0.046 Db= 0.045	Ra= 0.006 Rb= 0.008	Da= 0.003 Db= 0.002
OCEAN	1 = ocean within 0.25 mile of residence, 0 otherwise	Census TIGER database (1992) MapInfo computed	+	Ra= ------- Rb= -------	Da= 0.180 Db= 0.125	Ra= ------- Rb= -------	Da= 0.385 Db= 0.331
WATER	1 = lake, river, or stream within 0.25 mile of residence, 0 otherwise	Census TIGER database (1992) MapInfo computed	+	Ra= 0.292 Rb= 0.298	Da= 0.430 Db= 0.390	Ra= 0.455 Rb= 0.458	Da= 0.496 Db= 0.489
				Nuclear and *Time* variables			
DISTANCE	Distance measured between the plant and the residence	MapInfo computed	?	Mean of DISTANCE			
DISTSQ	Distance squared			Ra= 11.786 Rb= 13.305	Da= 10.191 Db= 9.412	Ra= 2.904 Rb= 1.439	Da= 2.345 Db= 2.726
DATE	A sequential time trend defining the date of the sale	TRW	?	Mean of DATE			
DATESQ	The variable takes on a value of 1 on January 1, 1990, and a value of 1826 on December 31, 1994			Ra= 883.880 Rb= 1112.636 Da= 1094.800 Db= 1316.080		Ra= 550.377 Rb= 508.796 Da= 540.512 Db= 411.037	
DIST×DATE	Distance of residence from the plant interacted with the time-trend variable	MapInfo computed	?	Ra= 10163.38 Rb= 14769.86 Da= 11262.27 Db= 12504.42		Ra= 6860.980 Rb= 6916.827 Da= 6369.315 Db= 5454.315	
DIST×ANNC	Whether residence sold more than 45 days after application to NRC to build a dry-cask storage facility (Rancho Seco-10/14/91) or after announcement about storage issue (Diablo Canyon - 7/24/92) (i.e., 1 = yes, 0 = no) interacted with distance of residence from the plant	MapInfo computed	?	Ra= 6.932 Rb= 10.415	Da= 6.591 Db= 7.678	Ra= 6.135 Rb= 5.583	Da= 5.247 Db= 4.472

the influence of the recession by using a nonlinear time-trend variable (i.e., time of the sale in linear and nonlinear form). To allow the slope of the housing price gradient to vary with time, we interacted the time-trend variable with distance from the respective plant.

The *Nuclear* category contains four selected variables, all of which are related to the distance of the residence from the nuclear plant. We included distance, in linear and quadratic form, to allow for a nonmonotonic relationship between residence sale price and distance.

For example, it is possible that proximity to the plant is desirable (e.g., for workers at the plant). We also included date and announcement variables, which were interacted with distance from the plant, and, as previously noted, a time–distance interaction variable. Finally, we defined a variable to capture the influence of announcements about potential HLW storage decisions. To proxy public information on the status of spent fuel at the plant, we defined an announcement variable for each of the two plants. For Rancho Seco, the announcement variable equals 1 if the residence was sold at least 45 days after information about the application to the NRC to build a dry-cask storage facility first appeared in the dominant local newspaper, the *Sacramento Bee*, on October 14, 1991.[20] We staggered the variable by 45 days because we assumed that information made available within 45 days of the sale could not influence the sale price; presumably, a contract on the sale had already been accepted. Because we were interested in the influence of the announcement on the slope of the housing price gradient, we interacted the announcement variable with the distance of the residence from the plant. For Diablo Canyon, the announcement variable is the date the issue of dry-cask storage at the plant first appeared in the local newspaper, *Telegram-Tribune* (July 24, 1992), pertaining to DOE's position that it had no obligation to take spent fuel beginning in 1998.[21] Again, the announcement variable was staggered by 45 days, and it is interacted with distance from the plant to test the impact on the housing price gradient.

3.4. Empirical Findings

Chow tests were performed to determine whether residences below the median price could be combined with those above the median. The results revealed significant differences in the structures of the samples and indicated that pooling the samples would be inappropriate.[6] A White test was conducted to detect the presence of heteroskedasticity, and the null hypothesis of no heteroskedasticity was rejected at the 95% level of confidence for each of the above-median regressions (White's correction was used to generate consistent estimates of the standard errors). The empirical findings of the test are reported in Table II. The overall fit was substantially better for the Rancho Seco regressions, with the models explaining 39–48% of the variation in the log of real sales prices. By comparison, the Diablo Canyon models explained only 24–30% of the variation in the dependent variable.

For the Rancho Seco samples, additional structural features and larger lots generally increased the value of a residence, and these coefficients were frequently statistically significant at the 95% level of confidence.[7] Multistory residences had lower values, other factors being equal. This finding may reflect the preference of elderly buyers for single-story residences. Older residences sold for lower prices, but the coefficient was not statistically significant in the above-median sample, and it was significant only at the 90% level in the below-median model. The general insignificance of coefficients in the Diablo Canyon samples was somewhat surprising. Specifically, only bathrooms (half bathrooms in the above-median, and full bathrooms in the below-median samples) and fireplaces (in the above-median sample) significantly influenced real residential property prices. Larger lot sizes increased sale prices in the above-median sample, but surprisingly, they were associated with lower valued residences in the below-median model.

In the *Neighborhood* category, there is some evidence that proximity to railroads (Rancho Seco, below-median sample) lowered real sale prices. Proximity to the ocean increased residential property values for above-median Diablo Canyon residences, but interestingly, the coefficient on the ocean variable in the below-median sample was negative and significant. Although none of the occupancy rate variables were significant in the Diablo Canyon samples, three of the four coefficients in the above-median Rancho Seco samples were statistically significant. Specifically, high occupancy rates were associated with higher residential property values in the below-median Rancho Seco sample, whereas they were correlated with lower values in above-median sample. This result may reflect the absence of negative externalities associated with housing abandonment in lower-priced neighborhoods, whereas lower occupancy rates in higher-priced neighborhoods may result from active new construction activity. High owner-occupancy rates (as opposed to rental occupancy) increased real residential property prices in the above-median sample. Contrary to the predictions of urban location theory, prices became higher as the average commute increased. Note, however, that the geographic

[6] For the Rancho Seco model, the actual $F = 22.44$ (at the 95% level of confidence) exceeded the critical $F_{30,703} = 1.46$. Likewise, the actual $F = 12.55$ was greater than the critical $F_{30,336} = 1.46$ in the Diablo Canyon sample.

[7] Although sign predictions exist for some coefficients, we chose to evaluate all coefficients by using two-tailed t-tests for the sake of simplicity. We also noted that all coefficients on variables in the *Time* and *Nuclear* categories, which are the variables of primary interest in this article, did not have sign predictions and should be tested by using two-tailed t-tests.

Table II. Hedonic Regression Findings for Residential Properties Selling within 15 Miles of a Nuclear Power Plant (*t*-statistics in parentheses)

	Diablo Canyon samples			Rancho Seco samples	
Variable	Below median coefficient	Above median coefficient	Variable	Below median coefficient	Above median coefficient
Constant	10.74895***	13.85858***	Constant	8.032354***	13.14613***
	(5.04)	(9.75)		(5.95)	(18.45)
			Structural variables		
BEDROOM	−0.010414	0.036152	BEDROOM	0.062134***	0.061428***
	(−0.33)	(1.30)		(4.28)	(3.46)
HALFBATH	−0.052459	0.082793**	HALFBATH	0.083594***	0.093517***
	(−1.05)	(2.05)		(2.61)	(3.73)
FULLBATH	0.096395**	0.030001	FULLBATH	0.036743	0.122492***
	(2.27)	(0.75)		(1.59)	(2.68)
----------	----------	----------	CNTRLAIR	0.059098***	−0.069352*
				(2.69)	(−1.86)
FIREPLACE	0.003134	0.045378*	FIREPLACE	0.124603***	0.037575*
	(0.10)	(1.65)		(6.81)	(1.84)
NUMSTORY	−0.032388	−0.020246	NUMSTORY	−0.054680	0.078309***
	(−0.94)	(−0.79)		(−1.54)	(−3.37)
AGEHOUSE	0.000423	−0.001725	AGEHOUSE	−0.001090*	0.002001
	(0.25)	(−1.08)		(−1.72)	(−1.55)
LOTSIZE	−1.41E-05***	9.10E-06***	LOTSIZE	1.40E-07	7.01E-07***
	(−4.21)	(3.97)		(0.37)	(6.06)
			Neighborhood variables		
OZONE	−0.009209	0.051723	OZONE	−0.219655	0.323859
	(−0.03)	(1.45)		(−0.77)	(0.99)
INTERSTATE	−0.079505	−0.059272	INTERSTATE	−0.009287	0.029768
	(−1.05)	(−1.28)		(−0.28)	(0.94)
RAILROAD	−0.062872	−0.037725	RAILROAD	−0.039129*	−0.018133
	(−0.60)	(−0.54)		(−1.74)	(−0.76)
WATER	0.053349	−0.006238	WATER	−0.029366	−0.000785
	(0.98)	(−0.15)		(−1.52)	(−0.03)
OCEAN	−0.139979**	0.176873***	----------	----------	----------
	(−2.00)	(2.97)			
%OWNEROCC	−0.001312	−0.003485	%OWNEROCC	−0.006483	0.005503**
	(−0.31)	(−0.92)		(−1.43)	(2.49)
%OCCUNIT	0.009149	−0.006502	%OCCUNIT	0.027390***	−0.024944***
	(1.05)	(−0.96)		(2.82)	(−5.72)
%WELFARE	0.062817*	0.004764	%WELFARE	−0.028639**	0.004381
	(1.85)	(−0.24)		(−2.50)	(0.48)
COMMUTE	0.033924	−0.020627	COMMUTE	0.031657*	0.000639
	(1.02)	(−0.74)		(1.89)	(0.04)
%ASIAN	−0.024255*	−0.004896	%ASIAN	0.029243	−0.024986
	(−1.83)	(−0.34)		(1.46)	(−1.63)
%AFRAMER	−0.019936	0.052033	%AFRAMER	−0.071736**	0.060765***
	(−0.20)	(0.81)		(−2.54)	(3.52)
%HISPANIC	−0.049775	−0.031186*	%HISPANIC	0.021655**	0.007048
	(−1.52)	(−1.78)		(2.20)	(0.99)
TSRATIO	−0.319548	4.033966	TSRATIO	16.18235***	1.898584
	(−0.02)	(0.50)		(3.22)	(0.56)
TAXRATE	−54.85800	5.924070	TAXRATE	2.263648	−30.35946**
	(−1.27)	(0.82)		(0.49)	(−2.15)
TRI	−0.044389	----------	TRI	−0.001270	−0.070373**
	(−0.59)			(−0.05)	(−2.10)

* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.

Table II. Continued

Variable	Diablo Canyon samples: Below median coefficient	Diablo Canyon samples: Above median coefficient	Variable	Rancho Seco samples: Below median coefficient	Rancho Seco samples: Above median coefficient
POPDENSITY	−4.28E-06*	−3.82E-06*	POPDENSITY	−1.57E-05	1.88E-05
	(−1.89)	(−1.76)		(−1.02)	(1.47)
AIRPORT	0.077568	0.104871	AIRPORT	−0.034583	0.040883
	(0.38)	(0.53)		(−0.93)	(1.39)
SUBURB	−0.273325	0.053472	SUBURB	0.842166	0.983682
	(−1.41)	(0.34)		(1.16)	(0.27)
MORROBAY	0.066387	−0.008998	----------	----------	----------
	(0.67)	(−0.16)			
		Time and nuclear variables			
DATE	−1.73E-06	−0.000469***	DATE	0.000388***	0.000287**
	(−0.01)	(−2.89)		(2.69)	(2.17)
DATESQ	−1.07E-07	1.36E-07***	DATESQ	−9.03E-08**	1.16E-07***
	(−1.47)	(2.51)		(−2.16)	(−2.58)
DISTANCE	0.119518	−0.091606	DISTANCE	−0.036092	0.102421***
	(0.67)	(−0.67)		(−0.41)	(3.16)
DISTSQ	−0.005364	0.003004	DISTSQ	0.001406	−0.005406***
	(−0.67)	(0.49)		(0.32)	(−2.48)
DIST×ANNC	−0.006264	−0.001734	DIST×ANNC	−0.001907	−0.002864
	(−0.86)	(−0.29)		(−0.59)	(−0.85)
DIST×DATE	1.74E-05	1.71E-05	DIST×DATE	−1.91E-05**	−1.17E-05
	(1.05)	(1.54)		(−2.05)	(−1.58)
Number obs.	200	200		382	383
R^2_{Adjusted}	0.245	0.304		0.393	0.482
F-statistic	3.017***	3.805***		9.974***	12.462***

* Significant at .10 level.
** Significant at .05 level.
*** Significant at .01 level.

scope of the study (15 miles from the plant) limited the number of central city residences included in the samples. Proximity to manufacturing facilities on the Toxic Release Inventory significantly reduced residence values in the above-median Rancho Seco sample. Finally, population density significantly decreased residential property prices in both Diablo Canyon subsamples.

There is some evidence that the racial and ethnic makeup of the neighborhood influenced real residential property prices, although the direction of the influence varied across samples. Residences in census tracts with a relatively high proportion of African-Americans sold for lower prices in the below-median Rancho Seco sample. However, an increase in the percentage of African-Americans was related to higher real sale prices in the above-median Rancho Seco sample. It should be noted that the percentage of African-Americans in all samples was quite low (ranging from 1 to 2%). Increases in the percentage of Hispanics significantly increased values in the below-median Rancho Seco sample (note that the Hispanic population averaged 14% in this sample), although it had the opposite effect in above-median Diablo Canyon samples where Hispanics averaged just 7% of the population.

Fiscal variables influenced real residential property values. Higher teacher/student ratios in public schools increased the value of residences in the below-median sample in Rancho Seco. Relatively higher property tax rates decreased values in the above-median Rancho Seco market, although the tax rates of properties varied only slightly as a result of California property tax reforms.

In the *Nuclear* category, very few variables revealed any statistically significant influence. In fact, significant linear and quadratic distance variables were observed only for the above-median Rancho Seco sample. In that sample, real residential property prices rose for the first 9.5 miles and fell thereafter. Note that the majority of the data, 79%, were for areas located beyond

the peak, so although it appears that prices rose for 9.5 miles (other factors being equal), very few residences drove this trend. Furthermore, the date–distance interaction term had a negative coefficient, implying that the peak of the distance gradient moved 0.39 of a mile closer to the plant each year of the sample, moving to 7.6 miles by the end of 1994. However, this coefficient was not quite statistically significant ($t = 1.58$). For the Diablo Canyon samples, none of the distance-related variables were statistically significant. The announcement interaction variables were statistically insignificant in both Diablo Canyon samples.

Finally, the variables in the *Time* category were frequently statistically significant. For the Rancho Seco samples, residential property prices increased at a decreasing rate with time. The peak in the below-median sample occurred beyond the last year of data (i.e., October 1995). This is somewhat surprising, given the economic recession that took place in the early 1990s in California. However, note that these findings assume that the interaction term between distance and time is, in fact, zero. Taking the influence of the negative interaction term into account, we found that the peak for residential properties at the average distance from the plant (13.3 miles) occurred in January 1992. These findings are more in line with expectations. For the above-median Rancho Seco sample, real residential property prices peaked in September 1991 for the residences at the average distance (11.8 miles), although the interaction term was not quite significant ($t = -1.58$). The only Diablo Canyon sample with any significant time-related coefficients was the above-median sample. Here, unlike in the Rancho Seco sample, residential property prices declined *ceteris paribus* through December 1991 (for the residence at the average distance of 10.2 miles) and then began to improve. Note that again, the interaction term between time and distance was also slightly below significance at the 90% level of confidence ($t = 1.54$).

4. CONCLUSIONS

Evidence collected in public opinion surveys indicate that the public holds intensely negative images and a fear of stigmatization with regard to anything "nuclear" and "radioactive," including nuclear reactors, spent nuclear fuel storage facilities, permanent repositories, and the transport of HLW. The public's perception of risk has been a strong emotional impediment to the implementation of congressionally mandated and court-reaffirmed HLW storage and disposal alternatives. Claims have been made that there is the potential for possible significant economic impacts to accompany any siting of HLW facilities.[24] It is critical, therefore, for policy- and decision-makers to both listen attentively to the public's concerns and understand the economic implications of those concerns, as reflected by patterns of past and present individual economic behaviors.

Our study of two California plants reveals that decisions and announcements about spent nuclear fuel storage activities have not affected the local residential property market to the extent predicted by surveys of attitudes and images. Our hedonic model results indicate that this finding of no property value effect is the case regardless of whether a plant is operating or closed or whether the HLW is to be placed in dry-cask storage facilities immediately or as part of a future action. Of course, these findings reflect only the current residential property value situation around the two California plants; we made no attempt to determine whether there were effects on residential property values at the time of the reactors' siting announcements and construction.

From a policymaking perspective, our findings seem to suggest that policy initiatives that attempt to anticipate public reaction to nuclear facility siting based only on surveys of public perceptions and images may be overestimating the extent of the reaction in the local economy, as reflected in residential property values. If people's choices and economic behaviors do not reflect their opinions, the storage and disposal placement options might have no economic effect, regardless of whether the spent fuel were to remain at a reactor for the foreseeable future, be relocated to interim storage facilities, or be relocated to a permanent repository.

If the many predictions about possible significant adverse economic impacts and social costs in an area hosting spent nuclear fuel storage facilities do not appear to correlate with revealed economic behaviors, it may be that the public bases behavior on a countervailing pragmatic logic built on practical knowledge, experience, and personal context. There is a vital need for more research regarding the causal links between people's perceptions of risk and fear of stigmatization and their individual behavioral actions related to nuclear reactors, HLW storage and disposal activities, and HLW transportation. Research should match property value studies with surveys of people in the vicinity of reactors where changes are occurring in spent fuel storage methods. It could determine, for instance, whether they are aware of the reactor and its location, whether they can provide information on the national and local spent fuel situation, when they moved into the area, what they knew

about the reactor when they relocated, and what factors influenced their decision to purchase a residence in the area. Researchers should also review trends in residential property values along corridors where HLW has been transported or will be transported in the future.

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The impacts of nuclear facilities on property values and other factors in the surrounding communities

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Abstract: This paper addresses the issue of the impact of the siting of nuclear facilities on the adjacent communities. It reviews previous studies on the issue and then empirically examines the impacts of seven major nuclear facilities located throughout the USA on the surrounding communities. The analysis focuses on the effects on local property values, economic growth, tax revenues, public services, community development, jobs and employment, and schools. Using published data, economic and statistical analyses, literature reviews and interviews, it finds that the impacts of these facilities have been largely positive. The findings are placed in perspective, caveats are noted concerning the generalisation of the conclusions derived and recommendations for required further research are provided.

Keywords: nuclear facilities impact; property values; nuclear energy benefits; local community tax revenues; nuclear facilities jobs.

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1 Introduction

The impacts of nuclear facilities on adjacent communities have long been a controversial issue – impacts on real estate, property values, employment, taxes, public and social services, economic development, cultural parameters, *etc*. Those opposed to the siting of nuclear facilities contend that they depress property values and have other negative effects on nearby communities, while the industry contends that the opposite is the case. While the debate among advocates, interest groups and industry has been intense, there has been insufficient empirical analysis of the issues involved. Here we assess the impacts of seven major nuclear facilities located throughout the USA on the surrounding communities. Using published data, economic and statistical analyses, literature reviews, and interviews, we find that the impacts of these facilities have been largely positive.

There are five major factors that influence property values, and the presence of nuclear facilities tends to have a favourable impact on all of these. First, the quality of the available real estate is important, and the jobs and incomes generated by the facilities often enable construction of quality housing. Second, jobs and incomes in the local economy are critical, and, as discussed in Section 4, the facilities provide jobs and incomes for local area residents. Third, good schools are a prime determinant of property values and, as discussed in Section 6, the tax revenues generated significantly improve the schools. Fourth, reasonable property tax assessments are important, and the taxes paid by the facilities permit lower commercial and residential real estate assessments. Finally, adequate public services and infrastructure are important and, as discussed in Section 5, the revenues generated by the facilities fund a higher level of public services. We found these factors to be positive for the facilities analysed.

However, we caution against making valuation decisions relating to any particular property's or groups of properties' market values on the basis of the research summarised here. This is not the intent, and individual property conclusions cannot and should not be drawn from this paper. Rather, we present findings that indicate that there are market experiences that are known and that should be considered.

2 Previous studies

Over the past three decades, there have been a number of studies on the impact of nuclear facilities on the adjacent regions, although some are now dated. Below, we summarise the more significant of these.

Nelson (1981) examined the effect on residential property values of the Three Mile Island (TMI) nuclear accident. He noted that, while two government reports argued that the accident caused a decline in property values, particularly in residential areas closest to the plant, neither report utilised even elementary statistical inference methods. His objective was to determine if the accident caused a statistically significant decline in prices (or a slower appreciation rate) for houses situated within five miles of the plant, and if a permanent, lasting concern about the accident had been capitalised negatively into property values. He first used a hedonic price model to examine the effect of TMI on sale prices of homes in two communities located within four miles of the plant, and then extended the analysis to include all multilisting sales within five miles of the plant.

He found that the accident at TMI caused neither an absolute decline in prices nor a slower appreciation rate for housing sales recorded during the period May–December 1979, and that there were no statistically significant differences between prices in the five-mile area and two control areas. His empirical analysis thus showed no statistically significant decline in residential property values in the vicinity of TMI. The results suggested that the cost of the accident was perceived as short-term, or that, at least, any expected future costs had not been capitalised into the value of residential property.

In a landmark study, Gamble and Downing (1982) presented statistical evidence for sales values of single-family properties in the vicinity of four nuclear power plants in the north-east during the period 1975–1977, and in the vicinity of the TMI nuclear plant during the period 1977–1979. They concluded that there was no significant impact on property values due to proximity to a nuclear power plant, even after the March 1979 accident at TMI.

Gamble and Downing used regression analysis with linear and log-log functional forms to determine whether proximity to the TMI nuclear facility after the TMI accident had any measurable effect on property prices. They compared 583 residences within 25 miles of the plant with homes in a control neighbourhood 75 miles away, both before and after the accident occurred using a hedonic model to isolate the pricing impacts of the event. Their analysis of all valid single-family house sales over a four-year period before the accident and over the nine months following the accident, and within a 25-mile radius of the plant and in two control areas, disclosed no evidence that the accident had measurable lasting effects on residential property values. Shortly following the accident, there was a sharp decline in the volume of residential sales within ten miles of the plant and there was a collapse in the property market around the plant, but the real estate market returned to normal within two months, considering the financial market conditions at that time. They thus found no statistically significant relationship.

They found that immediately after the accident there was a collapse in the property market around the plant, but within eight weeks, the market appeared to recover. Gamble and Downing reported that there was a large influx of clean-up workers and nuclear technicians after the accident and surmised that this influx may have had a positive effect on property prices. They also suggested that the absence of observed capitalisation effects from the accident may have been due to expectations of government compensation. However, these observations were speculative. In particular, the workers would have been short-term residents who may have put upward pressure on rents, but would not be expected to affect long-term expectations of capital growth in housing prices.

Galster (1986) analysed the Gamble and Downing findings and argued that their research overlooked potentially significant short-run impacts because it implicitly employed a long-run perspective. Galster contends that the Gamble and Downing findings and related research can only be interpreted as having demonstrated that nuclear power plants do not have any significant long-run impacts on proximate property values and that theory suggests that the short-run impact may be considerably higher. To test this hypothesis, he recommends empirical investigations which collect data on property values soon after a plant location is announced. He feels that just because a long-run impact is nil does not necessarily remove the issue from the agenda of public concern, and that the short-run adjustment costs borne by some located near nuclear power sites may be substantial.

Clark *et al*. (1997) used a hedonic model and geographic information system techniques to estimate housing prices around two nuclear power plants in California. Based on the evidence from the plants chosen, their findings did not support the contention that negative imagery surrounding nuclear power plants or stored nuclear waste has a significant detrimental influence on residential home prices in the immediate vicinity of these facilities. In fact, they found that the opposite was the case; that is, housing located closer to the plants commanded a premium in the market.

Their findings at Diablo Canyon indicated a housing price premium until the household is about 23 miles from the plant, and they found that any negative property value impacts resulting from perceived risks associated with the plant do not overwhelm accessibility and other desirable attributes, which are correlated with proximity to Diablo Canyon. For the Rancho Seco plant, which is no longer operating and which is more visible than the Diablo Canyon plant, they found that residential home prices actually rose with proximity to the plant for those properties closest to the plant (within 11 miles). Their research suggests that some individuals may actually be likely to place premiums on proximity to nuclear plants. They thus concluded:

> "Based on evidence from the two California plants studied, we conclude that any negative imagery associated with nuclear power plants or stored nuclear waste does not translate into a significant detrimental influence on residential home prices in the immediate vicinity of the facilities studied."

In Rephann (1997) noted that nuclear power plants tend to employ relatively few local residents, instead requiring trained specialists likely to be selected from national employment searches. They represent a small risk because of the known hazards associated with fission reactors. Because of their potential dangers, it is conceivable that they may deter residents and firms from locating to the area. However, such an assessment is not supported by hedonic price studies that show nuclear power plants having no negative impact on local property values. He hypothesised that the negative effects of nuclear power plants may be offset by the often huge surplus tax revenues that result from taxing the commercial facilities. In effect, the enterprise subsidises residents and firms, making the communities more attractive candidates for additional private investment than they would be otherwise.

The effects of nuclear power plants should be most noticeable in transportation, communication and public utility earnings because nuclear power plants are public utilities. In addition, state and local government earnings should be stimulated if the plant contributes generously to the local property tax base, as previous studies seem to indicate. Rephann's findings confirmed these expectations and also indicated that transfer payments are stimulated. However, he found that there were no corresponding employment effects and that secondary multiplier effects in tertiary sectors were also absent. Therefore, he concluded that the direct employment effects of nuclear power plants are relatively small and thus do not create ripple effects through the local economy.

Metz *et al*. (1997) used market-based techniques to interpret five years of historically generated property transaction data from around two California nuclear power plants. Their goal was to assess actual individual behaviour and choice in relation to a property's proximity to nuclear reactors, where high-level nuclear waste storage was an issue. Regression results were found to be statistically significant for properties within 15-mile and 25-mile circles of the Rancho Seco plant, based on distance-related variables in the

nuclear category; that is, they found that there was a premium associated with proximity to the plant. They reported no statistically significant findings on the effect of proximity to the Diablo Canyon plant.

In their analysis of the influence of general newspaper coverage, they found that only a very small number of property sales within 25 miles of Rancho Seco reflected a statistically significant aversion to the plant. When the effects of specific published announcements about plans to store current and future spent nuclear fuel at the plants on property sales within 15 miles were analysed, the results indicated only minor influences from media coverage, and the general shape of the housing-price gradient was unchanged. Their results thus suggest that any perceived risk, negative imagery or stigma that may exist with respect to the nuclear facility is overwhelmed by accessibility effects associated with a desire to reside close to the workplace or other local economic or environmental influences.

Clark and Allison (1999) analysed whether public knowledge of spent fuel storage at nuclear power plants, and any local adverse risk perceptions that may have occurred, affect the sale price of single-family residential properties. They presented evidence from the Rancho Seco, California, plant on residential property values using a hedonic modelling framework, and included a large number of control variables, data with a high level of spatial detail and a number of public information variables in order to model property market effects within a 15-mile radius of the plant. Their findings indicated that proximity and visual reminders of the plant have some influence on local property markets, and that there is a small media coverage effect on single-family home sale price.

Folland and Hough (2000) examined the effects of nuclear power plants on property values by assembling a large panel of all commercial market areas in the contiguous USA, observed 11 times over roughly equal intervals covering the span from 1945 to 1992. They found that the preponderance of significant, negative estimated effects across all varieties of models strongly suggested a negative nuclear externality and one that appears throughout the major portion of the nuclear era. Part of the observed negative effect on land prices is only apparent, most likely contributed by the actions of energy companies and governments who seek out cheap land for installations. Removing spurious effects nevertheless left a significant negative installation effect.

Their findings supported the hypothesis that the discrepant findings in literature derive less from error than from alternative study designs. Comparisons across areas, which reported a significant negative effect of nuclear power plant installation, are compatible with studies of variations within areas, which show little or no effect on housing prices due to the distance from the plant. They concluded that a meta study reexamining the distance gradient studies should show different asset price levels when compared to matched nonnuclear areas.

In Gawande and Jenkins-Smith (2001) utilised data on 9400 real estate transactions in South Carolina to model the effects of a series of highly publicised shipments of spent nuclear fuel to a storage facility at the Department of Energy's Savannah River Site. They obtained results with important implications for the kinds of effects that nuclear waste shipments may have on property values. In areas with lower risk perception and more experience with nuclear materials management, they found that the shipments did not affect property values. However, in more populous urban areas, property values appear to have been lowered in a substantial manner. They noted that, if shipments of radioactive waste are shown to lower property values due to public perceptions of risk, it might not matter whether public perceptions of risk are accurate.

3 The nuclear facilities analysed

Seven nuclear facilities, which cumulatively have about 140 years of operation, were analysed. Three are waste disposal facilities and four are nuclear power plants – (Table 1). They represent various types of major nuclear facilities located throughout the country, but they are not meant to be comprehensive and do not constitute a statistically valid random sample of all the nuclear facilities in the UA.

3.1 The Barnwell Nuclear Waste Disposal Facility

Barnwell is a low-level radioactive waste disposal facility operated by Chem-Nuclear Systems on 235 acres in Barnwell County, South Carolina, 103 acres of which are used for waste disposal, and is the only low-level radioactive waste management facility in the country that has operated continuously since its start-up. It commenced operations in 1971 and currently employs 300 persons. About 28 million cubic feet of low-level radioactive waste have been buried at the site since 1971.

3.2 The Waste Isolation Pilot Plant

The Waste Isolation Pilot Plant (WIPP) is a transuranic waste disposal facility located in Eddy County, New Mexico, 26 miles East of Carlsbad, and is the world's first deep geologic repository for long-lived radioactive waste. WIPP is a repository for US defense-related transuranic waste, which is disposed of in underground salt beds. WIPP is capable of holding up to 6.2 mcf of waste. WIPP began operations in 1988 and received its first shipment of waste in March 1999. It is managed by the Department of Energy and operated by TRU Solutions, and employs 800 people.

3.3 The Envirocare Facility

Envirocare of Utah, Inc. (1988) operates a low-level radioactive waste and mixed waste disposal facility in Clive, Utah that accepts waste that contain both radioactive and hazardous contaminants. It commenced operations in 1988.[1] It treats 150 tons of material per day, disposes of 12 320 000 cf of material annually and is licensed to dispose of 300 different mixed waste (Envirocare of Utah, Inc., 2001). The facility employs 400 workers.[2]

3.4 The South Texas Project nuclear generating station

The South Texas Project (STP) is located in Matagorda County, Texas, 90 miles South-west of Houston, and consists of two 1250 MW Westinghouse pressurised water reactors.[3] Unit 1 went into service in August 1988 and Unit 2 in June 1989. STP is the largest electricity-generating station in Texas, and is among the largest generating stations in the country. The site covers 12 200 acres, – including a 7000 acre cooling water reservoir, the largest above-ground reservoir in the world – provides enough electricity to serve 500 000 homes, and employs 1500 persons.

Table 1 Summary of the seven nuclear facilities examined

Facility	*Description*	*Location*	*Initial year of operation*	*Employees*	*Size* (acres)
Nuclear Waste Management Facility	Commercial low-level radioactive waste disposal facility	Barnwell County, South Carolina	1971	300	235
Waste Isolation Pilot Plant	Transuranic waste disposal facility	Carlsbad, New Mexico	1988	800	5100
Envirocare Mixed Waste Disposal Facility	Low-level radioactive waste and mixed waste disposal facility	Clive, Utah	1988	400	640
South Texas Project	2500 MW nuclear power plant	Matagora County, Texas	1988	1500	12 200
River Bend Nuclear Generating Station	940 MW nuclear power plant	West Feliciana Parish, Louisiana	1986	800	3400
Callaway Nuclear Power Plant	1150 MW nuclear power plant	Callaway County, Missouri	1984	750	7200
Wolf Creek Generating Station	1200 MW nuclear power plant	Coffey County, Kansas	1985	850	10 000

Source: Management Information Services, Inc. (2005)

3.5 The River Bend Nuclear Generating Station

The River Bend Station (RBS) is a nuclear electric power plant located in West Feliciana Parish, Louisiana, on the Mississippi river. The plant is owned by Entergy and has an electricity-generating capacity of 940 MW. It utilises a General Electric boiling water reactor, occupies 3400 acres, and serves 1 000 000 retail customers. The plant was completed in 1986 and employs 800 persons.

3.6 The Callaway Nuclear Power Plant

The Callaway Nuclear Power Plant (CNPP) is located in Callaway County, Missouri, ten miles south-east of Fulton. The plant is a pressurised water reactor using a Westinghouse nuclear steam supply system, and is owned by the AmerenUE company. It entered service in 1984 and produces 1150 MW. AmerenUE owns 7200 acres at the site, 6800 of which are administered by the Missouri Department of Conservation and Wildlife Management. The plant serves 750 000 customers, is the largest generating station in the AmerenUE system, and has 750 employees.

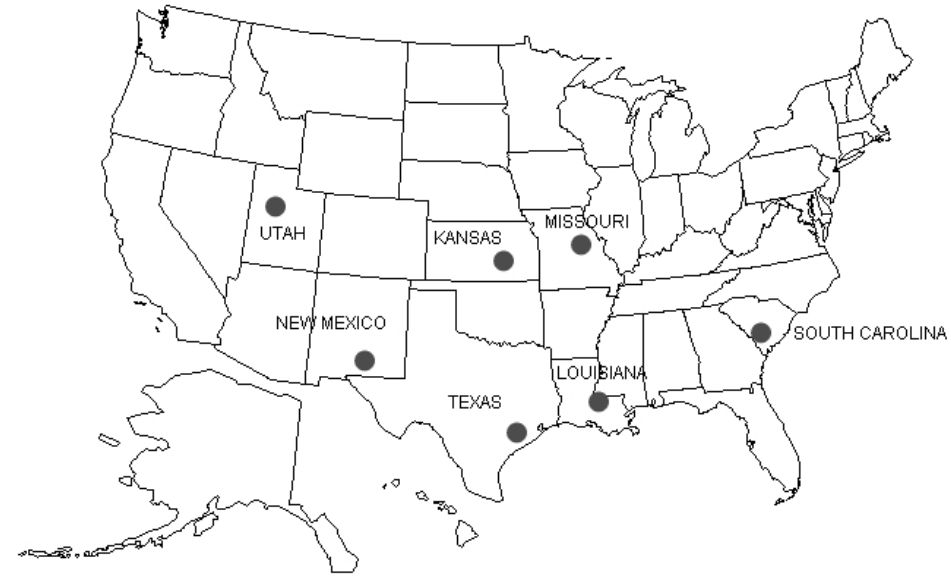
3.7 The Wolf Creek Generating Station

The Wolf Creek Generating Station (WCGS) is a nuclear electric power plant located in Coffey County, Kansas. The plant has an electricity-generating capacity of 1200 MW, utilises a Westinghouse pressurised water reactor, and occupies 10 000 acres, including a 5000 acre cooling reservoir.[4] The plant serves 700 000 customers in Kansas and Missouri and was completed in 1985. It has 850 employees.

3.8 Diverse site characteristics

The seven sites are highly diverse. First, as shown in Figure 1, they are located widely throughout the USA, although predominately in the south, Midwest, and west. Second, they include a high-level waste disposal facility, a low-level waste facility, a mixed-waste facility, and four nuclear power plants. Third, the facilities' employment ranges from 300 to 1500. Fourth, the site areas range from 200 acres to over 12 000 acres. Fifth, some sites, such as STP and RBS, account for a third of local area employment and income; others, such as WIPP and Barnwell, account for smaller portions of local area jobs and incomes. Finally, Barnwell has been in operation since 1971, whereas WIPP began accepting waste shipments in 1999. These sites thus represent a diverse – but not comprehensive – sample of US nuclear facilities, and analysis of their impacts on the surrounding areas can allow us to gain insights applicable to the local impacts of such facilities.

Figure 1 Location of selected US nuclear facilities examined



Source: Management Information Services, Inc. (2005)

4 Impact on property values

One of the most important and contentious issues is the impact of nuclear facilities on property values in adjacent areas. Concerns that the siting of nuclear facilities may depress property values and make it more difficult to sell real estate near the facilities have been raised. Our research indicates that the opposite is usually true.

For example, the Barnwell facility has over the past 30 years exerted a strong, positive effect on the local real estate market and on home values, and since it began operating housing values in the community have increased, on average, 3% to 5% annually, and commercial real estate has also appreciated significantly. New houses in subdivisions in proximity to the facility originally sold for $30,000 in the early 1970s. By the early 1990s, these homes were selling for $65,000 – $70,000, and by 2001, were selling for between $100,000 and $150,000.

One half-mile from the Barnwell facility, a new development was begun in the early 1990s, with new homes constructed on three- to five-acre lots selling for $100,000 to $200,000. By 2001, these homes were selling for $350,000 to $400,000. In general, the average price of homes close to the facility tends to be higher than the average price of homes in Barnwell County. Local government officials and real estate agents verify that the facility has had a positive effect on the local housing market, that it has not been a deterrent to new home buyers and that the incomes from the jobs created support the housing market.[5]

We also found that WIPP has had a substantial, positive impact on the local real estate market:[6] New home construction is booming in Carlsbad, and WIPP has been identified as the major factor responsible for the boom (Marshall, 1998,p.vi). The new homes built in Carlsbad over the past several years are larger and more expensive than the general housing stock in town. WIPP employees' desires for quality housing are responsible for a substantial portion of these new homes (Marshall, 1998,p.vi–vii), since much new construction is designed to meet the housing needs of management and professional level project staff.[7]

We derived similar findings with respect to the impact on real estate values of the other five nuclear facilities. For example, the Envirocare facility contributed to the construction boom and record construction of new homes in Tooele County in recent years. Local officials confirm that it has been responsible for at least a portion of this activity because the facility has given the county another source of income other than defense spending (which accounted for 85% of county income) at a time when defense spending in the county had been declining.[8]

STP has exerted a strong, positive effect on the local real estate market and home values, and since 1970, housing values in the surrounding area have increased more than six-fold. Average 2000 sq. ft. homes in Bay City were selling for more than $100,000 in 2001 and have been increasing in value steadily for the past decade, and the salaries and wages derived from STP have been an important factor in increasing the value of the area's housing.[9]

RBS has had a favourable effect on the local real estate market, and since 1970, housing values in the surrounding area have increased more than fivefold. The same is true for CNPP, and since 1970, housing values in the surrounding area have also increased more than fivefold.

Similarly, WCGS has exerted a strong, positive effect on the local real estate market and home values: real estate in the surrounding area has consistently increased in value, and the presence of WCGS allows Coffey County to assess real estate at much lower rates than surrounding counties. In addition, the plant has protected property values. During periods of economic decline, the economic stability and steady employment provided by the facility prevented property values from decreasing, as they did elsewhere in the state.

5 Economic and employment impacts

The most significant local impact of the facilities is on jobs and incomes. We found that all of the nuclear facilities generate substantial economic and employment benefits to the surrounding communities and are economic mainstays (Table 2).

STP creates significant economic benefits for the surrounding area.[10] It has a full-time staff of 1500, and there are over 2000 employees on the site, including contract labour. The project is the largest employer and largest taxpayer in Matagorda County, and 30% of county employment derives from STP.

With 800 employees, RBS is West Feliciana's second largest private employer. It is a mainstay of the local economy, directly employing 15% of the parish private workforce and indirectly creating jobs for another 12%. The plant's annual payroll constitutes 20% of the parish total annual wages.

Table 2 Summary of the facilities' jobs and incomes effects

Facility	*Percent of local area jobs created (%)*	*Percent of local area incomes created (%)*
Nuclear waste management facility	8	10
Waste isolation pilot plant	5	12
Envirocare mixed waste disposal facility	8	12
South Texas project	30	35
River bend nuclear generating station	27	20
Callaway nuclear power plant	15	15+
Wolf creek generating station	20	25

Source: Management Information Services, Inc. (2005)

With 750 employees, CNNP is the county's largest employer. Fifteen percent of those employed in the county owe their jobs to the plant, and plant-related income constitutes more than 15% of county personal income.

WCGS is Coffey County's largest employer and is a major factor in the local economy: Over 20% of county employment is generated by WCGS, and WCGS-related income constitutes more than 25% of total county personal income.

Envirocare, with 400 employees, is the tenth largest employer in the county (Knold, 2000,p.31), and the facility generates 900 jobs in the local area – about 8% of the total,[11] and the jobs the facility has created since 1988 have helped Tooele County compensate for the loss of 3300 defense-related jobs over the past decade.[12]

Similarly, the wages and salaries paid at WIPP are more than twice the local average, and it creates 5% of local area jobs, but 12% of earnings.

6 Community growth and development

The nuclear facilities have helped to revitalise the communities and to turn around declining local economies. For example, RBS has provided substantial benefits to West Feliciana: The parish population was 20% higher in 1999 than in 1970, employment increased 80%, personal income increased sevenfold, per capita income increased fivefold and the parish has become wealthier relative to the nation and the state. Significantly, the parish was willing to forego ten years of property tax payments (1986–1995) of $50 million/yr. to obtain the plant. In the early 1970s, West Feliciana Parish was the second poorest in Louisiana, a state that is one of the poorest in the nation, and the parish viewed RBS as an economic godsend.[13]

Similarly, WCGS has provided substantial benefits to Coffey County. The county's population had been declining for decades, but this decline has been reversed, and between 1990 and 2000 its population increased from 8400 to 8900 (6%). Further, since the early 1970s, employment increased substantially, personal income increased more than sixfold, per capita income increased more than fivefold, and the county has become wealthier relative to the nation and the state.

WCGS's taxes allowed the county to improve its infrastructure, attract new business, and lower its property tax rates while upgrading municipal services. The combination of low property taxes and efficient municipal services has attracted small- and medium-sized industries to Coffey County. The tax base, employment, and salaries that the plant provides have encouraged commercial development and have helped make the region's economy more stable. The plant's tax payments were responsible for improving the county's hospital, roads, sewers, schools and recreation facilities, and these improvements are a selling point to industrial prospects. The plant has also brought a more highly educated, technical work force to the county and its employees support community improvements.

WCGS provided an important psychological boost: it gave the county a new lease on life and reversed a 90-year economic and demographic decline. The economic base provided by WCGS has allowed Coffey County to develop one of the best school systems in Kansas. This is important for attracting new business, for quality education is a top selling point for enticing managers and professionals to relocate. The quality of the WCGS labour force is as important as the facility's payroll and taxes. Local officials emphasise that skilled workers and professionals contribute immeasurably to the quality of life: they support cultural, educational, and community activities at levels unlikely to exist if other types of industries of equivalent size were present in the area instead of WCGS.

In the late 1960s South Carolina promoted the development of nuclear energy facilities within the state, and Barnwell County officials encouraged Chem-Nuclear to locate near Barnwell. Since the initiation of commercial operations, Barnwell County's economy has been robust: the county's population has increased 30% since 1970, between 1990 and 2001 employment increased 20%, and personal income in the county increased more than eightfold over the past 30 years. Since 1970, per capita income in Barnwell County has increased fivefold, rising faster than the national and state averages. In 1988, Barnwell County's per capita income ranked 26th in the state; by 1998, it had risen to ninth in the state.

The Chem-Nuclear facility has played an important role in the area's economic development.[14] It has allowed surrounding jurisdictions to increase their services and the quality of their schools, it has allowed the county to establish a revolving loan fund that is used to finance economic development and it has attracted other industries to the area.[15]

Since the late 1980s, the Carlsbad economy has become stronger and more diverse, and WIPP has played an important role in this economic revival. Community leaders credit WIPP with revitalising the local economy; the facility has become a key agent of local economic development, and the improvements in transportation infrastructure made as a part of WIPP have opened up south-east New Mexico to increased commerce and are enhancing the region's economy.[16]

Since WIPP began operations, the populations of Carlsbad and Eddy County have increased substantially, and WIPP is responsible for a major portion of this growth (see Marshall, 1998,pp.ii–xii). Over the past decade, per capita personal income in Eddy County has increased at least as rapidly as the state and national averages. Since WIPP contributes 5% of the local area's wages but 12% of earnings, these higher-than-average earnings have increased average per capita income in Carlsbad (see Marshall, 1998,p.v). WIPP also helped the Carlsbad region overcome the closing of local potash mines.[17]

WIPP attracts large numbers of scientists, engineers, government officials and researchers for visits and hosts numerous scientific and technical meetings. Overwhelmingly, Carlsbad residents confirm that the facility has been positive for the community, providing employment, helping business and enhancing attitudes about the community.

Prior to WIPP, the Carlsbad Department of Planning concluded that the area lacked employment opportunities and was losing its best and brightest. WIPP changed this and has become a 'substantial economic boon' to the region by creating jobs that give young residents the option of remaining in the region. The 800 jobs at WIPP include a wide range of skills and offer opportunities for local residents, many of whom have already risen through the ranks. In addition, and of special importance to the local community, former Carlsbad residents (who had left the area to seek employment elsewhere) are returning to take advantage of the WIPP jobs (see Marshall, 1998,Chap.7).

The Envirocare facility has also had a favourable economic impact and has assisted Tooele County in expanding and diversifying its economic base (Knold, 2000,p.23). It generates a payroll of over $1.5 million annually (Knold, 2000,p.23) and, in addition to the taxes it pays, the facility pays 5% of its gross revenues each year to Tooele County – nearly $5 million annually (Knold, 2000,p.23). This is a substantial portion of the county's budget.[18]

STP has been the catalyst for growth in Matagorda County over the past three decades.[19] Comparison of the period since it began operation with that prior to construction (early 1970s) is salient: The county's population increased by 50%, employment increased more than 70%, personal income increased eightfold, and per capita income increased sixfold.

7 Effects on schools

One of the most important impacts we identified is on the local schools, for the tax revenues generated by the nuclear facilities have been critical in upgrading and transforming the quality of local schools. For example, the revenues generated by STP provide 70%–90% of the county and school district budgets. Similarly, the taxes generated by RBS provide substantial revenues for the parish and school district budgets. Since it began commercial operation, RBS has paid over $70 million in special sales tax assessments to the West Feliciana School Board, and this revenue has had significant impact: both teachers and students have consistently ranked higher than state averages for attendance, and high rankings have also been achieved in the number of teachers certified to teach the subjects they teach, the number of graduate degree teachers, and teacher-evaluation scores. West Feliciana teachers are among the highest paid in the state.

The taxes generated by WCGS provide a large portion of Coffey County's and the school district's budgets: the plant's tax payments constitute over 50% of the taxes levied by the Burlington School District and nearly 40% of the total revenues for Coffey County. An important advantage of the large tax base provided by WCGS is that it permits the District to generate capital funds for facilities and school purchases of equipment and materials, and Burlington has significantly better facilities than the surrounding school districts.

Chem-Nuclear pays $44 million annually to the local and state governments, and its property taxes are the mainstay of the Barnwell local government and school system. Over the past five years, Chem-Nuclear has generated $200 million in earmarked funds for local school districts in South Carolina, including Barnwell.[20]

8 Impacts in perspective

The impacts summarised above must be viewed in perspective, since over the past two decades all regions of the USA experienced impressive rates of economic growth, increasing personal incomes and rising property values. This is illustrated in Tables 3, 4 and 5. These data are at a more macro level than is ideal, and they compare trends for the USA as a whole, the seven states in question and the seven counties in which the nuclear facilities are located. Analysis of comparative data focusing solely on the areas in very close proximity to each facility would be preferable, but was outside the scope of the research. Nevertheless, these tables do provide some interesting perspectives.

Table 3 shows the increases in the median value of owner-occupied housing units during the 1990s. Increases in housing values in four of the counties in which nuclear facilities are located significantly exceeded the US average of 51%: Tooele County (112%), West Feliciana Parish (75%), Callaway County (75%) and Coffey County (74%). The increase in housing values in Barnwell County (48%) was about equal to the national average, and the increases in housing values in Eddy County (43%) and in Matagorda County (16%) were below the national average. Property markets are, of course, regional, and housing values in four of the counties – Tooele, West Feliciana, Callaway and Coffey – increased at least as much as those in the relevant states, whereas housing values in the other three counties increased less than those in the relevant states.

Table 3 Median value of owner-occupied housing units: 1990–2000

Median value of owner-occupied housing units	*1990 ($)*	*2000 ($)*	*Change (%)*
Barnwell County	44,900	66,600	48
South Carolina	61,100	94,900	55
Eddy County	44,800	64,200	43
New Mexico	70,100	108,100	54
Tooele County	60,400	127,800	112
Utah	68,900	146,100	112
Matagorda County	53,000	61,500	16
Texas	59,600	82,500	38
West Feliciana Parish	61,300	107,500	75
Louisiana	58,500	85,000	45
Callaway County	48,900	85,800	75
Missouri	59,800	89,900	50
Coffey County	34,800	60,700	74
Kansas	52,200	83,500	60
USA	79,100	119,600	51

Source: US Department of Commerce, Bureau of the Census (2001c)

Table 4 shows the increases in median household incomes during the 1990s. Increases in median incomes in four of the counties in which nuclear facilities are located significantly exceeded the US average of 40%: Tooele County (52%), West Feliciana Parish (104%), Callaway County (47%) and Coffey County (55%). Increases in median incomes in the other three counties were below the national average – Barnwell County (22%), Eddy County (37%) and Matagorda County (27%). Median incomes in three of the counties – West Feliciana, Callaway and Coffey – increased more than in the relevant states, median income in Tooele County increased about the same as in Utah overalland median incomes in Eddy County and Matagorda County increased less than the relevant state averages.

Table 4 Median household incomes: 1990–2000

Median household income	*1989 ($)*	*1999 ($)*	*Change (%)*	
Barnwell county	23,501	28,591	22	
South Carolina	26,256	37,082		41
Eddy County	23,418	31,998	37	
New Mexico	24,087	34,133		42
Tooele County	30,178	45,773	52	
Utah	29,470	45,726		55
Matagorda County	25,368	32,174	27	
Texas	27,016	39,927		48
West Feliciana Parish	19,402	39,667	104	
Louisiana	21,949	32,566		48
Callaway County	26,663	39,110	47	
Missouri	26,362	37,934		44
Coffey County	24,435	37,839	55	
Kansas	27,291	40,624		49
USA	30,056	41,994		40

Source: US Department of Commerce, Bureau of the Census (2001c)

Table 5 shows the increases during the 1990s in per capita incomes. Increases in per capita incomes in each of the counties in which nuclear facilities are located, except in Matagorda County, equaled or exceeded the US average of 50%. Per capita incomes in three of the counties – West Feliciana, Callaway and Coffey – increased more than in the relevant state, median income in Eddy County increased about the same as New Mexico overall and median incomes in Barnwell County and Matagorda County increased less than the relevant state averages.

Table 5 Median per capita incomes: 1990–2000

Per capita income	*1989 ($)*	*1999 ($)*	*Change (%)*	
Barnwell County	10,611	15,870	50	
South Carolina	11,897	18,795		58
Eddy County	10,490	15,823	51	
New Mexico	11,246	17,261		53
Tooele County	10,568	16,321	54	
Utah	11,029	18,185		65
Matagorda County	11,374	15,709	38	
Texas	12,904	19,617		52
West Feliciana Parish	6,796	16,201	138	
Louisiana	10,635	16,912		59
Callaway County	11,024	17,065	55	
Missouri	12,989	19,936		53
Coffey County	11,451	18,337	60	
Kansas	13,300	20,506		54
USA	14,420	21,587		50

Source: US Department of Commerce, Bureau of the Census (2001c)

The two major outliers appear to be Matagorda County and West Feliciana Parish. The former county underperformed both the national and state averages with respect to the three economic indices analysed. On the other hand, West Feliciana Parish greatly outperformed the respective national and state averages. For example, in this parish, during the 1990s, median housing values increased 50% more than the national average and 67% more than the Louisiana average, median household income increased 2.5 times more than the national average and more than twice as much as the Louisiana average, and per capita income increased nearly three times as much as the national average and more than twice as much as the Louisiana average.

9 Summary, conclusions and implications for further research

We found that the nuclear facilities tend to be economic mainstays of the local communities. They provide hundreds, and in some cases thousands, of professional and skilled jobs paying wages and salaries above the average community wage; the facilities are responsible for as much as 20% or 30% of the total employment in the respective counties, and for as much as 35% of local area incomes. The taxes and fees the facilities pay often fund over half of the county and school district budgets and provide levels of public and educational services that are far above those of surrounding counties and greater than the state averages.[21]

In each of the seven regions, housing and real estate values have benefited from the operations of the nuclear facilities: total property values, assessed valuations and median housing prices have often increased at rates above the national and state averages. In each local area, housing prices were several times higher than prior to the opening of

the nuclear facilities, and there is evidence that in Barnwell, proximity to the nuclear facility may actually increase housing values.[22] Further, the presence of a nuclear facility has protected property values: during periods of relative economic decline in the local region, the economic stability, including steady employment, provided by the facility prevents property values from decreasing, as elsewhere in the state and the surrounding communities.

In each case the nuclear sites have contributed to robust economic growth. Economic development in the seven local areas has usually exceeded national and state averages by most quantifiable measures: per capita incomes have (with the exception of Matagorda County) increased faster than the national and respective state averages, employment and jobs have increased faster than national and respective state averages and local area unemployment rates have generally been below the national and state averages. Each county has grown progressively wealthier and the economic stability provided by the facilities helped the local areas avoid cyclical downturns and 'boom-bust' development. This economic performance has been widely shared by all sectors of the local economies.

Finally, local government officials, civic leaders and community activists have generally confirmed the beneficial effects which the facilities have had, for example:

- Local officials originally campaigned hard to get Chem-Nuclear to locate in Barnwell, and have never regretted it; they feel that it is the best thing that ever happened to the local community.
- West Feliciana Parish officials wanted the River Bend Station within the Parish strongly enough to grant it a ten-year exemption from property taxes. The local Chambers of Commerce and the Parish Tourist Commission have made the nuclear plant a part of their campaigns to increase economic development in the area, feeling that the plant is a major attraction.
- In Callaway County, the local Chambers of Commerce have also made the nuclear plant a cornerstone in their campaigns to increase economic development, feeling that the presence of the plant benefits the region.
- In Coffey County, the WCGS is credited with 'saving' the local area, stopping and then reversing the economic decline of the County (Many other rural Kansas counties have suffered from economic decline, but WCGS has saved Coffey county from this fate.), and with leading an economic/industrial revival.
- In public opinion polls, Carlsbad residents say that WIPP has been positive for the community, in providing employment, helping business and in intangible attitudes about the community.

In sum, while we do not contend that the research reported here is comprehensive or definitive with respect to the topic of proximity effects of nuclear facilities on property values or other community factors, it does call into question the perception that nuclear facilities have detrimental effects on adjacent communities and property owners. As noted, we present findings of actual market experiences that are known and that should be considered.

However, a number of caveats are in order. First, and most important, this paper reports general findings about specific factors, effects and implications of the impacts on adjacent communities associated with the siting of various nuclear facilities. We must again emphasise that it does not purport to derive conclusions with regard to any

particular property's or groups of properties' market values. It is not the intent that conclusions regarding individual property valuations should be drawn from the results reported here. The local community impacts differ according to the characteristics of the facility and of the local communities, and the local area impacts – including impacts on property valuations – of any specific existing, new or planned facility will be unique and must be assessed and evaluated on an individual basis. Market value opinions must be based on specific property and analysis and the circumstances that constitute that property's physical and economic composition.

Second, while the seven sites examined are diverse and geographically dispersed, they account for only a small portion of the hundreds of nuclear facilities located throughout the USA and do not necessarily constitute a statistically representative sample of these facilities. Further, the sites analysed are located throughout the USA, have different nuclear usage, greater or lesser numbers of workers, larger or smaller acreage parcels and diverse dates of initial operation, and the findings reported here do not necessarily allow us to develop general conclusions.

Third, as discussed, most of these nuclear facilities were sited in areas with depressed or blighted economies and, indeed, were actively courted by local government officials as a means of rejuvenating the local economy. While the facilities succeeded in doing so, it should be realised that the economic benefits reported here are based on local economies that were often severely depressed prior to the siting of the facility. That is, some of these local economies were so relatively poor at the time of facility siting that only acceptance and positive economic benefit were bound to result. Indeed, most nuclear facilities are located in more rural, sparsely populated, and often economically depressed locations, rather than more prosperous metropolitan areas, and the siting of such a facility will almost inevitably generate higher-paying jobs, an influx of technical and professional staff, *etc*. Our findings confirm this. Further, while the nuclear facilities provided a major stimulus and continuing economic benefits to the local areas, similar benefits would also likely have resulted from the siting of other types of major facilities, such as a large manufacturing plant, telemarketing/call centre, casino, government operations facility, *etc*. In addition, since all of the facilities are located in rural sites, the employees probably have no other realistic housing choices. If the facilities had been in urban areas, the results might be different, and our findings thus cannot be generalised to nonrural areas.

Fourth, while property values increased significantly after the siting of the nuclear facilities, it must be realised that the entire country has experienced a surge in housing construction and property values over the past three decades. When viewed in this perspective, the impacts of several of the nuclear facilities on local property values, while still positive, are somewhat less impressive.

Moreover, most of the facilities studied are located in the sunbelt or south-west – two regions that have experienced above average growth rates, and, for example, the positive effects shown for STP may reflect, at least in part, its relative proximity to the rapidly growing Houston metropolitan area.

Finally, additional research is required to assess and extend the findings reported here. One useful extension would be to analyse how the increases in property values, employment, tax revenues and cultural amenities compare to other counties or parishes in the specific state that do not benefit from a nuclear facility. This would test the hypothesis that the facility is responsible for the improvements and benefits documented

here. In addition, the large increases in property values, salaries and revenues could be compared directly to property appreciation in other counties that are comparable except for the nuclear facility. Thus, a type of 'paired sales' approach using another similar community outside the influence of the nuclear facility could be utilised to assess the favourable impact the latter has on the housing market. These further analyses could be conducted on the facilities described here as well as on other facilities located in other parts of the country. This would allow the development of more robust conclusions with respect to the impact on local communities and property valuations based on paired sets of empirical data about technically and geographically diverse nuclear facilities.

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Notes

1 *A Brief History of Envirocare of Utah, Inc.*, http://www.envirocareutah.con

2 Based on discussions with Envirocare officials, April 2001.

3 It is owned 16% by Austin Energy, 25% by Central Power and Light, 28% by City Public Service of San Antonio and 31% by Reliant Energy.

4 WCGS is owned by three utilities: KGE (a Western Resources Company) and Kansas City Power and Light Company each own 47%, and Kansas Electric Power Cooperative, Inc., owns 6%.

5 Based on discussions with local real estate agents and with officials from the County Tax Assessor's Office and from the Barnwell Chamber of Commerce, April 2001.

6 The significant impact of WIPP on the local real estate market is documented in Marshall (1998, Chap. 4), and in discussions conducted in April 2001 with the Director of the Eddy County Board of Assessors and with local real estate agents.

7 Based on discussions with Carlsbad real estate agents, April 2001.

8 Based on discussion with the Executive Director of the Tooele County Chamber of Commerce, May 2001.

9 Based on discussions in April and May 2001 with the President of the Bay City Chamber of Commerce and Agriculture and with local real estate agents.

10 These estimates were derived on the basis of information from Management Information Services, Inc., 1992, and discussions in April and May 2001 with staff from STP, officials from Matagorda County and Bay City, officials from the Bay City Chamber of Commerce and Agriculture and the Bay City Conventional and Visitors Bureau, and local real estate agents.

11 There are about 11 100 jobs in Tooele County; see Utah Department of Workforce Services (2000–2001).

12 Based on a discussion with the Executive Director of the Tooele County Chamber of Commerce, May 2001.

13 Based on discussions in April and May 2001 with officials from West Feliciana Parish and St. Francisville, officials from the West Feliciana Parish Tourist Commission and the Greater St. Francisville Chamber of Commerce, and local real estate agents.

14 Based on discussions with officials from the County Tax Assessors Office, the County Department of Economic Development and the Barnwell Chamber of Commerce, April 2001.

15 For example, a laundry facility has been established to service the Chem-Nuclear facility and an industrial park is being developed next to Chem-Nuclear – the European firm Cronotex invested $160 million in the park to construct a wood laminate plant.

16 Research has shown this resurgence of the Carlsbad economy to be, to a significant degree, the result of the economic activity generated by WIPP (see Marshall, 1998,pp.2–20).

17 Based on discussions with Carlsbad real estate agents, April 2001.

18 In 1999, county expenditures for general government functions totaled $5.5 million and for public safety totaled $5.8 million (see Tooele County, 1999).

19 Based on discussions in April and May 2001 with staff from STP, officials from Matagorda County and Bay City, officials from the Bay City Chamber of Commerce and Agriculture and the Bay City Conventional and Visitors Bureau, and local real estate agents.

20 Aside from the taxes paid, the nuclear facilities also provide substantial in-kind and pro bono support to local school systems. For example, WIPP employs a full-time educational outreach specialist to talk to students and educators about WIPP, careers, science and math, and teaches educators how to apply for grants. WIPP also provides support to schools and educational consortia for website development, supports math and science nights at local schools, donates excess equipment and computers to schools, supports numerous school programmes, conducts summer intern programmes and sponsors work-study students. Chem-Nuclear funds transportation costs for Barnwell County special-needs children attending a summer camp programme coordinated by the Barnwell County Health Department. Similarly, the Callaway plant has been active in supporting the local community and schools: it has provided pro bono management and technical assistance to local area governments and has sponsored a Partners in Education Programme, which provides assistance to local schools.

21 This is not unique to the seven facilities studied here. For example, during the 1990s, revenues generated by the Clinton Nuclear Power Plant, in Clinton, Illinois, accounted for 73% of the budget of the Clinton School District (see Ingram, 2000).

22 This finding is similar to that reported by Clark, Michelbrink, Allison and Metz, who found that housing prices increased with proximity to the Diablo Canyon and Rancho Seco nuclear power plants in California.

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Waste Sites and Property Values: A Meta-Analysis

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Abstract Recent studies suggest that some of the most contaminated waste sites in the United States have idiosyncratic or no discernable effects on nearby property values. This paper presents a meta-analysis of the literature measuring the economic impact of sites harboring waste materials on real estate values. A sample of 46 North American studies issued from 1971 to 2008 yields 129 distinct estimates that survive outlier diagnostics. The estimation results are highly robust and significant across estimators and specifications. They suggest that all classes of waste sites affect real estate prices, but sites classified as hazardous, especially aquatic hazardous sites, are associated with the greatest discounts. The estimated impacts of nonhazardous waste and nuclear sites are not statistically different from one another. Surprisingly, estimated impacts associated with sites included on the EPA's National Priority List (NPL) are generally smaller (although still statistically significant) than those for non-NPL hazardous waste sites. The estimates for sites in Canada and Mountain, Middle Atlantic, and South Atlantic states exceed those for other regions. Larger impact areas and aggregated data, such as census block observations, are associated with lesser estimates.

Keywords Meta analysis · Hedonic method · Property values · Waste sites

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1 Introduction

Over the past 20 years, the US Environmental Protection Agency (EPA) has located and analyzed the risks associated with tens of thousands of hazardous waste sites.[1] By the early 1990s, more than $10 billion had been collected from a tax on chemical feedstocks to help pay for remediation of the contaminated sites considered most hazardous. In addition, by 1995, polluters who were found responsible for the contamination had committed more than $11 billion dollars toward cleanup (USEPA 1996). Nevertheless, hundreds of sites remain on the National Priority List (NPL) and thousands more have been recommended for remediation. The potential costs of cleanup are daunting, and the pressure to ensure a return on investment is accordingly great. The potential for external impacts of these sites on human and ecosystem health may impair the usefulness and value of neighboring properties, and this elevates the issue from a private to a public concern. For property owners and local officials alike, the possibility of recovering lost property values, both on- and off-site, is often an important motivation for cleanup.

This paper presents a meta-analysis of the literature on North American waste sites issued between 1971 and 2008 measuring the economic impact of waste sites on real estate values. Efforts to measure these impacts have focused on the market prices of properties potentially subject to harm. The usual hypothesis is that preferences concerning local environmental conditions, including the presence of waste materials, are capitalized into property values. Following Ridker's (1967) pioneering study of air quality impacts, dozens of articles and reports have tested the effects of geographically-defined waste sites. The literature has grown to the point where quantitative assessment to discover regularities is now possible. This paper provides such an assessment of 46 hedonic property value studies of the economic impact of waste sites.

This assessment is timely in view of recent studies suggesting that some of the most contaminated sites in the United States—those selected for the NPL under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, commonly known as the Superfund Law)—have idiosyncratic (Kiel and Williams 2007) or no discernable effects (Greenstone and Gallagher 2008) on nearby property values. NPL sites are supposedly those that present the greatest risk to human health. An absence of measurable offsite effects would weaken the case for actions to promote remediation, such as those called for under CERCLA.[2] However, the results of these recent studies are at odds with prevailing interpretations of the pertinent literature. Those interpretations appear in four previous literature reviews of the property value impacts of contaminated sites. Three of those reviews are qualitative (Faber 1998; Kiel and Boyle 2001; Simons 2006) while the fourth (Simons and Saginor 2006) uses formal meta-analytical techniques. The latter study is closest in spirit to

[1] Once contaminated sites are discovered, they are entered into the Superfund Information System (USEPA 2008b), also known as CERCLIS. EPA then evaluates the potential for a release of hazardous substances from the site using the Hazard Ranking System (USEPA 2008a). The severely hazardous sites are put on the National Priority List (NPL) for cleanup. In addition to terrestrial sites, 43 severely-contaminated aquatic sites in the Laurentian Great Lakes Basin have been designated as Areas of Concern under the terms of the Great Lakes Water Quality Agreement between the US and Canada (International Joint Commission 2003).

[2] For more than two decades, federal agencies have been required by Presidential Executive Orders to analyze the benefits and costs of significant regulatory proposals and actions and to show that the benefits justify the costs (Executive Office of the President 2007).

this paper, but the two differ in important respects. First, Simons and Saginor (S&S) commingle studies of likely positive environmental influences from parks, water bodies, and clean air together with studies of the negative effects likely to accompany not only NPL sites, but also high-voltage power lines, pipelines, nuclear sites, railroad easements, shopping centers, sex offenders, rental properties, confined animal facilities and other sources of air pollution. S&S use a single distance variable to capture the effect of proximity to a site plus dummy variables to distinguish the different types of site. In contrast to S&S, our analysis focuses on negative influences alone—in particular, sites that contain regulated waste materials: nonhazardous landfills, terrestrial sites contaminated by hazardous materials (both NPL sites and non-NPL sites), aquatic sites contaminated by hazardous materials, and nuclear sites.[3] We also limit the sample of studies to those that explicitly use standard market-based hedonic methods, while S&S also include surveys and case studies. Furthermore, we control for more potential influences on study findings: changes over time in institutions, knowledge and preferences; and features of the individual sites, studies, data sets, and study methodologies. We also do not limit the analysis to residential properties; we include as well the few studies that analyze effects on commercial and industrial real estate. Finally, several recent additions to the literature, including studies of aquatic hazardous wastes sites, have not previously been included in meta-analyses.

In focusing on studies of nearby property values, we do not mean to suggest that property values fully capture the externalities associated with these sites. Among the economic impacts unlikely to be embedded in property values are those expressed through bio-transport and bio-accumulation and affecting, for example, water-based recreation and fishing activities.

We hypothesize that hedonic studies of waste sites reveal systematic discounts in the prices of neighboring properties, with larger discounts for hazardous sites than for nonhazardous landfills. In a similar spirit, Smith and Desvousges (1986) found that 77% of survey respondents in Boston were unwilling to live within 5 miles of a nuclear power plant compared to 67% for landfills and 52% for coal-fired electric generating plants. We make no attempt to distinguish the specific mechanisms underlying the external impacts, which might range from quantifiable physical impacts (Gayer et al. 2000) to stigmatization (Dale et al. 1999; Messer et al. 2006). Whatever the means, we hypothesize that the market discounts proximity to all waste sites, but different types of waste sites have distinctive effects.

Our key results are as follows: (1) studies of river or harbor contamination produce systematically larger estimates of property value discounts than studies of terrestrial hazardous sites, and both of those classes produce larger estimates than studies of nuclear sites and non-hazardous waste sites, which are not statistically differentiable; (2) cleanup stages do not seem to affect the estimates of property value impact consistently and significantly; (3) studies of sites on the EPA's NPL for cleanup produce systematically smaller estimates of impact than studies of terrestrial hazardous sites not on the NPL; (4) smaller average effects are associated with studies of larger areas; (5) studies undertaken in West Northcentral, East Southcentral, and South Atlantic states, and Canada, produce systematically greater impact estimates than have been found for sites in other regions; and (6) studies of commercial properties and unpublished studies are more likely to report smaller and insignificant estimates of property value impacts.

The next section briefly reviews meta-analysis and the hedonic valuation method used by all of the studies reviewed here. The paper continues with a description of the meta-model, the data, the empirical results, and conclusions.

[3] Of these categories, nuclear sites alone are not regulated principally under environmental statutes. They are included here because they closely resemble hazardous waste sites in that materials known to pose risks to humans are stored onsite.

2 Meta-Analytic and Hedonic Models

Meta-analysis is a statistical method used to integrate and summarize research results from many studies addressing a common subject. It highlights points of agreement and disagreement. First used in psychological research (Glass 1976), meta-analysis has become widely accepted in the behavioral, social, health, and economic sciences (Stanley 2001), including environmental economics (Nelson and Kennedy 2009).

The studies analyzed here are all drawn from the hedonic property value literature. In brief, following Freeman (2003) and Taylor (2003), the market equilibrium prices of housing are assumed to be described by a hedonic price function

$$P = P\,(S, N, A) \tag{1}$$

where the price of a home P is a function of vectors of structural S, neighborhood N, and environmental A variables, respectively. The marginal cost of an additional unit of a particular characteristic equals the equilibrium marginal willingness to pay (MWTP) for it, and both equal the partial derivative of the hedonic price function. The partial derivative of the hedonic price function with respect to an environmental variable is the basis of all price impact estimates in the literature reviewed here.[4]

Most hedonic studies of localized disamenities use the distance from such a site as a proxy for exposure to negative externalities. Under certain conditions (Taylor 2003), the marginal price of an additional unit of distance measures the MWTP to avoid the disamenity conditional on location. The difference in price between a property i affected by the externality (A_i) and the closest equivalent property not so affected (A_0) measures the economic effect of exposure:

$$\Delta P_i = P(A_i|S, N) - P(A_0|S, N) \tag{2}$$

Isolating the effect of a contaminated site depends on controlling for many other factors that can affect location decisions: e.g., other commercial zones, highways, schools, public parks, crime rates, etc. These factors are captured in vectors S and N in Eqs. (1) and (2).

Virtually all of the studies restrict the geographic scope of the price effects. The assumption is that property prices beyond a particular distance are unaffected, and thus, serve as a benchmark for comparison. A hedonic price function that is linear in distance yields a constant MWTP while the marginal estimates in a nonlinear specification vary with distance.

In lieu of distance, some studies use the number of waste sites within a study area as a measure of the density of exposure (Ketkar 1992) or use a dummy variable to indicate the presence of a contaminated site (e.g., Guntermann 1995; Ho and Hite 2005). In these instances, the marginal price effect of an additional contaminated site, or the presence of a single contaminated site, is the MWTP to avoid the waste site.

The hedonic property value model has been implemented in two distinct ways. The original and most-used approach employs cross-sectional data on property sales (e.g., Freeman 1974). The second approach analyzes repeat sales using panel data techniques (e.g., Palmquist 1982).

[4] Estimation of the hedonic price function and the marginal implicit attribute prices constitute the "first-stage" of the method outlined by Rosen (1974). They characterize the intersection of marginal willingness to pay and marginal supply costs. For non-marginal changes in attributes, however, marginal values might change along the respective demand and supply curves. Estimation of the welfare effects of such changes would require so-called "second-stage" estimation of the underlying demand function. Serious econometric challenges of identification confront second-stage estimation (Taylor 2003), so virtually all applied studies settle for a lower-bound approximation of the true welfare value. The approximation consists of the estimated marginal value times the magnitude of the change in the attribute.

The latter approach typically examines changes in the property market before and after a shock, such as the discovery or elimination of contamination. It has the advantage of reducing the need for detailed structural and neighborhood data, as long as those variables remain stable over time. Changes in the environmental condition of interest are represented by discrete dummy variables and MWTP is calculated for a change in the dummy variable. Even though there are differences in the meaning of MWTP between the standard single-period hedonic price model and the repeat-sales model, their theoretical bases and the functional forms used in estimation are very similar.

As the literature reviewed above indicates, the hedonic methodology has been used extensively to assess the economic consequences of environmental quality and public infrastructure and amenities. Nevertheless, the limitations of the hedonic methodology have long been recognized, particularly the potential for variable omission, market segmentation, spatial interdependence, and market disequilibrium (Freeman 2003). Greenstone and Gallagher (2008) have argued against the standard hedonic model in favor of a difference-in-differences methodology that overcomes some of these limitations. However, their application relies on the use of aggregated data (e.g., census median home values) which obscures the fine-scale price variation that underlies the hedonic hypothesis. Each approach has advantages and disadvantages. Our purpose here is not to engage this debate; rather, to the extent allowed by the accumulated literature, we attempt to assess the standard hedonic literature applied to waste sites, including to the degree possible efforts to control for spatial interdependence.

In addition to the market-based hedonic model, discrete choice methods have been applied to housing choices in the presence of disamenities (e.g., Cropper et al. 1993). Although these applications also focus on property values, the theoretical basis for the estimation of willingness to pay differs from hedonic studies. The different theoretical basis motivates their exclusion here.[5]

3 Meta-Analysis Model

The first requirement of meta-analysis is a comparable measure of outcomes. This serves as the left-hand-side variable in the meta-function to be estimated. Because the studies reviewed here differ in time and place, we need an indicator that is robust to inflation and differences between local markets. Following Nelson (2004), for each study i, we use a measure of relative impact—the proportional price effect (PPE_i)[6]:

$$PPE_i = \frac{|\Delta P_i|}{P_i}. \tag{3}$$

We hypothesize that PPE_i depends on three classes of influences: site characteristics, the nature of properties affected, and the methods of analysis:

$$PPE_i = f(\text{site characteristics, data, characteristics, methodology}) \tag{4}$$

[5] The discrete choice model starts with estimating an indirect utility function while the hedonic approaches estimate the hedonic price function of housing. In addition, the discrete choice approach is based on hypothetical choices, not real market data. The studies by Braden et al. (2004, 2008a,b) report estimates based on both hedonic analysis of property values and conjoint choice experiments. Only the hedonic estimates are used here.

[6] As noted earlier, hedonic models use either a continuous distance variable and or a discrete variable, such as an added contaminated site, as the instrument measuring environmental exposure. In either case, the reported hedonic price effect is an average for the area studied.

The variables used here to capture these influences are defined in Table 1 and described below.

3.1 Site Characteristics

3.1.1 Type of Disamenity

Our sample contains studies of non-hazardous sites (*Nonhaz*), hazardous waste sites, either terrestrial (*Terr*) or aquatic (*Aquatic*), and nuclear power plants (*Nuclear*). Non-hazardous sites include sanitary landfills and recycling centers. Terrestrial hazardous waste sites include hazardous waste landfills, inactive industrial sites where hazardous materials remain, and hazardous waste incinerators. Aquatic hazardous sites are river or harbors contaminated by hazardous substances. Since proximity to water has often been found to have pronounced effects on property prices (Luttik 2000), we separate aquatic hazardous sites to determine whether the literature reveals distinctive effects for waste sites as well. Nuclear sites include nuclear power plants, railroad easements where nuclear materials are transported, and radioactive material storage sites. Virtually all nuclear power plants store radioactive waste materials on-site. Of course, they may also be associated with risks other than the storage of hazardous materials—risks with very different potential geographic footprints.

The four diamenity categories are mutually exclusive. By including studies of sites that store waste materials but are not classified as hazardous, we can perform a crude test of the hazard classification.

3.1.2 Geographic Location

Previous studies have detected regional differences in property markets (Simons and Saginor 2006). To learn if the literature indicates regional differences in the effects of waste sites, we include variables for the region(s) to which each study applies. Two studies (Lim and Missios 2007; Zegarac and Muir 1998) use Canadian data and the rest are linked to US census regions: Pacific, Mountain, West Northcentral, East Northcentral, Middle Atlantic, New England, West Southcentral, East Southcentral, and South Atlantic. One study (Folland and Hough 1991) examines sites in multiple regions.

3.1.3 National Priority List

National Priority List designation indicates the most hazardous sites regulated by EPA. With the notable exceptions of Kiel and Williams (2007) and Greenstone and Gallagher (2008), virtually all studies have found that NPL status significantly influences nearby housing values. The literature varies on whether remediation reverses negative price effects (e.g., Kiel 1995; McCluskey and Rausser 2003b).

3.1.4 On-Site Employment (Job)

We hypothesize that *PPE* is affected by the presence of job-creating economic activity at the site. On-going employment at a waste site may attract residents and offset the disamenity effect (e.g., Nelson 2004).

Table 1 Variable description and summary statistics

Variable	Definition	$N = 142$		$N = 129$	
		Mean	Std. dev.	Mean	Std. dev.
PPE	Marginal property price effect (both significant and insignificant)	6.365	23.35	4.488	8.98
PPE_sig	Significant marginal property price effect, 0 if insignificant	5.412	22.46	3.831	8.47
Nonhaz	1 if a nonhazardous site, otherwise 0	0.246	0.43	0.225	0.42
Terr	1 if a terrestrial hazardous waste site, otherwise 0	0.585	0.49	0.589	0.49
Aquatic	1 if an aquatic hazardous waste site, otherwise 0	0.099	0.30	0.109	0.31
Nuclear	1 if a nuclear or radioactive site, otherwise 0	0.070	0.26	0.078	0.27
M_Site	1 if multiple sites, otherwise 0	0.415	0.49	0.395	0.49
Pacific	1 if study site is in Pacific region, otherwise 0	0.035	0.18	0.023	0.15
Mountain	1 if study site is in Mountain region, otherwise 0	0.021	0.14	0.023	0.15
WN_Cent	1 if study site is in West Northcentral region, otherwise 0	0.042	0.20	0.047	0.21
EN_Cent	1 if study site is in East Northcentral region, otherwise 0	0.282	0.45	0.256	0.44
Mid_Atl	1 if study site is in Middle Atlantic region, otherwise 0	0.120	0.33	0.132	0.34
New_Eng	1 if study site is in New England region, otherwise 0	0.239	0.43	0.264	0.44
WS_Cent	1 if study site is in West Southcentral region, otherwise 0	0.092	0.29	0.101	0.30
ES_Cent	1 if study site is in East Southcentral region, otherwise 0	0.021	0.14	0.023	0.15
S_Atlant	1 if study site is in South Atlantic region, otherwise 0	0.155	0.36	0.140	0.35
Canada	1 if study site is in Canada, otherwise 0	0.049	0.22	0.054	0.23
NPL	1 if site is in NPL list, otherwise 0	0.197	0.40	0.209	0.41
Job	1 if site includes job-generating activities otherwise 0	0.197	0.40	0.217	0.41
Stage 0	1 if a potentially contaminated site is proposed but not recognized by public, otherwise 0	0.049	0.22	0.054	0.23
Stage 1	1 if contamination is recognized but no plan for cleanup yet otherwise 0	0.310	0.46	0.326	0.47
Stage 2	1 if site has a cleanup plan, otherwise 0	0.197	0.40	0.202	0.40
Stage 3	1 if site has been fully or partially cleaned up,otherwise 0	0.127	0.33	0.116	0.32

Table 1 continued

Variable	Definition	$N = 142$		$N = 129$	
		Mean	Std. dev.	Mean	Std. dev.
Cleanup	1 if it is post-cleanup period, otherwise 0	0.127	0.33	0.116	0.32
Residen	1 if residnetial property data are used, otherwise 0	0.873	0.33	0.884	0.32
Range	Geographical range (miles of radius from site to farthest property studied)	6.524	7.24	6.668	7.19
Sample	The sample size of study	4,290.7	11,709.3	4,581.7	12,231.5
Mean_dt	Mean distance from site to properties (miles)	3.070	4.50	2.979	3.73
Ind_sale	1 if individual sales data are used, otherwise 0 (census, assessed, or county data)	0.894	0.31	0.891	0.31
Demoecon	1 if socio-economic data are included (e.g., income, poverty, school quality, etc.), otherwise 0	0.493	0.50	0.488	0.50
Access	1 if other accessibility data are included (e.g., highway, airport, etc.), otherwise 0	0.570	0.50	0.566	0.50
Industry	1 if industrial activities data are included (e.g., industry zone, etc.), otherwise 0	0.113	0.32	0.101	0.30
Time	Time trend of data year starting at 1966 = 0	22.254	6.85	22.023	6.59
Mort_rt	Annual national average conventional single-family mortgate interest rate	9.325	1.91	9.409	1.90
Publish	1 if a study is published in a journal, otherwise 0	0.887	0.32	0.907	0.29
Linear	1 if regression is linear, otherwise 0 (log–log, log–linear, inverse, etc.)	0.211	0.41	0.217	0.41
Discre	1 if a discrete variable (e.g., before/after) is used for environmental change, otherwise 0	0.141	0.35	0.140	0.35
Sig	1 if the distance estimate is significant, otherwise 0	0.697	0.46	0.705	0.46
Exp_sig	1 if the distance estimate has both expected sign and is significant, otherwise 0	0.585	0.49	0.597	0.49
Sar	1 if spatial autocorrelation is controlled in the model, otherwise 0	0.063	0.24	0.070	0.26

3.1.5 Stage of Cleanup (Stagei, i=0,1,2,3)

It seems likely that the discovery and confirmation of contamination (stages 0 and 1) would negatively affect nearby property values, but plans for and actions accomplishing remediation (stages 2 and 3) could mitigate the negative effects. To examine these conjectures, following

Kiel and McClain (1995a,b, 1996) and Kiel and Zabel (2001), we divide the cleanup process into the four noted stages and assign the *PPE* estimate(s) from each study of an NPL site to one of those stages depending on the status during the period represented by the data.[7] However, there are no standard definitions of status that have been applied across sites. Individual studies are often unclear about that status. Thus, considerable judgment is required to assign a site status that allows the testing of these hypotheses. The studies of *Nonhaz* and *Nuclear* sites are not readily categorized in these ways, so they are subsumed in the case where all of the *Stage* variables take on zero values.

3.1.6 Cleanup

As a bivariate alternative to the cleanup stage variable, we also test a dummy variable *Cleanup* which distinguishes hazardous waste site studies conducted before cleanup from those undertaken afterwards.

3.2 Data Characteristics

3.2.1 Property Type (Residen)

The *Residen* variable controls for whether the estimated price impacts are for residential or non-residential properties. Commercial and industrial properties are more likely than residential properties to be located near waste sites and thus may reveal greater price impacts (Ihlanfeldt and Taylor 2004).

3.2.2 Individual Parcel Data (Ind_sale)

Ind_sale controls for the use of sales data for individual parcels as opposed to assessment data for individual parcels or aggregate value data (e.g., for census blocks). In our sample, five studies used census data and two relied on assessment data. Individual sales data avoid the potential for lags and approximations in property assessments as well as the averaging and potential inaccuracy inherent in self-reported census data.

3.2.3 Geographical Range (Mean_Dt)

As most nonlinear property value models imply, the proportional impact of a waste site is probably greatest for properties nearest to the site. Other things equal, data drawn from a larger geographic scale should yield a lesser *PPE*. The mean distance from each property to the site of each study (*Mean_dt*) controls for this effect.

3.2.4 Number of Sites (M_Site)

This variable tests for whether the presence of multiple waste sites in a study affects the magnitude of the measured *PPE*.

[7] For aquatic hazardous sites in the Great Lakes Basin, a standardized categorization has been developed by the International Joint Commission. The stages include nomination of the site as an AOC, formal designation as an AOC, completion of a remedial action plan, and delisting following remediation (http://www.epa.gov/glnpo/aoc).

3.2.5 Sample Size (Sample)

The studies analyzed range in sample size from a minimum of 25 observations to a maximum of 70,328 observations. Variation in sample size may affect the statistical precision and significance of the estimates.

3.2.6 Neighborhood Characteristics

Dummy variables reflect whether the studies included specific types of neighborhood control variables. *Demoecon* indicates whether a study controlled for some economic features such as the income or poverty level; *Access* represents the inclusion of controls for transportation accessibilities; and *Industry* reflects whether industrial activity data were included in some way, such as with distance to the center of employment concentration or whether the study site is in an industrial zone. Twenty of the 46 studies included economic controls, twenty-five controlled for accessibility, and four controlled for industrial activities.

3.2.7 Time Trend (Time)

Over time, as new information emerges and experience accumulates, levels of concern may change. *Time* controls for this possibility. *Time* is measured in annual increments beginning with the year of the data (1966 = 0) used in the earliest study in the data set (Havlicek et al. 1971). For studies that use data from multiple years, if the years are bunched together and the study is not a before-after analysis, then the middle year of the interval is chosen to compute *Time*; for before-after analyses, the event year is chosen. The longest intervals in individual studies are 21 years (1968–1988) (Mendelsohn et al. 1992) and 18 years (Ihlanfeldt and Taylor 2004). Most other multi-year studies cover periods of less than 10 years.

3.2.8 Mortgage Rate (Mort_rt)

To control for economic market conditions, we also include the national annual average interest rate for a conventional 30-year mortgage.

3.3 Methodological Variables

3.3.1 Model Type (Linear)

In their meta-analyses of air quality and airport noise, respectively, Smith and Huang (1995) and Nelson (2004) found that linear functions yielded larger values than other functional forms such as log–log, log–linear, and linear–log. Most of the studies analyzed here use some combination of linear, log–linear, log–log and linear–log models. To preserve degrees of freedom, we use only a single dummy variable to distinguish linear from nonlinear models.

3.3.2 Type of Environmental Variable (Discre)

Some studies represent the environmental condition through a count or dummy variable reflecting discrete, and often substantial, changes in the environmental condition. Others use a continuous distance variable to capture incremental changes in exposure to a static condition. The *Discre* variable captures the potential differences between continuous and discrete representations of the environmental condition.

3.3.3 Publication (Publish)

Smith and Huang (1995) suggest that peer-reviewed publication may indicate higher analytical quality and larger measured impacts. We control for these possibilities by distinguishing studies published in peer-reviewed outlets from those found in the "grey literature." Of the estimates drawn from published studies, 71% are statistically significant. The notoriety of a site could also contribute to the significance and magnitude of impact (Kiel and Williams 2007), but there is no obvious way to control for notoriety.

3.3.4 Significance

The *PPE* variable measures magnitude but not significance. We include a dummy variable (Sig) to control for the statistical significance of the environmental variable used in each study. Other things equal, we expect significant estimates to be larger in magnitude.

3.3.5 Spatial Autocorrelation (Sar)

In spatial data, especially in hedonic housing prices, failure to control for spatial autocorrelation can produce biased and inconsistent estimates. In fact, controlling for spatial autocorrelation in the hedonic housing price model offers the additional benefit of mitigating the endogeneity problem and biases due to the omission of unobservable variables (Brasington and Hite 2005). However, amongst the 46 studies reviewed, only two (Brasington and Hite 2005; Gawande and Jenkins-Smith 2001) address this issue. In our meta model, the dummy variable *Sar* tests whether controlling for spatial autocorrelation or addressing endogeneity issue in hedonic studies affects the resulting estimates of *PPE*.

4 Data

A web-based journal search identified more than 70 papers using property value models to study waste sites. Some are theoretical studies without empirical evidence. Others report only appreciation rates or lack sufficient information to calculate *PPE* (e.g., Greenberg and Hughes 1993; Kiel and McClain 1995b; McCluskey and Rausser 2003a; Smith and Desvousges 1986; Zeiss and Atwater 1989). In the end, 46 studies conducted in North America and issued between 1971 and 2008 provide enough information to calculate *PPE*s. These studies are denoted by asterisks in the reference list. Among them, seven deal with aquatic hazardous sites (Braden et al. 2004, 2008a,b; Chattopadhyay et al. 2005; McMillen 2006; Mendelsohn et al. 1992; Zegarac and Muir 1998), five address nuclear sites (Clark et al. 1997; Folland and Hough 1991; Gamble and Downing 1982; Gawande and Jenkins-Smith 2001; Mrozek and Taylor 2002), and twelve deal with non hazardous sites (e.g., Bleich et al. 1991). The rest focus on terrestrial hazardous waste sites. Some of the studies estimate more than one *PPE* value. Overall, there are 142 observations of *PPE* from the 46 studies.[8,9]

[8] The study by Kiel and Williams (2007) examined more than 50 sites on the NPL for cleanup. Their data would increase substantially the number observations. However, the published study provides insufficient detail on the individual sites for use in our analysis. Repeated efforts to obtain their underlying data were unsuccessful.

[9] Excluding the estimates associated with non-hazardous sites would reduce the observations from 142 to 107. If we exclude the non-hazardous sites, the mean *PPE* is 8.27%, the mean radial distance of study area is 7.57 miles, and the mean distance to the closest waste site is about 3.48 miles.

With a few exceptions (Adler et al. 1982; Hite 2006; Ho and Hite 2005; Ready 2005; Zegarac and Muir 1998), all of the papers included in our analysis were published in refereed journals. The first and last of these unrefereed sources were written for governmental agencies or nongovernmental organizations while the others are working papers. Even though these studies have not cleared peer-review, we judged the methods, data, and results to be sound.

The average radius of the study areas is just over 6.5 miles. The sample mean of the average distance from the closest waste site is 3 miles. Unless a site undergoes remediation, we expect a positive MWTP and *PPE* estimate, indicating that property values are discounted. As shown in Table 1, the average *PPE* of the sample of 142 observations is a discount of approximately 6.37%. The estimated *PPE*s vary from −83.68% to 174.01%. Negative coefficients reflect increases in property values near a target site. This could happen following elimination of a disamenity or from failure to control for factors that offset the effect of a disamenity, such as the employment effects of a nuclear installation (Clark et al. 1997; Folland and Hough 1991). The most negative estimate (−83.68%) relates to the effect of landfills in Columbus, OH on the property values in census block groups with poverty rates greater than 16% (Hite 2006).[10] Some waste sites produced no statistically significant price effect (Adler et al. 1982; Bleich et al. 1991; Nelson 1981).

The use in hedonic property value studies of distance from a noxious site as a proxy for exposure to risky substances is fraught with potential for introducing bias (Braden et al. 2010). First, a site may be noxious not only because of the materials present, but also because it is unsightly, smelly, infested with pests, or other factors. In the single-site studies that dominate the literature, it is impossible for the distance proxy to disentangle the various attributes of the site itself. Second, other influential characteristics of a local area may be imperfectly controlled. While many studies attempt to control for the quality of schools and other public services, for parks and other amenities, for transportation networks, and for proximity to economic hubs, it is nearly impossible to represent all environmental factors that may influence property values. A meta-analysis is yet one more step removed from the actual market processes underlying value determination. It must find common ways of describing studies that are heterogeneous. Here, we control for whether individual studies accounted for potential environmental influences. The variable *Demoecon* indicates whether a study controlled for characteristics of the population and public services. The variable *Access* indicates whether a study controlled for transportation access. Finally, the variable *Industry* indicates whether a study controlled for the presence of industrial activity. These variables are undoubtedly imperfect and incomplete in distinguishing between studies.

5 Empirical Results

This section reports the results of our empirical analyses. First, we identify outlying observations and test for multicollinearity. Using a basic OLS estimation, we conduct some preliminary hypothesis tests. Next, recognizing the potential for correlation between and overrepresentation due to the inclusion of multiple estimates produced by a single study, we re-estimate the model using panel and weighted least squares estimators. We also examine parsimonious relatives of our full model. Section 5.3 identifies findings that are robust across the different models. Finally, we use logit models to examine factors that account for the significance of the location effect across studies.

[10] Hite (2006) provides very little explanation for this surprising result.

5.1 Regression Diagnostics

First, we run a robust OLS estimation with the full sample of 142 observations.[11] The estimated model had a very low adjusted-R^2 value. This suggests a need for regression diagnostics to identify outliers. Since an outlier may be an observation with large residuals, the first method identified observations with standardized residuals greater than two in absolute value. This criterion isolated eight outliers. A second method is Cook's D (Cook and Weisberg 1982) which measures the overall influence of each observation on the regression coefficient estimate. This criterion identified ten outliers. The third, DFITS (Belsley et al. 1980), reveals unusual observations by combining leverage and the studentized residual. Here, it identifies 10 outliers, four of which were also identified by Cook's D and four of which stood out in residuals detection. Combining all three methods isolates 13 observations. These outliers are excluded in our final model estimation, reducing the number of observations to 129. Table 1 lists the summary statistics of the resulting sample. The mean *PPE* decreases from 6.37 to 4.49%.

A multicollinearity test of the explanatory variables excluding outliers produced VIF scores well below 10, indicating no appreciable multicollinearity. The Breusch–Pagan test for heteroskedasticity of the variance reject the null hypothesis ($p = 0.0475$) of constant variance in the error term, which means robust OLS is required to correct standard errors.

A t test of the overall sample mean *PPE* shows that it is significantly different from zero. Because we are interested mainly in whether the different site types and sites at different cleanup stages differ from each other, we also test for equality between group *PPE* means. Table 2 shows summary statistics of *PPE* by both type of sites and cleanup stages. Terrestrial hazardous waste sites dominate the sample, accounting for 76 of 129 observations. For these sites, using t tests, the null hypotheses that mean *PPE* equals zero are rejected at the 0.001 level for *Terr* and *Aquatic* and at the 0.05 level for *Nonhaz*, but not for *Nuclear* at the 0.05 level.[12] We are also interested in whether each group mean *PPE* by type of sites differs from the overall sample mean *PPE*. From the results shown in the table, the mean *PPE*s of *Aquatic* (15.937) and *Nuclear* (−0.489) are significantly different from the overall sample mean while the means for *Terr* and *Nonhaz* are not.[13] This implies that the effects of aquatic and nuclear sites may be significantly different from those of non-hazardous landfills and terrestrial hazardous waste sites while the effects of the latter two categories are not significantly different. A homogeneity test of equal variance between the different types of sites confirms differences between the types of site at the 0.01 significance level.[14]

Another issue of interest is how cleanup status affects *PPE* estimates. Only terrestrial hazardous waste sites and aquatic sites are subject to formal cleanup processes, so we can only analyze the issue for the 90 observations in these two categories. From Table 2, it is apparent that most of the observations are in Stage 1 where contamination is acknowledged but no cleanup plan has been developed. The average *PPE*s of each stage for the *Terr* and *Aquatic* sites are 4.569 (*Stage_0*), 4.610 (*Stage_1*), 6.979 (*Stage_ 2*), and 5.702 (*Stage_3*). T tests of the null hypothesis that each of the mean *PPE*s is zero are rejected for stages 0, 1,

[11] For detailed results, see Table 1 in the Supplemental Tables file posted at the *Environmental and Resource Economics* website.

[12] Respectively, the t statistic and p value for *Terr* are 4.47 and 0.0000; for *Aquatic*, they are 4.97 and 0.0003; the values for *Nonhaz* are 2.00 and 0.054; and the values for*Nuclear* are −0.261 and 0.780.

[13] The t statistic and p value for *Aquatic* are 3.57 and 0.003; for *Nuclear*, they are −2.66 and 0.026.

[14] Bartlett's test for equal variances: $\chi^2(3) = 10.729$, Prob $> \chi^2 = 0.013$.

Table 2 Test of equivalence of group mean PPE

Type	By type ($N = 129$)					Stage	By cleanup stage ($N = 90$)[a]				
	Obs	Mean	Std. err.	95% Conf. interv			Obs	Mean	Std. err.	95% Conf. interv.	
Nonhaz	29	3.148	1.700	−0.334	6.629	Stage 0	7	4.569	2.095	−0.557	9.694
Terr	76	3.546	0.794	1.964	5.127	Stage 1	42	4.610	1.082	2.425	6.795
Aquatic	14	15.937	3.206	9.010	22.863	Stage 2	26	6.979	1.743	3.390	10.567
Nuclear	10	−0.489	1.872	−4.723	3.745	Stage 3	15	5.702	3.785	−2.417	13.821

[a] Since the cleanup processes applied to Terr and Aquatic sites do not apply to Nonhaz and Nuclear sites, the former categories together contain only 90 observations

and 2.[15] However, none of stage mean *PPE*s are significantly different from the overall sample mean *PPE* at the 95% level. This implies that different cleanup stages do not contribute significantly to variation of the overall sample mean *PPE*. Nevertheless, a homogeneity test demonstrates that the variances of the stage *PPE*s differ from each other at the 0.001 level.[16]

5.2 Adjusting for Multiple Estimates

Some studies provide multiple estimates of *PPE*. Without adjustment, the more estimates a study provides, the more importance it would assume in the meta-analysis. Several approaches are available to control for this effect. One is to use only one estimate from each study so that each study has the same weight in the meta-analysis (Taylor 2003). We applied this approach using the following rules: (1) If a study produced more than one result, use the estimate for residential properties in cleanup stage 1 or, if that estimate is not available, then use the estimate for stage 2; and (2) If multiple estimates are given for the same stage, then use the smallest estimate. These rules produced 46 observations—one per study for our final sample: 12, 23, 7, and 5 observations, respectively, for *Nonhaz*, *Terr*, *Aquatic*, and *Nuclear* sites. Among the 30 observations for *Terr* and *Aquatic,* 2, 17, 8, and 3 observations, respectively, are for *Stage_0*, *Stage_1*, *Stage_2*, and *Stage_3*. By eliminating nearly two-thirds of the estimates, this approach greatly diminishes the potential explanatory power of the model. The estimation results are reported in Electronic Supplementary Material.

Two other approaches to the weighting problem preserve sample size. One is to weight each estimate by the inverse of the number of estimates from the source study (Mrozek and Taylor 2002). This causes each study to be weighted evenly, although individual estimates are not. The other approach takes explicit account of panel characteristics in the data using fixed effects or random effects models (Smith and Kaoru 1990). Generally, a fixed effect model is preferable since it does not require the assumption that the individual effects, which are incorporated into the error term, are uncorrelated with the explanatory variables. However, the fixed effects model reduces the degrees of freedom since it requires the addition of many dummy variables. The point estimates from fixed effects model lack reliability when the within variation (variation across time) remains small or even constant and renders impossible the estimation of the coefficients of time invariant variables. If the individual effects are uncorrelated with the explanatory variables, a random effects model yields consistent

[15] The t statistics and p values for Stage 0 are 2.181 and 0.072; Stage 1 values are 4.26 and 0.0001; Stage 2 values are 4.005 and 0.0005, and Stage 3 values are 1.506 and 0.154.

[16] Bartlett's test for equal variances: $\chi^2(3) = 16.902$, Prob $> \chi^2 = 0.002$.

and efficient estimates while the estimates from a fixed effects model are consistent but not efficient (Johnson and DiNardo 1997). In order to conserve degrees of freedom, we apply the random effect model.

As a first step in applying these different weighting schemes, we include only the site characteristics as independent variables. The site characteristics are intrinsic and unaffected by researchers' judgments. Table 3 reports the results of robust OLS estimation (R1), random effects panel estimation (P1) and weighted least squares (W1–W4) applied to 129 observations. The Breusch and Pagan Lagrange Multiplier test for random effects cannot reject the null hypothesis at the 0.05 significance level ($p = 0.065$), implying that a pooled OLS model is appropriate. In terms of the adjusted-R^2 values, both the Robust OLS model and WLS models improve upon the panel model with the WLS model preferred. Since some of the site variables are consistently insignificant for all three basic models, we estimated three more specifications using WLS: W2 excluding 'job'; W3 excluding 'job' and replacing stage variables with the single dummy 'cleanup'; and W4 excluding 'job' and any stage variables or 'cleanup'. All four WLS specifications show a significant positive effect of *Aquatic* on *PPE*, indicating that, on average, aquatic sites have a higher price discount than other types of sites. Quite a few regional indicators, e.g., *Pacific*, are significant. These findings imply that the type of site and site location by region affect estimates of property value impacts.

Next, using the same methods, a variety of models are estimated with additional explanatory variables reflecting the data characteristics and analytical methods used. Table 4 displays the results of the full models. The "F" at the beginning of each model acronym reflects its legacy in the "full" specification. By the nature of meta-analysis, the specific magnitudes of the coefficients are not particularly meaningful (Boyle et al. 1994), so we focus mainly on signs and significance.

The Breusch and Pagan Lagrangian multiplier test for random effects fails to reject the null hypothesis ($p = 0.378$), so the pooled OLS is preferred to the panel random effect model. Based on a comparison of adjusted-R^2 values, all of the WLS estimates are superior to the robust OLS and panel model. Again, FW1 includes all variables; FW2 drops *Job*, *Industry*, *Time*, *Mort_rt*, and *Discre* because these variables are consistently insignificant across models; FW3, in addition to the deletions in FW2, replaces the three stage variables with a single 'cleanup' dummy; FW4 drops the five variables and all stage-related variables. Across the four WLS models, although FW1 has the highest adjusted-R^2, FW4 seems to perform as well as FW1 because it has fewer explanatory variables with only a slight reduction in adjusted-R^2. This reaffirms the negligible effect of the cleanup stage variables and is consistent with the bivariate analysis which found that the group mean *PPE*s by cleanup stage are not significantly different from the overall sample mean *PPE*. Given the consistency between the WLS models, in what follows, we focus on model FW4.

5.3 Interpretation

For all models, omitted classes of categorical variables are embedded in the constant term. The negative and significant coefficients of the constant terms thus reflect studies of non-hazardous sites in the East Northcentral region. The results for other site types and regions are properly interpreted by adding their coefficients to the constant term. In this type of analysis, the absolute magnitudes of the results are not particularly meaningful. The sign and significance of the coefficients are the interpretable features.

Looking across specifications, the results appear robust. Most of the signs and magnitudes are stable. Many variables that are significant in FW4 are also significant in one or more of the other models.

Table 3 Meta-analysis results-site characteristics only (dependent variable: MPPE)

	Robust OLS		Panel		Weighted least squares							
	R1		P1		W1		W2		W3		W4	
	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.	Coef.	Std. err.
Constant	2.221	3.279	0.651	2.908	0.228	3.448	−0.266	2.810	0.090	2.726	0.095	2.687
Terr	6.071*	3.477	7.216**	3.195	7.587**	3.638	7.814**	3.425	7.079**	3.123	7.076**	3.099
Aquatic	10.785***	3.515	11.378***	4.325	11.414***	3.648	11.550***	3.542	10.745***	3.400	10.774***	3.355
Nuclear	−1.756	2.217	−0.702	5.471	0.559	2.453	0.224	2.770	−0.057	2.711	−0.056	2.705
M_site	−6.884***	2.333	−4.611	2.886	−5.328***	2.071	−5.117***	1.984	−5.651***	1.868	−5.646***	1.860
Pacific	−5.071**	2.288	−5.717	7.950	−6.116***	2.366	−6.432***	2.117	−6.571***	2.050	−6.578***	2.041
Mountain	2.428	4.355	1.928	7.353	2.635	4.126	3.094	3.884	3.208	3.823	3.197	3.780
Wn_cent	−3.693	3.097	−2.689	4.333	−4.724	3.638	−4.302	3.518	−4.088	3.330	−4.092	3.316
Mid_atl	5.642**	2.186	5.994*	3.307	6.398***	2.104	6.265***	2.096	5.737***	1.958	5.723***	1.880
New_eng	0.816	1.807	0.550	2.944	0.936	1.446	0.919	1.446	0.949	1.343	0.938	1.273
Ws_cent	−4.923*	2.424	−5.788	4.511	−4.970**	2.505	−5.675***	2.074	−5.764***	1.983	−5.729***	1.776
Es_cent	2.797	3.127	2.060	7.085	2.551	3.071	1.673	2.531	1.988	2.374	1.985	2.370
S_atlant	−0.096	2.185	−1.806	4.139	−0.928	1.707	−0.636	1.669	−0.031	1.555	−0.029	1.544
Canada	12.641**	4.864	13.492**	5.380	13.368***	4.523	13.749***	4.313	13.198***	4.275	13.203***	4.307
NPL	1.784	2.128	−2.020	2.675	−0.069	2.429	−0.160	2.419	0.544	1.925	0.557	1.848
Job	−1.814	2.105	−0.450	3.016	−1.321	2.182						
Stage 0	−2.168	2.413	−5.444*	3.136	−3.673	2.631	−3.633	2.543				
Stage 2	−1.329	2.231	1.056	2.607	−0.319	2.097	−0.030	2.020				
Stage 3	−1.579	2.310	0.274	2.706	−0.062	2.521	−0.095	2.526				
Clean									0.115	2.347		
N	129		129		129		129		129		129	
K	18		18		18		17		15		14	
Adj. *R* sqr	0.350		0.323		0.417		0.421		0.424		0.429	

* Significance level at 0.1; ** significance level at 0.05; *** significance level at 0.01

Table 4 Meta-analysis Estimation Results with Selected Models (Dependent Variable: MPPE)

	Robust OLS		Panel model		Weighted least squares							
	FR1		FP1		FW1		FW2		FW3		FW4	
	Coef.	Rob. SE	Coef.	SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE
Constant	−52.182***	17.875	−43.435***	17.184	−59.684***	18.248	−44.348***	10.207	−43.915***	10.154	−42.949***	9.922
Terr	15.512***	4.230	12.641***	3.362	16.501***	4.265	14.873***	3.650	14.245***	3.336	14.049***	3.263
Aquatic	22.664***	4.406	20.787***	5.144	23.477***	4.178	22.050***	4.416	20.929***	3.919	21.219***	3.944
Nuclear	7.269	4.642	2.203	7.448	6.837	4.956	2.159	4.114	2.420	4.198	2.230	4.218
M_site	−5.251*	2.727	−2.348	3.614	−3.808	2.801	−2.829	1.905	−3.233*	1.789	−3.127*	1.708
Pacific	5.138	6.474	7.031	10.299	5.509	6.930	8.246	6.247	7.077	5.838	6.386	5.651
Mountain	16.947***	5.587	12.000	9.527	14.985***	5.150	12.493**	5.144	12.780**	5.228	12.495**	5.083
Wn_cent	−8.419**	4.610	−4.630	5.118	−8.474*	4.491	−7.006*	3.629	−6.524	3.433	−6.327	3.408
Mid_atl	9.853***	2.682	9.730**	4.355	10.920***	2.496	10.532***	3.049	10.013***	2.876	9.837***	2.826
New_eng	3.518	2.461	1.592	3.142	3.706*	2.181	1.752	1.435	1.609	1.339	1.268	1.238
Ws_cent	1.054	4.157	1.830	5.885	0.027	4.445	−1.725	3.932	−2.365	3.562	−2.272	3.490
Es_cent	7.879	5.029	8.364	9.929	8.828*	5.220	11.952***	3.393	12.250***	3.458	11.514***	3.219
S_atlant	6.742***	2.023	7.189	4.889	6.772***	2.032	8.215***	1.829	8.769***	1.844	8.831***	1.763
Canada	15.353**	6.340	15.764***	5.885	17.146***	6.538	16.642***	5.824	16.596***	5.845	16.828***	6.093
NPL	−5.769**	2.774	−5.673**	2.786	−7.364**	3.007	−5.985**	2.396	−5.840**	2.298	−5.452**	2.144
Job	−0.883	3.209	−0.412	3.257	−0.484	3.318						
Stage 0	−2.179	2.931	−4.256	3.384	−3.000	2.920	−3.192	2.545				
Stage 2	−0.763	2.330	1.091	2.877	−0.794	2.381	−0.513	1.759				
Stage 3	−0.369	3.113	0.261	3.308	0.611	3.484	1.817	2.466				

Table 4 continued

	Robust OLS		Panel model		Weighted least squares							
	FR1		FP1		FW1		FW2		FW3		FW4	
	Coef.	Rob. SE	Coef.	SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE
Cleanup									2.155	2.244		
Residen	16.123***	3.454	16.452***	5.506	16.258***	3.140	16.362***	3.014	16.412***	3.022	16.141***	2.854
Mean_dt	−1.205***	0.461	−1.012	0.630	−1.089	0.483	−1.005***	0.351	−0.975***	0.338	−0.916***	0.323
Sample	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ind_sale	10.225***	3.907	9.978	6.393	11.640***	4.091	12.910***	3.355	13.163***	3.442	12.815***	3.322
Demoecon	−4.363***	1.627	−6.410*	3.703	−5.399***	1.532	−6.305***	1.495	−6.236***	1.457	−6.259***	1.419
Access	6.767***	2.242	6.673	3.241	7.151***	2.285	7.233***	2.217	6.872***	2.128	6.305***	1.969
Industry	−0.492	3.316	0.147	4.855	0.128	2.716						
Time	0.337	0.259	0.128	0.258	0.381	0.273						
Mort_rt	0.670	0.525	0.013	0.600	0.828	0.579						
Publish	8.026**	3.540	11.253**	4.712	10.409***	3.479	10.057***	3.720	9.692**	3.754	9.820**	3.819
Linear	0.512	2.772	0.731	3.032	0.308	2.867	0.076	2.767	−0.725	2.499	−1.091	2.480
Discre	−2.945	3.775	−1.782	4.717	−1.579	3.876						
Sig	3.257**	1.557	2.814*	1.621	2.507	1.624	3.274**	1.523	3.635**	1.472	3.585**	1.468
Sar	−2.491	4.410	1.943	7.635	0.168	4.571	4.020	3.011	3.897	3.039	3.723	2.955
N	129		129		129		129		129		129	
K	32		32		32		27		25		24	
Adj. *R* sqr	0.504		0.467		0.569		0.564		0.568		0.568	

The model abbreviation use "F" to indicate that the basic model uses all independent variables. Otherwise, the models differ by the use of Robust OLS (R), Panel (P), or Weighted Least Squares (W) estimators, and by whether all independent variables are included

* Significance level at 0.1; ** significance level at 0.05; *** significance level at 0.01

The FW4 results indicate that the type of site is very important. *Terr* and *Aquatic* are positive, consistent in magnitude, and highly significant in all six models, implying that studies of these classes of hazardous sites yield generally larger estimates of proportionate impact than studies of nonhazardous sites. Although positive, *Nuclear* is not significant, implying that estimates for nuclear sites are not statistically distinct from the omitted category, *Nonhaz*. To further examine whether *Nuclear* sites differ systematically from other site types, we exclude the nuclear site observations and rerun the models in Table 4. In so doing, we also exclude the *Pacific* independent variable, because all observations in the Pacific region are associated with nuclear sites (although the converse is not true). The results appear in Table 5. Compared with the results in Table 4, the most important change is that *Mean_dt* becomes insignificant in all models other than FP1. As a group, the 10 *Mean_dt* values for nuclear site studies lie at the high end of our sample. Their exclusion reduces the average value (17%) and variability (21%) of the remaining *Mean_dt values* as well as the degrees of freedom (approximately 10%). All of these effects degrade the discriminative power of hypothesis tests. Nevertheless, this finding suggests that, when considered across sites and model specifications, the economic impacts of non-nuclear sites are not significantly related to the distance over which those impacts are measured. This result is consistent with the findings of Kiel and Williams (2007), but it is inconsistent with the basic premise of hedonic property valuation of environmental conditions.

Returning to Table 4, the estimated effects of aquatic sites are generally larger than for any other class and the difference is statistically significant. This result is robust to the exclusion of estimates for nuclear sites in Table 5. These regression results differ from the simple ANOVA comparisons of sample means, which suggest equivalence of *Terr* and *Nonhaz*. The inclusion of the *NPL* variable distinguishing subsets of *Terr* may account for the separation apparent in the regression results.

Geographic location matters in all models. In FW4, sites in the Pacific, West Northcentral, East Southcentral, and South Atlantic regions and Canada are associated with greater estimates of impact compared to those in the East Northcentral region. Studies of sites in mountain states produce significantly smaller estimates. *M_site* is significant but has an unexpected negative sign, suggesting that multiple sites mute the effects on nearby property values. This finding may reflect structural differences of neighborhoods in the vicinity of clusters of waste sites.

Contrary to expectations, the variable *NPL* is negative and significant. This indicates that studies of NPL sites, other things equal, produce *smaller* estimates of *PPE* relative to non-NPL hazardous sites. A joint hypothesis test on *Terr* and *NPL* is significant and positive, indicating that the depressive effect of NPL designation is not sufficient to offset fully the generic positive effect of hazardous waste sites.

Concerning the data features, *Residen, Ind_sale*, and *Access,* all are positive and significant at the 0.01 level. Thus, studies that use residential properties rather than commercial properties, or individual housing sales data rather than census or individual assessment data, or that control for other accessibility features, generate greater estimates of *PPE*. To examine the possibilities that studies of commercial properties and those utilizing assessed property values behave differently from studies of, respectively, residential properties and transaction prices, we also estimated the models in Table 4 excluding commercial properties and without assessed properties.[17] (Exclusion of *Residen* also results in the elimination of the *Mountain* variable because all of the Mountain observations involved commercial properties.) Neither

[17] For detailed results, see Tables 2 and 3 in the Supplemental Tables file posted at the *Environmental and Resource Economics* website.

Table 5 Meta-analysis estimation results without nuclear sites (dependent variable: PPE)

	Robust OLS		Panel model		Weighted least squares							
	FR1		FP1		FW1		FW2		FW3		FW4	
	Coef.	Rob. SE	Coef.	SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE
Constant	−44.989***	17.528	−39.096*	20.713	−53.829***	18.151	−47.888***	10.074	−49.623***	10.543	−49.211***	10.191
Terr	15.994***	4.299	12.293***	3.749	16.528***	4.435	15.121***	3.767	14.569***	3.312	14.374***	3.239
Aquatic	24.433***	4.591	22.084***	5.855	24.796***	4.423	22.608***	4.523	21.874***	4.015	22.201***	4.032
M_site	−5.837**	2.675	−2.497	3.955	−4.912*	2.733	−2.746	2.000	−2.948*	1.930	−2.801*	1.829
Mountain	18.347***	6.121	14.767	11.572	17.973***	5.636	13.655**	5.638	14.571	5.998	14.468***	5.807
Wn_cent	−8.211	5.492	−3.619	6.290	−7.719	5.905	−5.747	4.329	−5.355	4.103	−5.124	4.083
Mid_atl	11.308***	3.555	12.004*	5.461	12.153***	2.903	11.155***	3.500	10.774***	3.279	10.642***	3.256
New_eng	2.904	2.991	1.707	4.000	3.526	2.747	2.099	1.922	1.972	1.773	1.647	1.678
Ws_cent	−0.776	5.167	3.640	8.399	0.246	5.431	−2.319	5.483	−3.104	4.657	−3.107	4.581
Es_cent	8.914	6.799	10.120	13.231	10.955	6.982	14.382***	4.533	15.871***	4.298	15.503***	4.041
S_atlant	3.676	4.583	6.428	8.378	6.243	4.955	8.376***	2.514	9.792***	2.429	10.060***	2.218
Canada	16.428**	6.724	16.692**	6.939	18.107***	7.145	18.007***	6.455	17.834***	6.441	18.063***	6.650
NPL	−6.079**	2.981	−5.788	3.023	−7.189**	3.386	−6.174**	2.478	−6.042***	2.386	−5.663***	2.244
Job	−2.258	3.371	−1.204	3.647	−1.959	3.494						
Stage 0	−2.460	3.557	−4.747	3.718	−3.091	3.960	−2.763	3.490				
Stage 2	0.261	2.601	1.928	3.053	−0.519	2.723	−0.354	1.963				
Stage 3	0.472	3.550	0.910	3.527	1.094	4.044	1.958	2.452				

Table 5 continued

	Robust OLS		Panel model		Weighted least squares							
	FR1		FP1		FW1		FW2		FW3		FW4	
	Coef.	Rob. SE	Coef.	SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE	Coef.	Rob. SE
Cleanup									2.089	2.255		
Residen	13.912***	3.472	16.113**	6.710	15.567***	3.559	16.198***	2.478	16.910***	2.848	16.768***	2.508
Mean_dt	−0.973	0.718	−1.198	0.926	−0.995	0.780	−0.657	0.606	−0.582	0.534	−0.497	0.514
Sample	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ind_sale	8.944*	4.979	8.459	8.836	11.098**	5.236	14.060***	3.583	15.388***	3.730	15.325***	3.601
Demoecon	−4.700***	1.658	−6.661*	4.212	−5.636***	1.526	−6.409***	1.503	−6.351***	1.482	−6.381***	1.430
Access	8.355***	2.509	7.919	4.069	7.916***	2.570	7.998***	2.352	7.745***	2.286	7.217***	2.140
Industry	−0.136	3.643	0.167	5.553	1.469	3.038						
Time	0.153	0.266	−0.010	0.286	0.195	0.286						
Mort_rt	0.408	0.517	−0.185	0.623	0.563	0.572						
Publish	9.806***	3.843	13.407**	5.536	12.009***	3.739	10.697***	3.834	10.452***	3.860	10.601***	3.904
Linear	−0.355	3.110	0.181	3.538	−0.872	3.316	−0.272	3.043	−0.715	2.894	−1.014	2.866
Discre	−6.407	4.498	−4.723	5.926	−4.232	4.760						
Sig	4.126**	1.788	3.266**	1.784	3.550*	1.899	4.035**	1.754	4.409***	1.603	4.368***	1.595
Sar	−5.183	6.591	−0.375	12.489	−1.330	6.808	4.751	4.601	6.375	4.183	6.647	4.022
N	119		119		119		119		119		119	
K	30		30		30		25		23		22	
Adj. *R* sqr	0.623		0.579		0.648		0.626		0.624		0.620	

This is similar to Table 4 except that 10 observations from nuclear sites are excluded. Since those 10 observations constitute the universe of observations in the Pacific region, the "Pacific" variable also drops out

* Significance level at 0.1; ** significance level at 0.05; *** significance level at 0.01

of these variants of the basic model produce estimates that differ substantively from the original estimates in Table 5. The coefficients of *Mean_Dt* and *Demoecon* remain negative and significant, with the exception of *Mean_Dt* in the nuclear-free analysis. A negative sign for *Mean_Dt* is expected because of the dilution effect of larger geographic areas. Sample size seems unimportant.

Methodologically, *Publish* and *Sig* are consistently positive and significant in almost all models. The positive signs indicate, not surprisingly, that published and significant results tend to be greater in magnitude.[18] The coefficient of *Sar* is positive but insignificant. *Linear* is insignificant, implying little difference between the estimates from different functional forms.

5.4 Logistic Analysis

Kiel and Williams (2007) examine factors that make the coefficients of the environmental variable significant in each estimated model. Following their lead, we generate a new dependent variable (*Exp_sig*) which equals one for statistically significant and theoretically appropriate estimates of the distance variable and zero if the estimated coefficient is either insignificant or theoretically unexpected.[19] For our 129 observations, the mean of *Exp_sig* is 0.597. We analyze *Exp_sig* with both an ordinary logit model and a random effect logit model. The latter compensates for possible correlation between multiple estimates from each study. The other independent variables are the same as in full model. Table 6 shows the logistic regression results.

Based on the likelihood ratio χ^2 and their corresponding p-values and Log Likelihood, the ordinary logit models perform better than the random effects logit. The large p value of the random effect logit model indicates that the null hypothesis of no variation among the multiple estimates within one study cannot be rejected and that the ordinary logit model is preferred. However, the results from the two models are essentially consistent and robust in terms of signs, magnitude, and significance. Because the two sets of models measure different things and different variables, it would be incorrect to compare the results from the logit model with those from the previous models using nominal values of *PPE* as the dependent variable. For the same variable, whether the sign is positive or negative has a different meaning. For example, in the logit model, *Nuclear* has a significant negative sign. This indicates that studies of nuclear sites are less likely than those of non-hazardous sites to produce statistically significant and expected estimates of MWTP.

The estimates in Table 6 suggest that studies of nuclear sites, of sites in New England, controlling for socio-economic features and industrial activities, or using a discrete environmental variable are less likely to produce statistically significant and expected effects on property values. Studies that are more likely to produce estimates for the environmental variable that are statistically significant and have the expected effect on property values are those that are published, address aquatic sites or NPL sites, that focus on sites in the Mountain, Middle Atlantic, East Southcentral, and South Atlantic regions, that examine residential property values, that use individual parcel sales data, and that control for geographic scale, other accessibilities, and spatial autocorrelation.

[18] In other words, studies with higher estimates may be more likely to be published.

[19] The expected alternative hypothesis is that housing values increase as distance to a waste site increases. However, if the environmental variable is the inverse of distance, then the sign should be negative.

Table 6 Logit estimation results

Exp_Sig	Logit		Random effect logit	
	Coef.	Std. err.	Coef.	Std. err.
Constant	−51.3792***	15.543	−51.3832***	15.544
Terr	2.6745	1.867	2.6749	1.867
Aquatic	19.0788***	6.092	19.0804***	6.093
Nuclear	−22.1273***	6.033	−22.1291***	6.033
M_site	3.1146	1.988	3.1146	1.988
Pacific	−2.2304		−6.2366	15428.940
Mountain	13.8653**	5.649	13.8668**	5.649
WN_Cent	11.7823	303.073	11.7831	303.234
Mid_Atl	33.3538***	9.452	33.3564***	9.453
New_Eng	−2.7799*	1.664	−2.7799*	1.664
WS_Cent	−3.1721	3.659	−3.1719	3.659
ES_Cent	12.6790**	5.181	12.6799**	5.182
S_Atlant	9.6903***	3.705	9.6913***	3.705
Canada	2.8430	2.158	2.8430	2.158
NPL	5.2242***	1.919	5.2248***	1.919
Job	−0.6937	1.149	−0.6939	1.149
Stage 0	−2.7578	1.757	−2.7581	1.757
Stage 2	2.3914	1.960	2.3914	1.960
Stage 3	−0.8401	1.416	−0.8403	1.416
Residen	7.1006**	2.864	7.1013**	2.864
Mean_dt	0.5822**	0.295	0.5823**	0.295
Sample	$-3.85E-04$	2.38E−04	$-1.14E-04$	2.54E−04
Ind_sale	13.3080***	4.780	13.3090***	4.780
Demoecon	−5.4473**	2.267	−5.4479**	2.267
Access	3.6771*	2.091	3.6773*	2.092
Industry	−9.1291***	3.513	−9.1294***	3.513
Publish	28.5122***	7.976	28.5144***	7.977
Linear	0.5871	1.296	0.5872	1.296
Discre	−11.1226***	3.604	−11.1234***	3.604
SAR	16.5546***	4.668	16.5558***	4.668
N	129		129	
Pseudo R^2	0.495		0.552	
LR χ^2	86.18		22.15(Wald χ^2)	
Prob > χ^2	0.000		0.814	
Log likelihood	−43.887		−43.887	

* Significance level at 0.1; ** significance level at 0.05; *** significance level at 0.01

6 Discussion and Conclusions

This paper analyses the results of previous studies that have estimated the effects of waste sites on the market value of nearby real estate. These disamenities are hypothesized to negatively influence adjacent property values. Their remediation should reduce those impacts.

Our analysis across distinct types of studies and sites provides insight into the effects of sites characterized by different types and degrees of risk associated with materials deposited at those sites as well as into the effects of study characteristics.

Most of our key findings are robust across different empirical models. Here we point out a few of the most important ones. First, studies of river or harbor contamination produce systematically larger *PPE* estimates than studies of terrestrial hazardous sites, and both of those classes produce larger estimates than studies of nuclear sites and non-hazardous waste sites, which are not statistically differentiated. The importance of aquatic attributes is loosely consistent with Luttik's (2000) observation that water features are highly influential for house prices. It suggests that property owners may be especially concerned about the contamination of water where, even though the contamination may be trapped in sediments, it may be perceived to be more mobile and open to public exposure.

Second, nuclear sites tend to produce *PPE* estimates not very different from the effect associated with nonhazardous sites. This lack of differentiation may reflect greater on-site employment opportunities that may attract residents to live near nuclear power plants or a general comfort level with the risk levels at these highly regulated installations. The possibility that Nuclear sites are essentially different from the other types of waste sites is tested by rerunning the models without the nuclear observations included. The results are essentially unchanged, with one important exception that constitutes a third important result. It is that the distance variable becomes insignificant, implying that the size of the area studied does not affect the size of the estimates. This seems contrary to the fundamental premise of hedonic property valuation of environmental quality—that areas closer to a disamenity will experience it disproportionately. However, it is consistent with Kiel and Williams (2007) finding that, studied across contaminated sites, distance is not a consistent predictor of property value change.

Fourth, surprisingly, cleanup stages do not seem to affect *PPE* estimates consistently and significantly. In addition, other things equal, studies of sites on the EPA's NPL for cleanup produce systematically smaller estimates of impact than studies of terrestrial hazardous sites not on the NPL. This finding might reflect market expectations that sites on the NPL are or will be remediated with greater certainty than non-NPL sites. In other words, since property values embody both current use values and future economic prospects, the fact that NPL sites are given priority for remediation may more than offset the fact that these sites are among the most hazardous at the time they are placed on the list. The finding also suggests that, in focusing on NPL sites, Kiel and Williams (2007) and Greenstone and Gallagher (2008) may have examined samples that are less likely to reveal significant external effects. The very act of NPL listing may set in motion endogenous effects on expectations that serve to reduce those impacts.

Fifth, studies undertaken in some regions, such as West Northcentral, East Southcentral, South Atlantic states, and Canada, produce systematically greater *PPE* estimates than other regions. Finally, studies of commercial properties and unpublished studies, which also are more likely to report insignificant estimates, are associated with smaller *PPE* estimates.

Our results have at least two implications for future study of the effects of waste sites on nearby properties. One is that the failure of the distance variable to exert significant effects in the absence of nuclear site observations leaves in question the basic hedonic premise that properties nearer contaminated sites will be more significantly affected. Second, there is little evidence that a change in the status of a site, from discovery through remediation, produces significant and predictable effects on property values. This may imply either inertia in real estate markets or differences in the processes by which prices rise or fall in response to an intervention. Whatever the underlying cause, it is a sobering discovery for those who would

like to believe that removal of the disamenity will reliably lead real estate prices to recover. Many hedonic property value studies have been used by advocates of remediation to imply such a recovery, but the literature taken as a whole does not support it.

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Spent nuclear fuel and residential property values: the influence of proximity, visual cues and public information ⋆

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Abstract. This article examines whether public knowledge of spent fuel storage at nuclear power plants, and any local adverse risk perceptions that may have occurred, affect the sale price of single-family residential properties. We present evidence from the Rancho Seco, California, plant on residential property values using an hedonic modeling framework. We include a large number of control variables, data with a high level of spatial detail and a number of public information variables in order to model property market effects within a fifteen mile radius of the plant. Our findings indicate that proximity and visual reminders of the plant have some influence on local property markets, and that there is a small media coverage effect on single-family home sale prices.

JEL classification: R14, R20

Key words: Nuclear fuel, property values, hedonic modeling

1 Introduction

In this study, we are interested in determining whether public knowledge about spent nuclear fuel storage activities at nuclear power plants, and any adverse risk perceptions and stigmatization that may occur in the surrounding area, lead to measurable effects on the sale price of single-family residential properties. Spent

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nuclear fuel is currently stored in water pools at most of the nation's 72 commercial nuclear power plant sites awaiting the opening of a permanent federal disposal facility at Yucca Mountain in southern Nevada The project has experienced massive opposition from the State of Nevada and from local citizens groups, however, much of it based on heightened perceptions of risk associated with the long-term presence of nuclear waste in southern Nevada, spent fuel transportation to the repository site, as well as the potential effects adverse perceptions could have on tourism and economic development in the area.

Along with political opposition to the project a large literature has also developed, much of it based on the findings of public opinion surveys illustrating negative imagery and public perceptions of risk related both to the repository and to nuclear waste transportation and nuclear facilities in general. Much of this literature suggests that public concern and political opposition is rooted in the intense negative imagery that the public attaches to facilities, activities and technologies associated with the words "nuclear" and "radioactive," and the exaggerated adverse economic response that may be generated by events that are associated with nuclear energy, facilities and transportation through a process referred to as "the social amplification of risk." (see Kunreuther et al. 1988, Slovic et al. 1991, Erikson 1994, Jenkins-Smith 1994, Metz 1994).

Public and political opposition to the civilian spent fuel management program has led to significant delay in the opening of a repository, and as a result spent fuel pools at many of the nations nuclear power plants are approaching storage capacity. In response, a number of utilities who are facing immediate spent fuel pool storage capacity problems have constructed or are planning to construct dry storage facilities. As there is significant doubt over whether a repository will be available for the disposal of commercial spent fuel in the near future, dry storage of spent fuel at reactor sites is likely at all 72 of the nations nuclear power plants.

In this article, we present evidence of the impact of the plan to construct and operate a dry storage nuclear waste facility at the Rancho Seco nuclear power plant on local residential property values. The article is part of a larger study which examines a sample set of properties which were sold within a 15-mile radius of several California nuclear power plant sites along with a control site (see Clark et al. 1997, Metz and Clark 1997, Metz et al. 1997). The Rancho Seco plant, located approximately 25 miles southeast of downtown Sacramento, California, began operation in April 1975 and has been idle since June, 1989 when a public referendum resulted in the end of electricity generation at the plant because it was no longer able to produce competitively priced power. Since that time the plant has remained open as spent fuel is still stored in the pool storage facility inside the reactor building. In October, 1991, the Sacramento Municipal Utility District (SMUD), which owns the plant, applied for a license to construct and operate a dry storage facility. SMUD officials have estimated that they can reduce annual operating costs at the plant by nearly $1 million if the waste is placed in dry storage at the site.

Our analysis is aimed at addressing the claim that adverse risk perceptions and stigmatization as a result of existing and planned nuclear waste facilities

necessarily leads to local economic impacts. A number of studies have found adverse risk perceptions and stigmatization result from spent fuel storage activities in the area immediately surrounding power plant sites (Pasqualetti 1994, Bassett and Jenkins-Smith 1996). An examination of residential property market impacts in the vicinity of a nuclear power plant over a period in which plans to dry store spent fuel on-site have been made public is likely to indicate whether local economic impacts result from adverse risk perceptions. Our analysis covers the five-year period 1990 through 1994. As the announcement by the utility to dry store fuel came in October 1991, we are able to measure property value impacts from the plant during both the pre-announcement and post-announcement periods.

While the placement of spent fuel in dry storage at Rancho Seco does not increase the amount of waste stored at the site, placing the fuel in dry storage facilities has the potential to adversely affect the local economy, and in particular the local property market, in a number of ways. First, the application process to the Nuclear Regulatory Commission draws public attention to the fact that spent fuel remains at the plant, even though the plant is not operational. Second, the increased media coverage may serve to inform the public about the risks associated with the existence of spent fuel, and about the risks of transferring the waste from wet storage. Furthermore, some residents may view dry storage to be more or less hazardous than wet storage in pools. Finally, critics of dry storage have argued that it will effectively create *de facto* permanent waste storage facilities at individual utility sites should the Federal Government fail to successfully site a permanent repository in Nevada.

There is no evidence in the literature of any impact on residential property prices resulting from adverse perceptions associated with the siting of power plant spent fuel storage facilities. In a review of the literature on residential price effects of nuclear power plants, Fox et al. (1985) conclude that the siting of a temporary nuclear waste storage facility in Tennessee is more likely to be capitalized into residential property values if there is an increase in the public's knowledge or understanding of the risks associated with facility. They further contend that "the willingness to pay for distance from the facility" is likely to have significant price effects only for properties within approximately one mile of the plant.

2 Theoretical model

2.1 Literature review

Since the path-breaking work of Lancaster (1966) and Rosen (1974), the hedonic model has been used to determine the willingness to pay to avoid proximity to noxious or hazardous activities. For example, Michaels and Smith (1990), McClelland et al. (1990), and Kohlhase (1991) investigated the influence of proximity to hazardous waste dumps; Blomquist (1974) studied coal-fired power plants, and Kiel and McClain (1995) considered how proximity to an incinerator affects

residential home prices. The hedonic model has also been used to determine whether environmental accidents or natural disasters influence residential home prices. For example, Gamble and Downing (1982, 1986) and Nelson (1981) investigated the property value impacts of the 1978 nuclear accident at Three Mile Island, and Bernknopf et al. (1990) examined how earthquake and volcano hazard notices affect the perceived market value of properties. The Bernknopf et al. study is particularly interesting since it not only estimates the property value impacts of hazardous events, but also investigates how knowledge about the risks associated with future earthquakes (as conveyed by public notices of earthquake risks which are required at the time of sale) affect the property market.

2.2 A brief development of hedonic theory

The theory which underlies the hedonic model has been developed extensively elsewhere (see Hageman (1981) with specific regard to nuclear power plants) and thus, it is not reproduced in its complete form in this article. The hedonic model views housing as a differentiated bundle of attributes $z = (z_1, z_2, \ldots, z_n)$ where the vector z represents structural housing characteristics and features of the neighborhood. Assuming (a) perfect information about the bundle of attributes embodied in all properties in the market; (b) zero transactions costs in market trades of the packaged bundle; and (c) a continuous offering of attributes in the real estate market, the interaction between utility-maximizing consumers and cost-minimizing producers will generate an equilibrium price for housing which implicitly prices each attribute in the bundle, $p(z)$. The price function, $p(z)$ is generally assumed to be nonlinear, since the costs of repackaging a bundle of attributes is prohibitive once a house is built. Under these conditions, the implicit price of an attribute can be derived as the partial derivative of the equilibrium price function with respect to that attribute, $p_{zi}(z) = \partial p / \partial z_i$. Given the aforementioned assumptions, $p_{zi}(z)$, which is sometimes called the implicit price function, is equal to the marginal willingness to pay for a marginal increment in attribute z_i.

2.3 The role of information

Recall that the hedonic model assumes that sellers and buyers have perfect information about the quantities of all characteristics, z, in the housing bundle. In the absence of perfect information, however, the price function is dependent on the perceived level of the attribute vector, z_*. Thus, the equilibrium price function is also a function of the perceived level of attributes (i.e., $p(z_*)$). While the perceived level of knowledge about attributes is capitalized in the equilibrium price function, unknown attributes cannot be capitalized. Suppose the perceived level of an attribute (z_{*i}), is a function of an index of public knowledge (α) about the attribute (where $0 \leq \alpha \leq 1$), and the actual level of z_i (i.e., $z_{*i} = f(z_i, \alpha)$. The index is assumed to vary between no information, ($\alpha = 0$) and complete

information (α = 1). Thus, if α = 0 then $z_{*i} = f(z_i, 0) = 0$. In contrast, if α = 1 then $z_{*i} = f(z_i, 1) = z_i$. The implicit price for attribute z_i thus depends not only on the attribute level, but also on the level of public information. Using this as a background, we can evaluate the influence of new public information in the hedonic model.

Given that the equilibrium price function is $p(z_*)$, suppose that new information becomes available concerning a particular attribute, z_i. Press coverage that informs the public about the decision to build a nuclear waste dry storage facility has the potential to effect the level of the equilibrium price function since $p(z_{*i}(z_i, \alpha))$. That is, $\partial p(z_*)/\partial\alpha = \partial p/\partial z_{*i} \times \partial z_{*i}/\partial\alpha$ is nonzero if the attribute matters to local residents (i.e., $\partial p/\partial z_{*i} \neq 0$), and as long as information affects the perceived level of the attribute (i.e., $\partial z_{*i}/\partial\alpha \neq 0$). If news coverage raises public safety concerns, then $\partial p(z_*)/\partial\alpha < 0$ since $\partial p/\partial z_{*i} < 0$ and $\partial z_{*i}/\partial\alpha > 0$. Note that as the actual information tends towards complete information (i.e., $\alpha \to 1$), then $p(z_*) \to p(z)$. Second, additional information can also have an effect on the implicit price function, since anything that shifts the equilibrium price function (p_{zi}) is likely to influence the implicit prices that are derived from that function (i.e., $\partial p_{*i}/\partial\alpha$). For example, Kiel and McClain (1995) show that the effect of an incinerator plant on residential home prices varies with the phase of the project. In this model, as the project goes from the pre-rumor to the rumor stage, the value of α increases from zero to some positive value. Kiel and McClain found that the equilibrium price surface shifts, and also the implicit value of distance from the plant changes, with the phase of the project.

3 Empirical model

3.1 Model specification

Applications of the hedonic model have been criticized for focusing extensively on one phenomenon to the exclusion of other salient locational factors. The issue of specification is an important one. For example, a recent article by Smith and Huang (1993) found that the number of demographic and neighborhood characteristics affected the likelihood of identifying a statistically significant linkage between air quality (specifically particulate matter) and sale prices. If one is to avoid the bias from excluded variables in estimates of the implicit valuation of characteristics of nuclear plants, then other attributes which vary spatially, and which may be correlated with proximity to the plant, need to be included in the model.

The empirical model is broadly specified as follows:

$$\ln \text{RPRICE} = f\ (\text{STRUCTURE, NEIGHBORHOOD, CITY, TIME, NUCLEAR})$$

where the real sale price of housing (measured in logarithmic form) is a function of five vectors of determinants: STRUCTURE, NEIGHBORHOOD, CITY, TIME and NUCLEAR. Individual categories will be described shortly.

Property sales data were obtained from TRW REDI-Property and represent individual single-family residential home sales which took place between 1990

and 1994 within 15 miles of the Rancho Seco plant. Since we are interested in the role played by public information about the plant, we have chosen a period over which there was active media coverage about the plant in general, and nuclear waste in particular. One advantage of focusing on Rancho Seco is that since the plant is shut down and only a small workforce remains at the plant, employment effects, which can increase the value of properties for workers living close to the plant, are likely to be minimal. Several screens were applied to the data. First, we screened out properties which sold for less than $10,000 (in real terms) based on the possibility that these were not arms-length transactions. In addition, several observations had variables which appeared to be miscoded (e.g., one property reported a price in excess of $100 million) and were subsequently dropped from the sample. Finally, data were dropped when the latitude or longitude was missing, since this would prevent matching to the locational attributes. This resulted in a sample of 758 properties.

3.2 Use of GIS tools

An important empirical task is to match proximity of the phenomenon affecting property sales prices to individual properties. To accomplish this, we used Geographic Information System (GIS) software.[1] Since all property sales data are geocoded, distance to the closest hazard or annoyance factor can be readily computed provided the location of the activity can also be geocoded. If hazard data could not be accurately assigned a latitude/longitude coordinate, then the characteristics were matched according to other criterion (e.g., by census tract, or zip code).

3.3 Independent variables

Complete variable definitions, data sources, and descriptive statistics are reported in Table A.1. The vector STRUCTURE contains characteristics of the home, including the age of the house, the number of bedrooms, the number of full and half baths, the presence of central air conditioning, the number of stories in the structure, the number of fireplaces, the interior square footage of the building, and the size of the lot on which the house is located.

We included numerous attributes of neighborhoods in the NEIGHBORHOOD category to account for the influence of locational phenomenon on housing markets. These factors include demographic features such as racial and ethnic mix, as well as median income and poverty levels. Other measures include the occupancy rates of housing units in the neighborhood, the percent of neighborhood properties that are owner occupied and the average travel time to work in the neighborhood. School quality is proxied by the student-teacher ratio in local public schools. Although other public services are not included, the effective property

[1] PC-based GIS software packages from MapInfo and Scan/US were used in this project.

tax rate on the home is available, which can be used to proxy not only the local property tax burden, but also the level of public services within the community. Noxious activity in the community is proxied by several measures, including proximity to interstate highways, airports and railroads. Although controls for proximity to Superfund sites, hazardous waste disposal sites, and correctional facilities were contained in the database, no such facilities were within 5 miles of the closest property, and hence they were not included in the analysis.

3.4 Modeling public information

The goal of this study is to determine the extent to which $\partial p/\partial \alpha \neq 0$ and $\partial p_{*i}/\partial \alpha \neq 0$ (i.e., public information affects the equilibrium price, and implicit price functions respectively). To do so requires that public information, α, be measured. Accordingly, we examine articles about Rancho Seco appearing in the local newspaper, the Sacramento Bee, between 45 and 120 days of the sale of the property. Articles published within 45 days of the sale are assumed to have appeared after the offer to buy has been accepted, while press coverage appearing more than 4 months prior to the sale is assumed to be too early in the process to influence the sale price. Over the 5 year period, there were 62 articles or editorials written about the plant.

Although other media outlets (e.g., television, radio, national newspapers) exist, we chose to focus on press coverage in the dominant local newspaper for several reasons. First, any public information on the Rancho Seco plant which appears in national media outlets is also likely to be reported in the local media. Thus, local coverage actually proxies national coverage as well. The converse is obviously not true, with issues that are reported in the local media, in most cases not finding their way into national media outlets. Second, it is a relatively easy task to determine readership of local newspapers. The same cannot be said for the audiences of local television and radio stations. Third, even if estimates of audience size and geographic range could be obtained for television and radio markets, individual stations do not typically keep the transcripts of news reports in a readily accessible format. Thus, assembling data for all media outlets was not possible, and we use local newspaper coverage as a proxy for the level of public information from all sources (i.e., local and national newspaper, radio, television) about the activities at the plant.

3.5 Research questions

The model specifications explored in this article are designed to answer the following four questions:

1. Is there a relationship between housing prices and distance from the Rancho Seco plant and is that relationship stable over time?
2. Do visual cues about the Rancho Seco plant influence the relationship between the real sales price and distance from the plant?

3. Have announcements about spent nuclear fuel affected the price-distance relationship?
4. Has newspaper coverage in the period between 45 and 120 days prior to the sale affected the sale price of the property either inside or outside the visual range?

To investigate these questions, the elements of the NUCLEAR vector are measured using several different specifications. To address the first question, we include variables measuring distance from the plant, as well as a dummy variable for the time period after the newspaper announcement of plans to build a spent fuel dry storage facility at the plant. To address the second question, a dummy variable for the visual range[2] of the plant is also included, and that dummy variable is interacted with distance from the plant. The third question is tested by including a dummy variable for properties that sold after the announcement was made regarding dry storage of spent fuel at Rancho Seco. That dummy variable is also interacted with distance from the plant. To address the fourth research question, the influence of newspaper coverage about the plant is measured in four ways. Total volume of press coverage is measured by the number of paragraphs in the articles which appeared in the relevant time period prior to the sale. The content of the articles is proxied by whether those articles dealt with general nuclear issues, spent nuclear fuel, or transportation of nuclear waste. The press coverage variable is interacted with distance from the plant and the visual range dummy variable.

4 Empirical findings

Complete variable definitions and descriptive statistics for each variable are provided in Table A.1. The model is estimated using a semi-log functional form. Although some authors have suggested using flexible functional forms (Rassmussen and Zuehlke 1990), others have expressed concern about the accuracy of implicit prices derived using flexible form specifications (Cassel and Mendelsohn 1985). Furthermore, when there is the possibility of an omitted variables bias, Cropper et al. (1988) have shown that the semi-log model outperforms other functional forms. The White test reveals no significant problem with heteroskedasticity in any of the models estimated. All of the models explained approximately 83% of the variation in the log of the real sales price.

Before evaluating the findings for individual models, the coefficients on the control variables are discussed. Since the signs and statistical significance of levels of coefficients on the control variables are insensitive to the specification of the nuclear variables, we discuss the findings on the control variables for the first specification only (Table 1).

[2] A survey of the area surrounding the plant was undertaken by the authors, consisting of photographs of the plant taken at locations where residential development is present. These photographs reveal that the plant is located on relatively flat terrain, with few natural or man-made surface features or vegetation interrupting views of the facility. Under normal weather conditions, the cooling towers at Rancho Seco are visible from a distance of up to approximately 10 miles in all directions.

Table 1. Evaluation of price gradient, announcement effects and visual cue effects. Dependent variable: log of real housing price

Variable	Coefficient	*t*-score	Variable	Coefficient	*t*-score
Intercept	9.753199	5.058			
	Structural characteristics		*City dummy variables*		
BEDROOM	−0.008132	−0.682	ACAMPO	−0.057327	−0.245
FULLBATH	0.025188	1.333	ELKGROVE	0.135675[a]	2.934
HALFBATH	0.017775	0.986	GALT	−0.173894	−0.442
CNTRLAIR	0.007453	0.391	HERALD	−0.195765	−0.499
FIREPLCE	0.038423	2.811	LOCKEFRD	−0.621811	−1.605
NUMSTORY	−0.073537[a]	−3.920	SLGHHOUS	−0.259757	−0.918
AGEHOUSE	−0.001679[a]	−2.898	WILTON	−0.449223	−1.036
LOTAREA	5.96E-07[a]	6.321			
BLDGAREA	0.000421[a]	21.346			
	Neighborhood characteristics		*Nuclear and date variables*		
%ASIAN	−3.196974	−0.916	DATE	9.36E-05	1.140
%BLACK	1.709588	0.609	DISTANCE	0.042521[a]	2.598
%HISPANIC	2.371015	1.111	VISUAL	0.208866[a]	2.464
%PUBASST	−0.642847	−0.311	ANNOUNCE	0.006125	0.245
MEDHHINC	−2.00E-05	−0.952	DIST*DATE	−1.86E-05[a]	−2.923
%OCCUPIED	−2.165146[a]	−2.905	DIST*VISUAL*ANNC	−0.011330	−1.633
%OWNEROC	2.295343[b]	1.831			
TRAVTIME	0.059638	1.239			
OZONE	−0.665362[a]	−2.362			
INTRSTAT	−0.008446	−0.296			
RAILROAD	−0.038185[a]	−2.424			
AIRPORT	−6.96E-08	−0.128			
TOXRELINV	−0.009127	−0.434			
WATER	0.015092	1.033			
TSRATIO	21.27992[b]	1.879			
TAXRATE	−8.197497[a]	−2.042			
POPDENSITY	−3.50E-06	-0.241			

Adjusted R^2: 0.833731 Log-likelihood: 362.4889 F-statistic: 98.32961 Number Obs: 758

Joint F-tests:

Structural characteristics:	$F_{9,748} = 159.920$[c]	Distance variables:	$F_{3,754} = 3.580$[c]
Neighborhood characteristics:	$F_{17,740} = 6.826$[c]	Date variables:	$F_{2,755} = 26.678$[c]
City dummy variables:	$F_{7,750} = 2.678$[c]	Visual variables:	$F_{2,755} = 3.147$[c]
		Announce variables:	$F_{2,755} = 1.038$

[a] Statistically significant at the 5% level of significance in a two-tailed test.
[b] Statistically significant at the 10% level of significance in a two-tailed test.
[c] Statistically significant at the 5% level of significance.

4.1 Findings on the control variables

Chow tests were conducted on each category of control variable, and all groups were found to be statistically important. Individual coefficients in the STRUCTURAL characteristics category were typically of the predicted sign and frequently significant. For example, the number of fireplaces and the square footage of the lot and the building increased the sale price, whereas multistory homes and homes that were older had lower sales prices *ceteris paribus*. Likewise,

NEIGHBORHOOD characteristics were often correctly signed and significant, although there were some exceptions. Whereas higher owner occupancy rates (among all occupied units) increased the sale price as expected, higher overall occupancy rates (across all units) had a negative and significant coefficient. The latter finding may reflect newer neighborhoods experiencing high levels of construction and hence lower occupancy rates. Noxious activity, measured by close proximity to railroads and high ozone levels, reduced housing prices, as did exposure to relatively high property tax rates. Finally, high teacher-student ratios in the local school system significantly increased housing prices. Variables in the CITY dummy variable category are expressed relative to Sacramento, the omitted dummy variable. We assume that these dummy variables capture amenities and disamenities not adequately captured in the NEIGHBORHOOD characteristics category. In addition, fiscal expenditures are also proxied by these variables. Compared to Sacramento, for example, housing prices are significantly higher in Elk Grove, whereas they are lower (although not quite significant at the 10% level in a two-tailed test) in Lockeford.

4.2 Findings on nuclear and date variables

To investigate the first two research questions, we estimate a model with six different variables. Temporal changes in the hedonic function and the price-distance gradient are captured by including a continuous measures of time (DATE)[3] and DISTANCE[4] separately, and then interacted. To test for the importance of visual cues of the plant, we include a dummy variable for the visual range (VISUAL) which takes on a value of one if the property is within the 10 mile visual range of the plant, and zero otherwise.[5] Finally, a dummy variable for the announcement of dry storage at Rancho Seco (ANNOUNCE = 1 for properties selling after the announcement) is also included. The variable DISTANCE is interacted with ANNOUNCE and VISUAL to permit the gradient within the visual range to change in the post-announcement period.

Question #1: Is there a stable price-distance relationship? Turning to the variables related to distance and time, there is support for the hypothesis that housing prices vary significantly with distance from the plant. The partial derivative of the hedonic function with respect to DISTANCE includes three separate terms: $\partial \ln P / \partial \text{DISTANCE} = 0.043 – 1.86E\text{-}5 * \text{DATE} - 0.011 * \text{VISUAL} * \text{ANNOUNCE}$ (Table 1). The first term indicates that real housing prices rise by about 4.3% per mile (i.e., $7476 in 1998 dollars evaluated at the mean housing price) at the

[3] Dummy variables for the year in which the property sold were also investigated, with no changes in the signs on the coefficients, and only minor changes in significance levels.

[4] An investigation of higher order terms reveals no support for quadratic or cubic distance specifications.

[5] Since visual cues for properties closer to the plant may be expected to be stronger, we experimented with different values for the visual range, ranging from within 3 miles, to within 10 miles. The highest significance levels on visual variables are found when VISUAL is defined as being within 10 miles of Rancho Seco.

beginning of the period. However, the second term implies that over the 1990–1994 period, the distance gradient has been significantly flattening approximately 0.7% per year (i.e., $1208 per year in 1998 dollars). Interestingly, Gamble and Downing (1982) initially find evidence of a rising gradient from Three Mile Island of $163 per mile which is approximately 0.5% of the average sale price of homes within 5 miles of the plant in 1978. Taking into account housing inflation since 1978, the real price would increase by $419/mile in 1998 dollars. However, Gamble and Downing conclude that the evidence of a positive gradient is an anomaly resulting from a misspecified model.

Viewed collectively, these two coefficients indicate a positive but flattening gradient for the five years of the sample. Thus, we can conclude that a price-distance relationship does exist but that it is not static. Rather, aversion to the plant, as reflected in a rising housing price with greater distance has been declining over the five years of the sample. The importance of the third term is discussed below.

Question #2: Do visual cues about the Rancho Seco plant influence the relationship between the real sales price and distance from the plant? We hypothesize that visual reminders of the plant can influence housing prices and also influence the price-distance gradient. The change in the housing price function resulting from being within the visual range is: $\partial \ln P / \partial \text{VISUAL} = 0.209\text{–}0.011 * \text{DISTANCE} * \text{ANNOUNCE}$. The first term shows housing prices significantly higher inside compared to outside the visual range (i.e., 20.9% or $37,201 higher for the mean valued home in 1998 dollars). This finding is somewhat surprising, since one would expect that if anything, visual cues would tend to stigmatize a property. Gamble and Downing (1982) also find positive impacts from a visibility dummy variable although they conclude that this is due to multicollinearity with site-specific amenities in the model. The second term suggests a flattening of the price-distance gradient within the visual range following the announcement of the dry storage facility at Rancho Seco, although the coefficient is not quite significant at the 10% level of confidence. While it could be argued that being within the visual range of the plant might actually proxy an "openness" amenity, this is not the case in this sample since the entire geographic area is relatively flat. Hence all properties would have access to this amenity.

Question #3: Have announcements about spent nuclear fuel affected the price-distance relationship? Collectively, as indicated by the Chow test, the two variables capturing the influence of the announcement of high level waste on property values are statistically insignificant. The individual coefficients are also insignificant, although the variable which evaluates the interaction between distance, the visual range and the announcement has a t-score of more than 1.6. Overall, these findings suggest that there is no evidence to support a significant detrimental influence of the announcement of a dry storage facility on sale prices, either directly or through its influence on the slope of the gradient.

Question #4: Has newspaper coverage in the period between 45 and 120 days prior to the sale affected the sale price of the property either inside or outside

Table 2. Evaluation of public information[1]

	Dependent variable = log of real sales price							
	Specification #2 Total paragraphs		Specification #3 Nuclear general		Specification #4 Nuclear transportation		Specification #5 Nuclear waste	
Variable	Coefficient	*t*-score	Coefficient	*t*-score	Coefficient	*t*-score	Coefficient	*t*-score
Intercept	9.750665	5.064	9.736714	5.049	9.676857	5.021	9.687632	5.024
				Structural characteristics				
BEDROOM	−0.00857	−0.72	−0.00893	−0.75	−0.00922	−0.774	−0.00929	−0.78
FULLBATH	0.025999	1.379	0.026431	1.4	0.025106	1.329	0.026151	1.386
HALFBATH	0.018415	1.023	0.018692	1.037	0.01814	1.007	0.01879	1.043
CNTRLAIR	0.013572	0.715	0.011976	0.626	0.013914	0.728	0.014275	0.737
FIREPLCE	0.038143	2.795	0.037791	2.766	0.037291	2.732	0.037424	2.74
NUMSTORY	−0.07309	−3.916	−0.07313	−3.91	−0.07294	−3.905	−0.07311	−3.912
AGEHOUSE	−0.00163	−2.817	−0.00166	−2.86	−0.00164	−2.834	−0.00163	−2.81
LOTAREA	5.83E-07	6.193	5.92E-07	6.292	5.80E-07	6.141	5.87E-07	6.233
BLDGAREA	0.000423	21.49	0.000422	21.42	0.000424	21.474	0.000423	21.447
				Neighborhood characteristics				
%ASIAN	−0.0272	−0.783	−0.029	−0.83	−0.029	−0.835	−0.03018	−0.869
%BLACK	0.014344	0.512	0.015265	0.544	0.014282	0.509	0.015143	0.54
%HISPANIC	0.022469	1.055	0.022892	1.073	0.023325	1.095	0.023477	1.101
%PUBASST	−0.00618	−0.299	−0.00641	−0.31	−0.00671	−0.325	−0.00665	−0.322
MEDHHINC	−1.88E-05	−0.896	−1.93E-05	−0.92	−1.97E- 05	−0.937	−1.99E-05	−0.948
%OCCUPIED	−0.02042	−2.751	−0.02078	−2.8	−0.02049	−2.759	−0.02082	−2.803
%OWNEROCC	0.021966	1.758	0.022314	1.783	0.022522	1.801	0.022699	1.814
TRAVTIME	0.057073	1.188	0.058273	1.211	0.059214	1.232	0.059473	1.237
OZONE	−0.60715	−2.166	−0.61406	−2.19	−0.60913	−2.172	−0.61899	−2.208
INTRSTAT	−0.01242	−0.436	−0.01015	−0.36	−0.01018	−0.358	−0.01001	−0.351
RAILROAD	−0.03589	−2.291	−0.03624	−2.31	−0.03637	−2.32	−0.03652	−2.329
AIRPORT	−1.02E-07	−0.188	−7.32E-08	−0.14	−1.14E-07	−0.211	−9.24E-08	−0.17
TOXRELINV	−0.01	−0.476	−0.00982	−0.47	−0.01037	−0.494	−0.00952	−0.453
WATER	0.014484	0.995	0.015518	1.063	0.014644	1.005	0.015188	1.042
TSRATIO	22.7768	2.029	23.39602	2.082	23.36644	2.082	23.84656	2.123
TAXRATE	−7.73156	−1.932	−7.62489	−1.9	−7.55787	−1.886	−7.61883	−1.9
POPDENSITY	−2.88E-06	−0.199	−2.49E-06	−0.17	−3.19E- 06	−0.221	−3.41E-06	−0.236

Table 2. (continued)[1]

	Dependent variable = log of real sales price							
	Specification #2 Total paragraphs		Specification #3 Nuclear general		Specification #4 Nuclear transportation		Specification #5 Nuclear waste	
Variable	Coefficient	*t*-score	Coefficient	*t*-score	Coefficient	*t*-score	Coefficient	*t*-score
				City dummy variables				
ACAMPO	−0.0249	−0.107	−0.04027	−0.17	−0.03493	−0.15	−0.04208	−0.181
ELKGROVE	0.135592	2.938	0.13276	2.874	0.135029	2.925	0.132146	2.861
GALT	−0.09988	−0.255	−0.10774	−0.28	−0.11067	−0.283	−0.11366	−0.29
HERALD	−0.10216	−0.263	−0.11156	−0.29	−0.11107	−0.285	−0.11551	−0.297
LOCKEFRD	−0.56816	−1.472	−0.59008	−1.53	−0.58712	−1.521	−0.6033	−1.563
SLGHHOUS	−0.22505	−0.798	−0.24014	−0.85	−0.24012	−0.852	−0.25023	−0.888
WILTON	−0.39938	−0.924	−0.41472	−0.96	−0.41866	−0.969	−0.42714	−0.988
				Nuclear and date variables				
DATE	1.18E-06	0.019	9.45E-07	0.016	−1.25E-08	0	3.05E-07	0.005
DISTANCE	0.03128	2.06	0.031844	2.094	0.031934	2.103	0.032199	2.12
VISUAL	0.131465	1.884	0.129646	1.855	0.130693	1.872	0.128811	1.844
DISTANCE*DATE	−1.18E-05	−2.494	−1.17E-05	−2.48	−1.15E-05	−2.431	−1.17E-05	−2.491
DISTANCE*NEWS	2.00E-05	1.865	0.000268	1.176	0.000986	1.653	0.000385	1.407
Adjusted R^2	0.834136		0.833654		0.833965		0.833792	
Lik.	362.8863		361.7861		362.4947		362.1006	
F-statistic	101.1837		100.8355		101.0596		100.9349	
Number Obs.	758		758		758		758	

[1] Full regression results available on request from authors.

the visual range? To measure the volume of press coverage about the plant, we determine the total number of paragraphs that were written about the plant during the period between 45 and 120 days prior to the sale. Each article written was then characterized three ways, according to whether it dealt with general nuclear issues (e.g., routine inspections by the NRC, emergency drills, etc.); issues related to nuclear waste (e.g., the building of the independent spent fuel storage installation); and/or issues related to the transportation of nuclear waste (e.g., discussions of transporting spent fuel to interim storage elsewhere in the country). Any one article may contain one or more of these characteristics.[6] Given the findings regarding the importance of visual cues, we experimented with several different specifications. We report our findings, including those for the media variable (NEWS) and the media variable interacted with distance (DIST*NEWS) in Table 2.[7] Given the insignificance of the announcement effects in the first specification, we drop ANNOUNCE from the models reported in Table 2.

In all models, the coefficient on distance is positive and significant at the 90% level of confidence or higher. As with the earlier specification, there is a significant and positive price gradient (i.e., prices rise approximately 3.1% per mile) that has been diminishing about 0.4% per year over the 1990-1994 period. Likewise, housing prices are significantly higher in the visual range. Turning to the influence of articles concerning nuclear waste, the volume of coverage does appear to steepen the distance gradient, although the impact is small. The mean number of total paragraphs (44.08 paragraphs) increases the slope of the distance gradient by just 0.08%, or $156/mile in 1998 dollars on the mean housing price. With regard to the content of the articles, neither the number of articles on nuclear power in general, or nuclear waste specifically has a significant influence on the slope of the housing price function. Articles on transportation of waste do have a significant influence at the 10% level of significance. However, the marginal influence on the housing price of the mean number of articles is even smaller 0.01% (or $16/mile). Furthermore, we note that these results on media coverage do not appear to be robust with variations in the model specification. Specifically, when the DISTANCE*NEWS is interacted with the visual range variable, the significance levels drop dramatically.

[6] Each article was classified using a modification of the Delphi method, where each article was classified independently with a view to eventually reaching a consensus classification. Three individuals (the two authors and a third colleague) independently ranked each article on each of the three criteria. When at least two individuals agreed on the classification, a consensus was assumed to have been reached. If there was no consensus, each individual was given the assessments of the other two individuals (with the identity of that person revealed) and asked to re-evaluate their classification decision. On the rare occasion where this did not lead to a consensus, the three individuals met to arrive at a consensus.

[7] Since other media coverage is not controlled, we remind the reader that newspaper coverage variables actually proxy all news sources, not just print media.

5 Conclusions and policy implications

In many regards, the Rancho Seco plant provides ideal circumstances to investigate the influence of spent fuel storage on property markets. The plant is no longer operating, so employment effects are insignificant. The plant has been located in the community for a considerable time, and hence the long-run adjustments in the residential mix, identified by Galster (1986), are likely to have already occurred. In addition, low activity levels at the plant have also meant that there have not been any protests outside the plant in recent years. Such protests may tend to accentuate property value impacts in the short run.

Our findings reveal that the Rancho Seco nuclear power plant does appear to exert some influence on the local real estate market, as housing prices rise significantly with distance from the plant, although the slope has been flattening over time. In addition, the magnitude of the slope is somewhat sensitive to the specification of visual and media control variables. There is also evidence that visual cues influence the hedonic function, although they do not appear to be detrimental. The reason for a positive coefficient on the visual variable is somewhat unclear. Finally, there is little evidence to support the contention that media attention on the plant has a strong detrimental influence on housing in the community. Although news coverage does appear to increase the aversion to the plant as indicated by a more positive price gradient, the magnitude of the impact is low.

With an increasing number of nuclear plants approaching spent fuel storage pool capacity, and significant doubt over a repository becoming available in the near future, dry storage of spent fuel at reactor sites is becoming highly likely at all 72 of the nations nuclear power plants. Using evidence from the Rancho Seco plant, this article has attempted to show that distance, visual reminders and media based public knowledge about spent fuel storage activities at power plant sites, may lead to measurable effects on the sale price of single-family residential properties.

Current opposition to the Yucca Mountain project in southern Nevada, spent fuel transportation and nuclear facilities in general is in large part based on the claim that significant adverse economic impacts will occur in proximity to the particular activity. Many opponents of the Federal repository and transportation program suggest that the solution to the spent fuel disposal problem will only become apparent with a fundamental restructuring of the Federal spent fuel management program. Unfortunately, the amount of time that will be needed in order to develop a fundamentally new program will require that spent fuel generated by nuclear power plants remains at the reactor sites. As the evidence presented in this article indicates, there are just as likely to be adverse economic impacts, albeit minor, of risk perceptions at the power plant sites as have been claimed for the repository in southern Nevada.

Table A.1. Data characteristics

Dependent Variable and Independent Variables in the STRUCTURAL Category			
Variable Name	Definition [mean, standard deviation]	Source	Predicted Sign
RPRICE	Real sale price of the property (1990 dollars) levels: [$\mu = 153,340.0$, $\sigma = 67,347.30$] logs: [$\mu = 11.864, \sigma = 0.328$]	TRW nominal price divided by the national CPI for housing	lnRPRICE is the dependent variable
BEDROOM	Number of bedrooms in house [$\mu = 3.292, \sigma = 0.654$]	TRW	+
HALFBATH	Number of half bathrooms in the house [$\mu = 0.185, \sigma = 0.389$]	TRW	+
FULLBATH	Number of full bathrooms in the house [$\mu = 2.061, \sigma = 0.486$]	TRW	+
FIREPLACE	Number of fireplaces in the house [$\mu = 0.869, \sigma = 0.484$]	TRW	+
CNTRLAIR	1=presence of central air conditioning, 0=otherwise. [$\mu = 0.800, \sigma = 0.400$]	TRW	+
NUMSTORY	Number of stories in the structure [$\mu = 1.172, \sigma = 0.378$]	TRW	?
LOTAREA	Lot size in square feet [$\mu = 37,903.39, \sigma = 85,926.24$]	TRW	+
BLDGAREA	Structure size in square feet [$\mu = 1,743.834, \sigma = 564.590$]	TRW	+
AGEHOUSE	Age of the house in years [$\mu = 12.047, \sigma = 12.625$]	TRW	?

Variables in the NEIGHBORHOOD and CITY Categories			
Variable Name	Definition [mean, standard deviation]	Source	Predicted Sign
OZONE	Distance weighted value of the nearest ozone monitor, computed as ozone concentration/ distance of monitor to property [$\mu = 0.459, \sigma = 0.170$]	EPA-AIRS AQS database	-
AIRPORT	Distance weighted value of nearest airport, computed as number of airport operations/distance of airport to property in miles [$\mu = 13,761.50, \sigma = 16,528.87$]	TRW	-
INTRSTAT	1=interstate highway within 0.25 miles of property, 0 otherwise [$\mu = 0.067, \sigma = 0.250$]	MapInfo computed	-
RAILROAD	1=railroad tracks within 0.25 miles of property, 0 otherwise [$\mu = 0.232, \sigma = 0.422$]	MapInfo computed	-
TOXRELINV	1= at least 1 manufacturing facility which are on the Toxic Release Inventory within 1 mile of the property, 0=otherwise [$\mu = 0.154, \sigma = 0.361$]	Landview II	-

Table A.1. (continued)

Variables in the NEIGHBORHOOD and CITY Categories			
Variable Name	Definition [mean, standard deviation]	Source	Predicted Sign
%ASIAN	Percent of census tract population that is Asian or Pacific Islander [$\mu = 0.03370, \sigma = 0.0165$]	Census STF-3A	?
%BLACK	Percent of census tract population that is Black [$\mu = 0.01807, \sigma = 0.0120$]	Census STF-3A	?
%HISPANIC	Percent of census tract population that is Hispanic [$\mu = 0.12121, \sigma = 0.0618$]	Census STF-3A	?
%PUBASST	Percent of census tract population that is receiving public assistance [$\mu = 0.0803, \sigma = 0.0371$]	Census STF-3A	-
%OCCUPIED	Percent of census tract housing units that are occupied [$\mu = 0.9512, \sigma = 0.0362$]	Census STF-3A	+
%OWNEROC	Percent of census tract housing units that are owner occupied [$\mu = 0.7772, \sigma = 0.0907$]	Census STF-3A	+
WATER	1=stream, river or lake within 0.25 miles of the property, 0=otherwise [$\mu = 0.290, \sigma = 0.454$]	MapInfo computed	-
TRAVTIME	Average household travel time to work in the census tract [$\mu = 27.042, \sigma = 2.560$]	Census STF-3A	-
TAXRATE	1994 tax payment /1994 assessed value [$\mu = 0.012, \sigma = 0.001$]	TRW	-
TSRATIO	Average teacher-student ratio for the public school district in which the property is located. [$\mu = 0.037, \sigma = 0.007$]	California Department of Education	+
POPDENSITY	Population density of the census tract, measured as persons per square mile [$\mu = 966.604, \sigma = 1,363.380$]	Census STF-3A	?
MEDHHINC	Median household income of the census tract [$\mu = 42,892.76, \sigma = 7,377.279$]	Census STF-3A	+
ACAMPO, ELKGROVE, GALT, HERALD, LOCKEFRD, SLGHHOUS, WILTON	City dummy variables for Acampo, Elk Grove, Galt, Herald, Lockeford, Sloughhouse, or Wilton. Dummy variable=1 if dwelling lies within the city political boundaries, 0=otherwise [$\mu_{\text{ACAMPO}} = 0.008, \sigma_{\text{ACAMPO}} = 0.089$] [$\mu_{\text{ELKGROVE}} = 0.523$, $\sigma_{\text{ELKGROVE}} = 0.500$] [$\mu_{\text{GALT}} = 0.269, \sigma_{\text{GALT}} = 0.443$] [$\mu_{\text{HERALD}} = 0.010, \sigma_{\text{HERALD}} = 0.102$] [$\mu_{\text{LOCKEFRD}} = 0.030$, $\sigma_{\text{LOCKEFRD}} = 0.171$] [$\mu_{\text{SLGHHOUS}} = 0.058$, $\sigma_{\text{SLGHHOUS}} = 0.234$] [$\mu_{\text{WILTON}} = 0.062, \sigma_{\text{WILTON}} = 0.241$]	TRW	?

Table A.1. (continued)

Variables in the NUCLEAR and DATE Categories			
Variable Name	Definition [mean, standard deviation]	Source	Predicted Sign
DATE	Time trend variable for date of sale. 1=January 1, 1990. [μ = 1007.758, σ = 535.]	TRW	?
DISTANCE	Distance (in miles) of property from Rancho Seco plant. [μ = 12.554, σ = 2.412]	Computed using MapInfo	?
ANNOUNCE	1=property sold 45 days after announcement of intention to construct dry storage waste facility in October, 1991. 0=otherwise. [μ = 0.702, σ = 0.457]	Computed.	?
VISUAL	1=property within 10 mile visual range. 0=otherwise. [μ = 0.117, σ = 0.321]	Computed using MapInfo.	?
NEWS	News variables defined for period between 120 and 45 days prior to sale. News measures include total number of paragraphs, number of articles covering general nuclear issues, number of articles covering nuclear waste issues, and number of articles covering nuclear transportation issues. [$\mu_{\text{PARAGRAPH}}$ = 44.089, $\sigma_{\text{PARAGRAPH}}$ = 43.988] [μ_{NUCGEN} = 1.396, σ_{NUCGEN} = 2.142] [μ_{WASTE} = 1.066, σ_{WASTE} = 1.832] [$\mu_{\text{TRANSPORT}}$ = 0.353, $\sigma_{\text{TRANSPORT}}$ = 0.798]	Computed using modified Delphi method from inventory of articles received from Sacramento Bee.	?

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Nuclear Power Plants and Residential Housing Prices

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ABSTRACT Nuclear power plants can theoretically influence property values through a number of different channels The public perception of risk associated with the potential hazard from the operation of a nuclear reactor and the storage of nuclear waste may lead to lower bids on properties in close proximity to the plant In contrast, workers at the plant may be less concerned with any potential hazards, and may actually value being in proximity to the workplace Hence, one cannot *a priori* sign the distance gradient of homes in the vicinity of a nuclear power plant In this study, a hedonic model coupled with geographic information system (GIS) techniques is used to estimate housing price surfaces around two nuclear power plants in California The use of GIS software allows more potential influences to housing prices to be accurately incorporated than previously included in hedonic studies Based on the evidence from the plants chosen, these findings do not support the contention that negative imagery surrounding nuclear power plants or stored nuclear waste has a significant detrimental influence on residential home prices in the immediate vicinity of these facilities

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Introduction

Nuclear power plants can theoretically influence residential housing prices in several ways First, negative imagery associated with these plants may reduce offer prices if buyers believe the plant poses a potential risk Indeed, survey research has consistently shown that nuclear technologies and radioactive waste are often viewed negatively by the general public. These attitudes are based both on individual perceptions of risk associated with proximity to nuclear reactors and waste facilities, as well as on community level perceptions that nuclear facilities, either existing or planned, will negatively affect the ability to attract and retain economic activity.[1] Even if a buyer is not personally fearful of nuclear technology, he or she may offer less for a property in the vicinity of a nuclear facility if there is fear that it will reduce the rate of appreciation of the housing asset. Second, there may be positive influences associated with accessibility to the workplace for plant workers. In general, employees of nuclear facilities may feel less threatened by nuclear technology than the population as a whole (Kivimaki and Kalimo 1993) and may offer more for properties close to a plant to reduce commute times.[2] This latter influence would be stronger with greater employment at the plant. Third, most nuclear plants are contributors to the local property tax base (Metz 1994). Thus, residents within jurisdictions (i e. school districts, counties, etc.) close to nuclear power plants may enjoy a lower property tax burden than residents in other areas. This would be likely to increase local property values in proximity to a plant if the local fiscal bundle is capitalized in the value of these properties.

Hedonic modeling can be used to determine if negative imagery translates into economic effects The hedonic approach has its origins in the works of Lancaster (1966) and Rosen (1974) and has been used to examine property value impacts of a variety of different spatial influences, including noxious activity (Kiel and McClain 1995; Kohlhase 1991), fiscal factors (Stull and Stull 1991), crime (Thaler 1978) and air quality (Nelson 1979). Several studies also address the issue of nuclear power plants (Metz and Clark 1997, Metz et al. 1997, Clark and Nieves 1994; Folland and Hough 1991; Gamble and Downing 1982, 1986; Galster 1986; Hageman 1981; Nelson 1981). While Blomquist (1974) finds significant impacts of a coal-fired plant on residential property values and Hageman (1981) has demonstrated the theoretical influence of nuclear power plants, the evidence on the impact of nuclear facilities on residential property values is mixed Clark and Nieves (1994) use 1980 microdata from the U.S. Census to show that wages are higher, and land rent is lower in regions with a larger number of nuclear power plants. Folland and Hough (1991) evaluate the influence of nuclear plants on agricultural land prices in nearly 500 market areas (comprised of counties) in the U.S. and find that land prices are significantly diminished by the presence of a nuclear reactor. This effect is also found to increase with the length the reactor has been operational. Both of these studies evaluate broad geographic areas, averaging 1500 square miles in the Clark

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and Nieves study, and nearly 3200 miles in the work by Folland and Hough. Studies which focus on more localized property markets have not found significant property value impacts. For example, Gamble et al. (1978) find no evidence of a significant distance gradient from the property to the Three Mile Island (TMI) Nuclear plant[3]. Additionally, Gamble and Downing (1982) find that the TMI accident generated no significant difference in sale prices Indeed, the lower prices within the 0-5 mile range were found to exist as early as 1970, which predated the operation of the plant. Likewise, Nelson (1981), who also studied properties near TMI, found that neither the absolute price, nor the appreciation rate of housing prices within 3-4 miles of the plant is significantly different after the accident. Furthermore, although Nelson found evidence of a temporary decline in prices and appreciation rates when compared with a control area 100 miles away, the real estate market recovered within three months of the accident. Finally, Metz and Clark (1997) evaluate whether announcements regarding nuclear waste significantly influencing properties sold around two plants in California. They find no evidence that announcement effects regarding nuclear waste significantly influence properties sold around two plants in California.

To clarify the impact of nuclear power plants on housing prices, this study uses a hedonic model of residential sales prices and geographic information systems (GIS) techniques to investigate potential influences over a 5-year period (1990-1994). Two nuclear power plants in California are chosen for investigation because of their size, public profile and for one of the plants, a significant change in status during this period. The first plant chosen was Diablo Canyon near San Luis Obispo, owned by Pacific Gas and Electric Company Diablo Canyon has been operational since 1985 and in 1992 underwent a license extension review to lengthen its operating life until 2025 It is a major employer in the San Luis Obispo area with a workforce averaging 1800 The utility also contributes to the local property tax base. The Diablo Canyon reactors are adjacent to the Pacific Ocean and are not visible from any of the properties in the vicinity of the plant, with a hilly coastal range coming between the plant and the surrounding area. The second plant chosen was Rancho Seco near Sacramento, owned by the Sacramento Municipal Utility District (SMUD). Rancho Seco has been closed since 1989, but since 1991 there has been an effort to transfer the spent fuel from the reactor to a recently constructed dry storage facility at the site. The plant has experienced a steady decrease in the workforce from about 500 in 1990 to less than 150 in 1995 In addition, because the plant is owned by the local municipal utility, it has not provided a property tax subsidy to local jurisdictions. The terrain around the plant is almost flat and the cooling towers from the plant can be seen from a distance of approximately ten miles in most directions.

The remainder of the paper is organized as follows. In the second section, a brief overview of the hedonic model is provided as it relates to economic and environmental activities which generate both perceived risks as well as

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employment effects, and then the empirical specification of the model used in this study is discussed. The third section describes the empirical findings and the final section contains concluding remarks.

The Hedonic House Price Model

A Brief Development of Hedonic Price Theory. The hedonic model views housing as a differentiated bundle of attributes, z_i, which collectively determine the value of a particular property. This attribute vector includes structural features of the property (e.g., bedrooms, bathrooms, age of the house, interior and exterior square footage) and locational attributes (e.g., amenities and disamenities, local fiscal conditions, accessibility to workplace). Assuming perfect information about the attributes of properties for both buyers and sellers in the market, and assuming transactions costs are zero, then marginal implicit prices can be derived as the partial derivative of the housing bid-price function Urban location theory suggests that locational equilibrium in the housing market generates utility equalizing tradeoffs between proximity to the place of work and housing prices. This gives a downward sloping housing bid-price gradient[4]. Specifically, evaluating the housing quantity gradient at a fixed point in space (i.e., at some distance from the plant, u) and assuming that the price of housing (H) and other goods (X) are also fixed at that point, the utility maximizing housing bid-price gradient is derived as $d\ln P_H/du=-t/(P_H*H)$. Assuming travel cost per mile is positive ($t>0$) and positive expenditure on housing, the housing bid-price gradient is negatively sloped. This finding of a negatively sloped housing bid-price gradient with distance from the place of employment is predicated on the assumption that accessibility to the workplace is the only locational attribute of importance to the household.

When neighborhood externalities are introduced into the model, the location equilibrium condition becomes more complex This is because the disutility of commuting, as well as the disutility of the negative externality must be introduced into the model[5] The slope of the housing bid-price function becomes.

$$\Psi_{workers}=d\ln P_H/du=[1/(P_H*H)]*[-t+(\partial V/\partial u)/\lambda+(\partial V/\partial E*\partial E/\partial u)/\lambda] \quad (1)$$

The first bracketed term is the inverse of the expenditure on housing. Assuming that this is nonzero and positive, the sign of the slope of the bid-housing price function depends on the sign of the second bracketed term. The term $\partial V/\partial u$ is the marginal disutility (i.e , it is expected that $\partial V/\partial u<0$) associated with another round trip mile, which is monetized by dividing it by the lagrangian multiplier,λ. The lagrangian multiplier represents the marginal utility associated with additional income. Assuming $\lambda>0$, the first term is expected to be negative. The second term, $(\partial V/\partial E*\partial E/\partial u)/\lambda$ represents the monetized value of the change in utility associated with a change in the hazard moving away from the plant. Thus, if an

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increase in the expected hazard decreases utility (i.e., $\partial V/\partial E<0$) and if the expected hazard decreases with distance from the plant (i.e , $\partial E/\partial u<0$) then the second term is expected to be positive

Finally, for residents of the community who do not work at the facility, the slope of the housing bid-price function depends only on the valuation of the expected hazard, and is given by equation (2):

$$\Psi_{nonworkers}=d\ln P_H/du=[1/(P_H*H)]*[(\partial V/\partial E*\partial E/\partial u)/\lambda] \quad (2)$$

The market housing price function, which can be derived empirically from data on housing transactions, is the outer envelope of the individual housing bid-price functions of workers at the plant and nonworkers. It is expected that nonworker households will have a positively sloped housing bid-price function, whereas the sign of worker bid-price functions can be positive or negative depending on the relative importance of accessibility versus aversion to the expected hazard. However, there are two reasons why worker bid-price gradients will be more negative than those of nonworkers (i e., $\Psi_{nonworkers}>\Psi_{workers}$). First, nonworkers by definition are unconcerned with commuting to the plant (i.e , $\partial V/\partial u=0$), and hence they are unwilling to pay an accessibility premium. Second, the risk aversion of nuclear workers to potential nuclear hazards is likely to be lower than for workers in other industries and hence the positive influence of the expected hazard (i.e., $(\partial V/\partial E*\partial E/\partial u)/\lambda$) is expected to be lower as well. For example, Kivimaki and Kalimo (1993) show that nuclear workers believe that the possibility of a serious nuclear accident is more unlikely than members of the general public. Thus, as long as worker households are able to outbid nonworker households for land anywhere in the region, they would be expected to occupy land closer to the plant.

Changes in the Shape of the Housing Price Function. Any change in the perceptions of risk relating to the plant, or changes in employment levels, should influence the shape of individual bid-housing price gradients, and hence the shape of the housing price gradient that is observed in the market. This issue is important to the current application for several reasons. First, there are two plants being investigated in this paper. As noted in the introduction, the Diablo Canyon plant has been operational throughout the study period and is a major employer in the community. Moreover, with the exception of reactor shutdowns for refueling, the operational status of the plant has not changed since it began operation in 1985. Thus, one would expect little change in the shape of the housing price gradient over the period of investigation (1990-1994) In contrast, the Rancho Seco plant was shut down in 1989 and the employment levels at the plant have steadily declined from about 500 in 1989 to less than 150 in 1994. In addition, recent action has been taken to move nuclear waste from wet storage adjacent to the reactor to a dry storage facility at the plant. Both of these events can lead to a change in the shape of the housing price gradient over time.

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Model Specification. In order to determine the extent to which proximity to a nuclear power plant influences home sale prices in the vicinity of the plant, it is important to control for as many influences as possible. That is, if the bias from excluded variables in estimates of the implicit valuation of characteristics of nuclear plants is to be avoided, then other attributes which vary spatially and may be correlated with proximity to the plant need to be included in the model.

Separate hedonic models are estimated for Diablo Canyon and Rancho Seco, using ordinary least squares. Each model includes the following categories of variables

$$\ln RPRICE_k = f(Structure, Neighborhood, City, Year, Distance\text{-}Related\ Nuclear)$$

where the real sale price of housing (measured in logarithmic form) in market k, is a function of five vectors of determinants: *Structure, Neighborhood, City, Year,* and *Distance-Related Nuclear.* Property sales data were obtained from TRW REDI-Property and represent individual single-family residential home sales which took place between 1990 and 1994 within 25 miles of the Rancho Seco and Diablo Canyon nuclear plants. The TRW sales price data are screened to include only those properties for which sales price and address data are complete.[6] Properties which had a real sales price less than $10,000 given the likelihood that these sales are either on properties with low qualitative values that are not adequately captured by the TRW data or the transaction is not arms-length, were screened out. Other data were dropped due to missing or miscoded data. This yielded 7694 properties for the region around Rancho Seco (which contains much of the city of Sacramento), and 606 properties for the less populous Diablo Canyon sample (which contains most of San Luis Obispo).

Michaels and Smith (1990) show that there are different submarkets operating within the Boston metropolitan area. Submarkets within the Sacramento and San Luis Obispo areas are accounted for by including a number of controls. First, various structural characteristics, including building area and lot size are included in each model. Second, a variety of neighborhood features, including household income levels, were included. Finally, dummy variables for the jurisdiction in which the property is located were included to account for submarkets related to the city of residence.

USE OF GIS TOOLS An important empirical task is to match proximity of *Neighborhood* and *Distance-Related Nuclear* variables to the individual property To accomplish this, GIS software was used.[7] Since all property sales data have been geocoded (i.e., assigned a latitude and longitude), the distance to a specific neighborhood or nuclear characteristic, can be readily computed as long as the location of the activity is also geocoded. This is the method used for most of the variables. However, if data cannot be accurately assigned a latitude/longitude coordinate, then the characteristics are matched according to other criteria (e.g., by

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census tract, zip code, or school district). This is the case for the various demographic, earthquake, and school district variables.

In addition to the distance calculation capability of GIS, it is possible to assess the proximity of a group of objects to another location whether it is a point, line, or region. This function was utilized to determine, for example, the number of Superfund sites within one mile of a property and which properties were within a quarter mile of an interstate or railroad. Again, this function is dependent on all of the data being geocoded.

Precision in geocoding is crucial when distance is the measure being used to define the neighborhood characteristics of properties. Key to geocoding is the accurate recording of property and facility addresses, the accuracy of the TIGER files from the U.S. Census Bureau and correct matching of the address to the geographic files. As the accuracy of the TIGER files can vary depending on the source from which the U.S. Census Bureau acquired geographic information, it is difficult to assign an overall estimate of accuracy to the files. However, as there is no systematic bias in these data, it is believed that the use of GIS tools to match properties to spatial characteristics of the neighborhood represents a substantial improvement over simple visual matching techniques. This is for three reasons. First, it avoids errors in measurement which are inherent in the visual techniques Second, it permits the development of much larger data sets than could be developed if manual distance calculations were required. Finally, given the increased tendency for geographic data to be geocoded, it allows for a broad range of spatial controls in the hedonic model When empirically deriving distance gradients, it is important to control for as many spatial variables as possible to avoid biases from excluded variables.

INDEPENDENT VARIABLES. A complete list of the variables, including variable definitions, data sources, descriptive statistics, and sign predictions are reported in Table 1 (p. 513). The vector *Structure* contains characteristics of the home Among the attributes included are the age of the house (in linear and quadratic form), the number of bedrooms, the number of full and half baths, the presence of central air conditioning, the number of stories in the structure, the number of fireplaces, and the square footage of both the building and lot.

Numerous attributes of neighborhoods (i e., in the *Neighborhood* category) are included to account for the influence of various locational phenomena on housing markets. These factors include demographic features such as racial and ethnic mix (i.e., Asian, African-American, White, and Hispanic), median household income level, and poverty rates as proxied by the percent of households on public assistance. Other neighborhood measures related to the composition of the local housing stock (i.e., occupancy rates, owner-occupancy) are also included. To capture the influence of local hazards and annoyance factors, a proxy for ozone air pollution, proximity to interstate highways, railroads, airport activity, Superfund sites, and the earthquake risks associated with the zip code in which the property is

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located are included. A determination is also made as to whether properties are within five miles of military bases (i.e., Mather AFB and McClellan AFB are both in the Rancho Seco region), or a coal-fired power plant in Morro Bay, north of Diablo Canyon The average travel time to work in the neighborhood is included to proxy access to jobs, whereas the fiscal bundle is measured by the average property tax rate and the teacher/student ratio in the local public school district. Proximity to the ocean, and also to lakes, rivers, and streams are included to capture access to scenic vistas and recreational opportunities. Finally, the population density of the census tract in which the property is located is included to capture unmeasured amenities and disamenities (e.g., remoteness, crime) correlated with density.

Dummy variables are included to capture differences in submarkets that are related to the jurisdiction in which the property is located. The Rancho Seco sample includes properties in 14 different communities, whereas the Diablo Canyon sample includes 10 communities. Note that the city dummy variables will also account for public service provision in the various jurisdictions Four dummy variables representing the year in which the property sold (the excluded dummy category is 1990) are also included. These variables are included because the California economy experienced a significant recession beginning in 1992.

It is assumed that the perception of a safety hazard from the plant is primarily related to the distance of the property from the plant. Recall that in the absence of employment effects, the influence of distance from the potential hazard on property values, (i e, $\partial V/\partial E^{*}\partial E/\partial u$), is expected to be positive, since both partial derivatives are expected to be negative. To capture the influence of proximity, the distance from the plant in linear and quadratic form is included. To account for any shifts of the distance gradient over time, distance is interacted with the year dummy variables. Finally, since media attention about the plant is likely to serve as a reminder of the presence of the plant, the number of paragraphs of press coverage about the plant's operation in the dominant local newspaper[7] is included, interacted with distance to the plant. Press coverage is measured for the period between 45 days and 120 days prior to the sale. The time period for media exposure is chosen to represent a period around the time of the sale for which the media coverage is most likely to influence the offer price of the buyer. Coverage within 45 days of the sale is presumed to be after an offer has been accepted.

FUNCTIONAL FORM. Assuming that implicit prices are not constants, nonlinear forms are preferred on theoretical grounds Although some authors suggest the use of flexible functional forms such as the Box-Cox or generalized quadratic functional form (Rasmussen and Zuehlke 1990), others have expressed concern about accuracy of implicit prices derived from flexible forms (Cassel and Mendelsohn 1985) Cropper et al. (1988) have shown that the semi-log model outperforms other forms when there is a possibility that the model is misspecified.

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Although care was taken to include a wide range of structural and locational features, all of the relevant variables were certainly not included. Thus, we employ the semi-log model.

Empirical Findings

A White-test was conducted to detect the presence of heteroskedasticity, and the null hypothesis of no heteroskedasticity is rejected at the 95 percent level of confidence for each regression. White's correction is used to generate consistent estimates of the standard errors. The empirical findings are reported in Table 2, (p. 517). The independent variables explain 78 percent and 64 percent of the variation in the log of the real house price for Rancho Seco and Diablo Canyon respectively.

Structural Characteristics. Most of the structural features are of the expected sign and significant in the Rancho Seco model although fewer are significant for the Diablo Canyon regression. Interior and exterior square footage significantly increases the sales price in both models. Although an additional bedroom significantly decreases the sale price in the Rancho Seco model, this is perhaps not surprising given that it implies smaller rooms since building area is held constant. Both central air conditioning and additional fireplaces increase real housing prices in the Rancho Seco model. Multistory homes sell for lower real prices, *ceteris paribus*, than single story homes in both samples although the variable is not quite significant in the Diablo Canyon model. Finally, real housing prices decline at a decreasing rate, with age of the house. The minimum occurs between 38-39 years of age. Note, however, that neither of these variables is statistically significant in the Diablo Canyon sample.

Neighborhood, Year and City Variables Demographic variables are found to be statistically significant in the Rancho Seco model. Housing in neighborhoods with relatively higher African-American and Asian populations sells for lower prices than in those with lower minority concentrations. Not surprisingly, home prices are higher when the house is located in a census tract with a relatively high median household income and a relatively low percentage of the population on public assistance. In analyzing overall occupancy rates, the greater the percent of occupied housing units, the lower is the home price. Indeed, the variable is negative and significant for both samples. In addition, high owner-occupancy rates significantly decrease housing values in the Rancho Seco model. The rationale for these counterintuitive findings is uncertain.

Several of the annoyance factors are statistically significant, although not always with the sign that was expected. For example, an increase in the number of Superfund sites within a mile of the property in the Rancho Seco model results in a positive correlation. Note that there are very few properties which are close to Superfund sites in the Rancho Seco sample (i.e., less than 1 percent of the observations), and no such properties in the Diablo Canyon sample. These

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unexpected findings persist even when a five-mile impact area is assumed. Properties which are located within a quarter of a mile of an interstate highway or a railroad almost always sell at lower real prices than properties that are less proximate to these factors, although the interstate dummy variable is not significant in the Rancho Seco model. In addition, the variable which proxies airport noise is negative in both models, and significant for Rancho Seco Although others (Beron et al. 1997) have found that earthquake risks are negatively capitalized in housing prices, our measure is negative but it is insignificant in both models. Proximity to the Mather Air Force Base significantly decreases property values for those properties in the Rancho Seco sample within five miles of the facility. Note that airport activity is controlled by the distance-weighted airport measure. Thus, the Mather proximity measure could be capturing factors related to the loss of a large employer in the area since it was announced in 1988 that Mather Air Force Base would be shut down; the facility was closed in 1993.

Consistent with the predictions of the urban location model, properties in neighborhoods with low commute times typically have higher real sale prices. Another neighborhood characteristic which tends to increase property value is proximity to the ocean. It increases value approximately 15 percent, other things equal, for properties in the Diablo Canyon sample.

Regarding the fiscal variables, school quality as proxied by the teacher-student ratio yields insignificant results whereas tax rate is negative and significant in both samples. Dummy variables for the largest jurisdictions in each region (i.e., Sacramento and San Luis Obispo) were excluded from each model. Of the dummy variables for the 13 suburban jurisdictions in the Rancho Seco model, eight were positive and significant, and only one was negative and significant Four of the suburban dummy variables were positive and significant in the Diablo Canyon model

The effect of time on the hedonic function is modeled as an intercept shifter and a slope shifter. Although some of the coefficients are not statistically significant, one can evaluate the point estimates Computing the time effect at the mean distance for each sample (19 2 miles for Rancho Seco and 13.6 miles for Diablo Canyon) reveals a pattern of declining real prices over the period 1990-1994 which is consistent with the deep housing recession which plagued California in the early 1990s When compared to 1990 (the excluded category), real prices fall by 0 3, 8.6, 17.7 and 22.6 percent for the period 1991-1994 in the Rancho Seco sample. Real housing prices fell by 6.7, 20 9, 27.3, and 36 4 percent compared to 1990 for the period 1991-1994 in the Diablo Canyon sample.

Distance-Related Nuclear Variables. Recall that, theoretically, the impact of a facility that is associated with hazardous activity may be positive or negative, depending on whether the benefits of proximity to the workplace overwhelm the

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disutility associated with higher perceived hazards at more proximate locations Given the high aversion to nuclear technology and radioactive waste that has been found among survey respondents (Kunreuther et al 1988; Slovic et al. 1991; and Erikson 1994), one suspects that the disutility from proximity would lead to significantly lower property values, especially for those properties close to the shut down and highly visible Rancho Seco facility. Positive impacts are more likely at Diablo Canyon, which remains the dominant employer in the region and whose location is relatively secluded.

DIABLO CANYON FINDINGS. Recall that the distance from the plant is included in linear and quadratic form and it is interacted with the year in which the property sold to capture any shifts in the gradient over the early 1990s Distance is also interacted with the number of paragraphs written about the plant in the dominant local newspaper. The linear distance variable for Diablo Canyon is negative and significant, whereas the quadratic term is positive although its t-score is only 1.50. Treating the coefficients on DISTANCE, and DISTSQ as point estimates gives a u-shaped distance gradient with a minimum at 23 4 miles.[9] Furthermore, additional paragraphs appearing in the newspaper around the time of the sale have a positive but statistically insignificant influence on the slope of the housing price gradient. The hedonic housing price function for Diablo Canyon is shown graphically in Figure 1. Mean values of nondistance related variables are substituted and the hedonic surface is simulated for each of the five years of the sample. The year-distance interaction terms are statistically insignificant. In addition, even treating the parameter estimates as point estimates, it is clear from Figure 1 that the slope of the hedonic housing price gradient changes very little over time. Since employment levels at the plant are relatively constant over the period in question, this finding is not surprising.

RANCHO SECO FINDINGS. Several of the individual variables in the *Distance-Related Nuclear* category are significant in the Rancho Seco samples. Again, hedonic price gradients are derived, assuming the properties have mean values for both the structural and neighborhood characteristics. The number of paragraphs written about the plant is also held constant at its mean level (i.e , approximately 43 paragraphs). The hedonic housing price surface is shown graphically in Figure 2. Like the Diablo Canyon surface, the Rancho Seco gradient is u-shaped.[10] However, both linear and quadratic terms are statistically significant. In addition, the minimum point is substantially closer to the plant (11.4 miles). Finally, note that the gradient is becoming significantly more negative over time with the distance-year interaction terms negative and significant for the period 1992-1994, which causes the minimum point of the gradient to increase By 1994 the minimum point increased to 13.4 miles.

The finding of a u-shape for the gradient is surprising in light of the small and declining employment levels at the plant and given the visibility of the plant from the surrounding area. Rather, one would suspect that any "geographic footprint"

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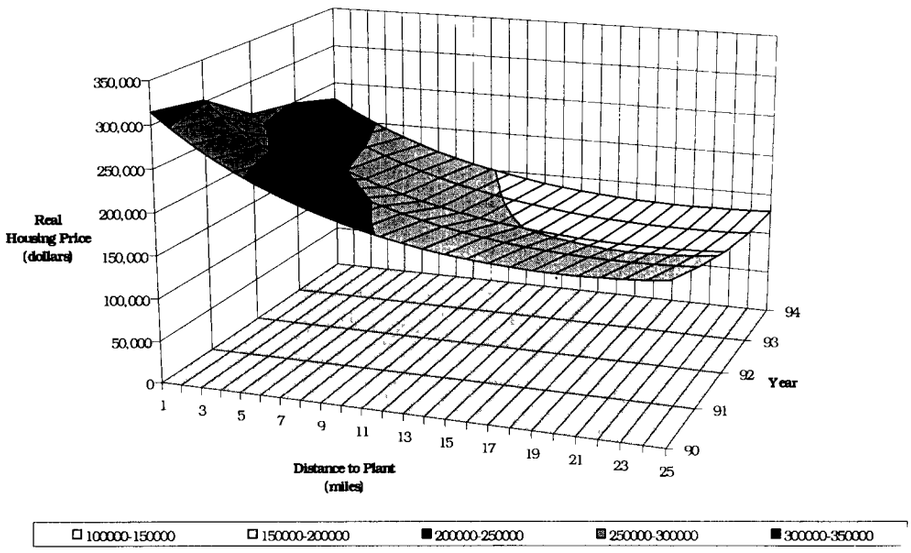


Figure 1. Housing Price Gradient, Diablo Canyon

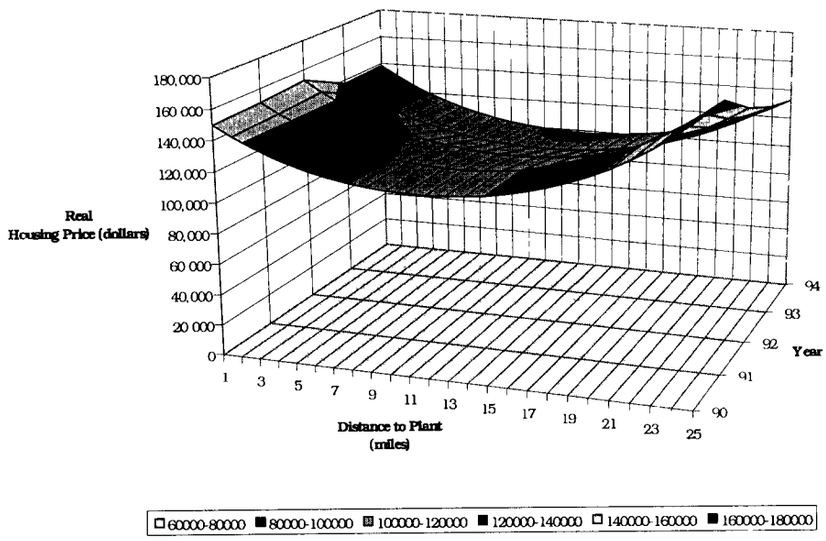


Figure 2. Housing Price Gradient, Rancho Seco

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that the plant might have on local real estate markets would reflect the disamenity associated with proximity to a local hazard (i.e. nuclear waste). In addition, theory would suggest that the minimum point should be moving closer to the plant, rather than further away, if employment effects are declining. These findings suggest reduced aversion to the facility over time even though the volume of waste currently stored at the plant has not changed. We suspect that the there are a number of possible factors which account for the attractiveness of proximity to the plant. First, the area surrounding Rancho Seco is relatively uncongested. Although population density is controlled for, it is possible that this is a poor proxy for this amenity Second, the fact that the plant has been shut down may confer a sense of safety upon nearby residents since no nuclear power is being generated and no additional waste is being produced. Third, there are several recreational activities which are available at the Rancho Seco site. SMUD, which owns the Rancho Seco Plant, operates 433 acres of the 2480 acre Rancho Seco site as a park and lake complex which includes group campgrounds, group and family picnic areas, and swimming and fishing opportunities. Fourth, since the shutdown of Rancho Seco, SMUD officials have investigated several options concerning the transition of the plant and property. A draft master plan issued in January 1994 called for the expansion of the park to 1600 acres. The proposed recreational development includes a public golf course, equestrian center, wetlands preserve, a nature center, and hiking trails (Sacramento Municipal Utility District 1994) Finally, SMUD officials have begun the process of moving nuclear waste from wet storage in the reactor building to a dry-storage facility at the site. Dry storage may be viewed by the public as being a less hazardous technology than wet storage. If residents see the transition at the Rancho Seco site as either reducing a hazard or creating better recreational activities, then a steeper gradient would be expected.

Concluding Remarks

Significant political debate exists at the local, state, and federal levels regarding the perceived risks, stigma, and negative imagery that are claimed to accompany nuclear power plants, and the storage and permanent disposal of spent nuclear fuel. Often cited in the debate is the large volume of local, regional, and national survey data that has been collected on public opinion regarding proximity to nuclear facilities. These surveys often reveal a high percentage of respondents who, when given a choice, consistently express an unwillingness to live, visit, or operate a business near nuclear related facilities Based on evidence from the two California plants studied, we conclude that any negative imagery associated with nuclear power plants or stored nuclear waste does not translate into a significant detrimental influence on residential home prices in the immediate vicinity of the facilities studied.

The findings at Diablo Canyon suggest a housing price premium until the household is about 23 miles from the plant While we have been careful to

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account for a wide range of neighborhood factors (indeed our model explains approximately 64 percent of the variation in real housing prices), it is possible that we have omitted some important locational influence which is being captured in the distance variable. For example, the region near the plant is less urban, and offers more remoteness to residents. However, it is clear than any negative property value impacts resulting from perceived risks associated with the plant do not overwhelm accessibility and other desirable attributes which are correlated with proximity to Diablo Canyon.

For the Rancho Seco plant, which is no longer operating and which is more visible than the Diablo Canyon plant, residential home prices actually rise with proximity to the plant for those properties closest to the plant (within 11 miles) Furthermore, aversion to the plant appears to be declining as the minimum point has moved nearly two miles further from the plant over the five years of the study even though plant employment has continually declined. We suspect that the fact that the plant is now shut down, combined with the relatively uncongested nature of the general area and the recreational opportunities that exist in the vicinity of the plant overwhelm any detrimental impact resulting from the nuclear waste that remains stored at Rancho Seco.

A major challenge for policy makers in their efforts to site temporary and permanent nuclear waste facilities and select routes for nuclear waste transportation is the need to balance survey evidence, that suggests that adverse economic impacts and stigmatization are likely to result, with findings of multivariate analyses, that suggest that any risk perceptions that exist may not be reflected in local economic behavior Indeed, our research suggests that some individuals may actually be likely to place premiums on proximity to nuclear plants. Policy initiatives that attempt to anticipate public reaction and behavior with regard to nuclear waste facility siting options based only on research on stated intent and imagery would therefore likely overestimate the extent of the reaction in the local economies concerned. The political and economic environments in which nuclear waste facility siting decisions are made may indeed be ones in which there are no permanent accompanying negative economic effects, but in which there is significant political opposition. Only when policy makers and planners are able to respond knowledgeably on the basis of both survey data and studies using multivariate analyses will they be able to generate greater public dialogue, public acceptance, and political approval.

NOTES

1 In the survey literature, see Kunreuther et al (1988), Slovic et al (1991), and Erikson (1994). See also Allison and Calzonetti (1992) and Metz (1994)

2 For example, in a survey of scientists and engineers, Barke and Jenkins-Smith (1993) find that perceptions of risks toward nuclear technology are significantly associated with the type of institution in which the scientist is employed In addition, life scientists tend to

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perceive higher risks associated with nuclear energy and nuclear waste management than physicists, chemists and engineers

3 Note that Gamble et al acknowledge that the substantial property tax subsidy may influence these findings. That is, positive capitalization from a lower property tax burden may overwhelm any negative capitalization from risks or other attributes of the plants. In our empirical modeling we avoid this potential bias by including adequate controls for the local fiscal bundle for residential housing.

4 Assume that households maximize utility, V(X,H) which is a function of a vector of nonhousing goods, X, and a housing good, H Households choose optimal levels of X and H subject to a budget constraint that includes expenditures on nonhousing goods (P_X*X); expenditures on housing (P_H*H); and out-of-pocket expenditures on commuting (t*u) where t = commuting cost of a mile spent commuting, and u = number of round-trip miles to work. Thus, the budget constraint is defined as $I=P_X*X+P_H*H+t*u$. Notice that there is no disutility associated with time spent commuting in this simple model Rather, commuting enters the optimization through the budget constraint only (Muth 1969). The locational equilibrium condition is derived by taking the first derivative of the lagrangian function ($L=V(X,H)+\lambda(I-P_X*X-P_H*H-t*u)$) with respect to u, and setting that function equal to zero.

5. Now the household utility function is, V(X,H,E(u),u) Thus, utility is now also a function of the expected hazard associated with the facility (E) which is perceived by residents to decline with distance from the facility (i e , $\partial E/\partial u<0$). Utility also depends directly on distance from the plant. The budget constraint is defined as before (i e , $I=P_X*X+P_H*H+t*u$). Again, the locational equilibrium condition is derived by taking the partial derivative of the lagrangian function ($L = V(X,H,E(u),u)+\lambda(I-P_X*X-P_H*H-t*u)$) with respect to u, and setting that function equal to zero.

6. TRW REDI Property Data obtained the data from yearly county tax rolls which are merged with weekly new deed reports from the county recorder's office Additional information (e g., structural characteristics) about the properties is obtained from various appraisal groups, as not all counties obtain the same level of detailed information on the properties In the state of California there are two situations which would result in a property sale not being included in the TRW REDI data set (1) A specific request for non-disclosure by the owner (usually a well known individual who would not want the public to know the price of the property) and; (2) The sales tax information (from which the price is calculated) is not located on the first page of the recorder's document which is the source of information for TRW REDI-Property While the first situation is likely to systematically undercount high priced properties, TRW has indicated that the second situation is unlikely to introduce systematic bias into the sample TRW estimates that 46% of the approximately six million residential properties had sales tax data

7 PC-based GIS software packages from MapInfo and Scan/US have been used in this project

8 The *Sacramento Bee* is the primary local newspaper in the Sacramento metropolitan area, and the *Telegram-Tribune* is the dominant paper in the San Luis Obispo region

9 It should be noted that the property tax rate is the actual tax burden for the property, since it reflects the ratio of the taxes paid to the assessed valuation Thus, any tax subsidy from the Diablo Canyon plant is incorporated in the measure

10 Although the variable COMMUTE may proxy travel time to the plant, we believe that it is primarily measuring proximity to San Luis Obispo. For the entire sample, the correlation between commuting time and distance from Diablo Canyon is low (0 29) but it is substantially higher and negative (-0 86) for homes within 10 miles of the plant. Moreover, dropping COMMUTE does significantly alter the findings on the distance

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variables. Specifically, DISTANCE becomes insignificant with a t-score below one, and DISTSQ also has a very low t-score We believe that if COMMUTE is left out of the model, then DISTANCE proxies both proximity to the plant, and distance from the city This is especially true given that the region is geographically a half circle, with the plant at the center and the ocean to the west Hence, we believe that it is preferable to keep the COMMUTE variable in the model.

11 We also experimented with higher order polynomial terms When we included a cubic term to allow for a second turning point, the linear, quadratic and cubic terms became insignificant

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TABLE 1 VARIABLE DESCRIPTION, SIGN EXPECTATION, MEAN VALUE AND STANDARD DEVIATION

Variable Name	Definition	Source	Sign	Mean Values	σ
Dependent Variable and Variables in the *Structure* Category					
LRPRICE	Natural log of the real sale price of the property (1990 $)	TRW nominal price divided by the national CPI for housing		RS = $130,821 (Rancho Seco) DC= $170,076 Diablo Canyon) (Note mean values are shown for actual real sale price)	RS =$59,083 DC= $68,019
AGEHOUSE	Age of house in years	TRW	?	RS= 19 342 DC = 22 977	RS= 21 259 DC= 14 429
AGESQ	Age of house in years squared	Computed	?	RS= 825 981 DC= 735 779	RS= 1449 487 DC= 979 130
BEDROOM	Number of bedrooms in house	TRW	+	RS= 3 116 DC= 2 777	RS= 0 717 DC= 0 674
BLDGAREA	Size of the residence in square feet	TRW	+	RS= 1528 346 DC= 1424 025	RS= 510 943 DC= 502 693
CNTRLAIR	1 = presence of central air conditioning, 0 otherwise	TRW	+	RS= 0 691 DC= -------	RS= 0 462 DC= -------
FIREPLACE	Number of fireplaces in the residence	TRW	+	RS= 0 868 DC= 0 698	RS= 0 435 DC= 0 569
FULLBATH	Number of full bath-rooms in the home	TRW	+	RS= 1 894 DC= 1 756	RS= 0 581 DC= 0 523
HALFBATH	Number of half bath-rooms in the home	TRW	+	RS= 0 148 DC= 0 148	RS= 0 355 DC= 0 365
LOTAREA	Size of the lot in square feet	TRW	+	RS= 10305 90 DC= 16541 19	RS= 29351 62 DC= 82485 13
NUMSTORY	Number of stories in the house	TRW	?	RS= 1 199 DC= 1 007	RS= 0 432 DC= 0 533
Variables in the *Neighborhood* Category					
AIRPORT	Distance weighted value of airport activity (i e , number of operations at airport divided by distance of airport to the property	FAA & MapInfo Computed	-	RS= 25055 73 DC= 22926 64	RS= 36901 54 DC= 23250 11
COALPLANT	Dummy variable=1 if property is within 5 miles of Morro Bay Power Plant, 0=otherwise	MapExpert & MapInfo Computed	?	RS= --------- DC= 0 361	RS= ---------- DC= 0 481

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Variable Name	Definition	Source	Sign	Mean Values	σ
COMMUTE	Average travel time of households living in that census tract	Census STF-3A 1990	-	RS= 24 632 DC= 19 705	RS= 3 618 DC= 2 466
EARTHQK	Earthquake classification of the zip code where the property is located (Left out dummy is always lowest risk classification) 1 if moderate risk, 0 if low risk for RS, 1 if high risk, 0 if moderate risk for DC	Risk Mgmt Associates study prepared for Freddie Mac	-	RS= 0 027 DC= 0 272	RS= 0 163 DC= 0 445
INCOME	Median household income of census tract where property is located	Census STF -3A 1990	+	RS= 38912 49 DC=32612 84	RS= 10835 41 DC= 5023 412
INTERSTATE	1= interstate highway within 0 25 miles of property, 0 otherwise (MapInfo computed	Census TIGER database 1992)	-	RS= 0 065 DC= 0 193	RS= 0 246 DC= 0 395
MCLELLAN	Dummy variable=1 if property is within 5 miles of McClellan AFB, 0=otherwise	FAA & MapInfo Computed	?	RS= 15 726 DC= --------	RS= 7 627 DC= -------
MATHER	Dummy variable=1 if property is within 5 miles of Mather AFB, 0=otherwise	FAA & MapInfo Computed	?	RS= 11 682 DC= --------	RS= 5 824 DC= -------
OCEAN	1 if property within 25 miles of ocean	Census TIGER database (1992) MapInfo Computed	+	RS= ------- DC= 0 112	RS= ------- DC= 0 316
OZONE	Distance weighted value of the nearest ozone monitor, the ozone concentration divided by the distance of the monitor to the property	EPA-AIRS AQS Database	-	RS= 1 893 DC=1 816	RS= 4 142 DC= 1 631
%ASIAN	Percent of the census tract population that is Asian or Pacific Islander	Census STF-3A 1990	?	RS= 12 577 DC= 3 200	RS= 8 513 DC= 2 408
%AFAMER	Percent of the census tract population that is African American	Census STF-3A 1990	?	RS= 9 921 DC= 1 022	RS= 10 105 DC= 0 742
%HISPANIC	Percent of the census tract population that is of Hispanic origin	Census STF-3A 1990	?	RS= 13 285 DC= 9 552	RS= 6 600 DC= 8 953
%OWNEROCC	Percent of the census tract occupied housing units that are owner occupied	Census STF-3A 1990	+	RS= 71 061 DC= 55 562	RS= 16 958 DC= 12 767

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Variable	Definition	Source	Sign	Mean Values	σ
%OCCUNIT	Percent of the census tract housing units that are occupied	Census STF-3A 1990	+	RS= 93 022 DC= 91 420	RS= 4 000 DC= 7 224
%PUBASST	Percent of the census tract population that is on public assistance	Census STF-3A 1990	-	RS= 10 497 DC= 6 381	RS= 8 876 DC= 2 960
POPDENSITY	Population density of census tract where property is located	Census STF-3A 1990	?	RS= 2497 321 DC= 2257 071	RS=3609 454 DC= 5543 101
RAILROAD	1= railroad tracks within 0 25 miles of property, 0 otherwise	Census TIGER database MapInfo computed (1992)	-	RS= 0 170 DC= 0 084	RS= 0 376 DC= 0 278
SUPERFUND	Number of sites which are on the National Priority List (i e , Superfund site), within 1 mile of the property [Abandoned, inactive and uncontrolled hazardous waste sites]	EPA, Office fice of Solid Waste & Emerg Response Landview II CERCNPL Database (1993)	-	RS= 0 003 DC= -------	RS= 0 056 DC= -------
TAXRATE	1994 tax payment divided by 1994 assessed valuation	TRW	?	RS= 0 011 DC= 0 011	RS= 0 002 DC= 0 001
TSRATIO	The student teacher ratio for the secondary or unified school district in which the property is located	CA State Dept of Ed Online Data Service	+	RS= 0 041 DC= 0 044	RS= 0 003 DC= 0 004
WATER	1 if property within 25 miles of lake, river or stream	Census TIGER database (1992) MapInfo Computed	+	RS= 0 320 DC= 0 407	RS= 0 506 DC= 0 492

Variables in the *City* Category

Variable	Definition	Source	Sign	Mean Values	σ
City Dummy Variables	Suburban communities in the Rancho Seco region include Acampo, Courtland, Elk Grove, Folsom, Galt, Herald, Lockeford, Lodi, Sloughhouse, Stockton, Wilton, Walnut Grove, Woodbridge Suburban communities in the Diablo Canyon region include Atascadoro, Cayucos, Grover Beach, Los Osos, Morro Bay, Nipomo, Pismo Beach, Santa Maria, Templeton	TRW	?	Acampo (0 001) Courtland (0 000) Elk Grove (0 191), Folsom (0 066), Galt (0 027), Herald (0 001), Lockefd (0 004) Lodi (0 064), Sloughse (0 006), Stockton (0 004),	Acampo (0 032) Courtlnd (0 019) Elk Grve (0 393). Folsom (0 247), Galt (0 027), Herald (0 001), Lockefd (0 004) Lodi (0 064), Sloughse (0 006), Stockton (0 004)

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Variables in the *City* Category (cont'd)

Variable	Definition	Source	Sign	Mean Values	σ
				Wilton (0 006), Walnut G (0 000), Woodbrdge (0 006) Atascado (0 249), Cayucos (0 010), Grover Bch (0 053), Los Osos (0 259), Morro Bay (0 097), Nipomo(0 030), Pismo Bch (0 054), St Maria (0 011), Templeton (0 013)	Wilton (0 006), Walnut G(0 030) Woodbrdge (0 079) Atascado (0 432) Cayucos (0 099) Grover Bch(0 224) Los Osos (0 438) Morro Bay (0 297) Nipomo (0 170) Pismo Bch (0 227) St Maria (0 011) Templeton (0 114)

Variables in the *Year* Category

YEAR91	1 if property sold in 1991	TRW	?	RS= 0 153 DC= 0 087	RS= 0 360 DC= 0 283
YEAR92	1 if property sold in 1992	TRW	?	RS= 0 171 DC= 0 127	RS= 0 377 DC= 0 333
YEAR93	1 if property sold in 1993	TRW	?	RS= 0 213 DC= 0 318	RS= 0 409 DC= 0 466
YEAR94	1 if property sold in 1994	TRW	?	RS= 0 232 DC= 0 365	RS= 0 422 DC= 0 482
DISTSQ	Distance squared	Computed	?	RS= 383 157 DC= 217 720	RS= 131 382 DC= 175 033
DISTANCE	Distance to the plant from the property	MapInfo Computed	?	RS= 19 247 DC= 13 568	RS= 3 564 DC= 5 804
DISTXPAR	Total number of paragraphs in articles written about the facility in the period 120 days and 45 days prior to the sale interacted with the distance of the property from the plant	Sacramento Bee, MapInfo computed	?	RS= 831 099 DC= 3808 999	RS= 832 897 DC= 2291 797
DISTXY91 DISTXY92 DISTXY93 DISTXY94	Distance of property from the plant interacted with the year in which the property is sold, for years 1991-1994	MapInfo computed	?	RS_{91}= 2 997 RS_{92}= 3 261 RS_{93}= 4 047 RS_{94}= 4 415 DC_{91}= 1 114 DC_{92}= 1 611 DC_{93}= 4 463 DC_{94}= 4 937	RS_{91}= 7 192 RS_{92}= 7 339 RS_{93}= 7 964 RS_{94}= 8 224 DC_{91}= 3 939 DC_{92}= 4 726 DC_{93}= 7 333 DC_{94}= 7 377

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TABLE 2 HEDONIC HOUSING PRICE FUNCTION

Dependent Variable: Log of Real Sale Price					
Rancho Seco Sample			Diablo Canyon Sample		
Variable	Coefficient	t-score	Variable	Coefficient	t-score
Intercept	12 80981**	50 850	Intercept	15 92051**	13 579
Structural Characteristics					
BLDGAREA	0 000452**	45 572	BLDGAREA	0 000367**	9 379
LOTAREA	7 85E-07**	4 787	LOTAREA	2 05E-07 *	1 759
BEDROOM	-0 009073*	-1 655	BEDROOM	-0 059460	-1 578
FULLBATH	0 011622	1 296	FULLBATH	0 048329	1 467
HALFBATH	0 005964	0 630	HALFBATH	-0 010751	-0 430
CNTRLAIR	0 029045**	4 073	----------		
FIREPLACE	0 069543**	9 778	FIREPLACE	0 027144	1 496
NUMSTORY	-0 045822**	-5 722	NUMSTORY	-0 026081	-1 511
AGEHOUSE	-0 003686**	-6 400	AGEHOUSE	-0 002436	-0 949
AGESQ	4 75E-05**	6 429	AGESQ	3 24E-05	0 878
Neighborhood Characteristics					
%ASIAN	-0 000633	-1 252	%ASIAN	0 007147	0 651
%AFAMER	-0.005247**	-9 974	%AFAMER	-0 047043	-0 963
%HISPANIC	-0.009448**	-15 766	%HISPANIC	-0 007403	-1 442
INCOME	2 06E-06**	2 670	INCOME	3 52E-06	0 665
%PUBASST	-0 006879**	-8.376	%PUBASST	-0 001081	-0 114
%OCCUNIT	-0 006022**	-6 453	%OCCUNIT	-0 019665**	-2 664
%OWNEROCC	-0 000863**	-2 757	%OWNEROCC	0 000162	-0 058
OZONE	-0 000838*	-1 814	OZONE	-0 005925	-0 542
INTERSTATE	-0 013887	-1 196	INTERSTATE	-0 149748**	-4 370
RAILROAD	-0 015913**	-2 322	RAILROAD	-0 066662*	-1 881
SUPERFUND	0 117320*	1 759	----------		
AIRPORT	-4 38E-07**	-3 313	AIRPORT	-6.41E-07	-1 048
----------			COALPLANT	0.160178	0 992

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TABLE 2 (CONTINUED) HEDONIC HOUSING PRICE FUNCTION

Variable	Coefficient	t-score	Variable	Coefficient	t-score
Neighborhood Characteristics *(continued)*					
MATHER	-0 088257**	-3 360	----------		
MCLELLAN	0 019203	0 625	----------		
EARTHQK	-0 021537	-1 389	EARTHQK	-0 293889	-1 393
WATER	0 001813	0 362	WATER	-0.050448	-1 531
----------			OCEAN	0 147352**	2 428
TSRATIO	-4 065770	-0.986	TSRATIO	-1 013095	-0 076
TAXRATE	-5 454212**	-2 381	TAXRATE	-17 95548**	-2 032
COMMUTE	-0.021681**	-10 975	COMMUTE	-0 073967**	-4 092
POPDENSITY	-2 98E-06**	-3 142	POPDENSITY	-2 60E-06	-0 788
City Dummy Variables					
ACAMPO	0 234412**	2 521	ATASCADORO	0 334426**	2 133
COURTLAND	-0 175597	-1 075	CAYUCOS	-0 017753	-0 055
ELKGROVE	0 106846**	14 724	GROVERBEACH	0 274942*	1 765
FOLSOM	-0 055195**	-3.112	LOSOSOS	0 012936	0 354
GALT	0 206517**	2 739	MORROBAY	-0 244236	-1 294
HERALD	0 029701	0 230	NIPOMO	0 698559**	3 303
LOCKEFORD	0 165921**	4 964	PISMOBEACH	0 109952*	1 687
LODI	0 083013**	3 810	SANTAMARIA	0 796291**	2 183
SLOUGHHOUSE	0 286838**	6 990	TEMPLETON	0 261226	1 198
STOCKTON	-0 055667	-0 917			
WILTON	0 336289**	6 796			
WALNUTGROVE	0 081571	0 919			
WOODBRIDGE	0 102099**	4 235			
Year Dummy Variables					
YEAR91	0 006034	0 115	YEAR91	-0 022122	-0 198
YEAR92	0 025423	0 498	YEAR92	-0 205191*	-1 771
YEAR93	-0 078647*	-1 652	YEAR93	-0 241395**	-2 118
YEAR94	-0 070302	-1 392	YEAR94	-0 349659*	-1 902

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Table 2 (continued) Hedonic Housing Price Function

Distance-Related Nuclear Variables					
DISTANCE	-0 051774**	-3 847	DISTANCE	-0.077131**	-2 008
DISTSQ	0 002227**	6 664	DISTSQ	0 001649	1 499
DIST×PAR	3 68E-06	1 179	DIST×PAR	9 52E-06	1 502
DIST×Y91	-0 000493	-0.178	DIST×Y91	-0 003321	-0 512
DIST×Y92	-0 005816**	-2 107	DIST×Y92	-0 000316	-0 053
DIST×Y93	-0 005136**	-1 977	DIST×Y93	-0 002343	-0 393
DIST×Y94	-0 008083**	-2 981	DIST×Y94	-0 001103	-0 125
N Obs = 7694	$R^2_{Adjusted}$ = 0 78	F-statistic = 516 57**	N Obs = 606	$R^2_{Adjusted}$ = 0 64	F-statistic = 23 91**

* Significant at 90% level of confidence in two-tailed test

** Significant at 95% level of confidence in two-tailed test

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THE EFFECT OF POWER PLANTS ON LOCAL HOUSING VALUES AND RENTS

Lucas W. Davis*

Abstract—This paper uses restricted census microdata to examine housing values and rents for neighborhoods in the United States where power plants were opened during the 1990s. Compared to neighborhoods with similar housing and demographic characteristics, neighborhoods within 2 miles of plants experienced 3%–7% decreases in housing values and rents, with some evidence of larger decreases within 1 mile and for large-capacity plants. In addition, there is evidence of taste-based sorting, with neighborhoods near plants associated with modest but statistically significant decreases in mean household income, educational attainment, and the proportion owner-occupied.

I. Introduction

ELECTRICITY consumption in the United States is forecast to increase 30% between 2008 and 2035, according to baseline estimates from the U.S. Department of Energy (2010a). Despite growing interest in renewable energy sources, most of this growth is expected to be met with increased production from power plants using coal, natural gas, and other fossil fuels. A substantial investment in new plants has already begun, with 450 new fossil fuel generators scheduled to be opened in the United States between 2010 and 2013 (U.S. Department of Energy, 2010b). Nationwide over $500 billion is expected to be spent on new fossil fuel power plants between 2010 and 2030 (Brattle Group, 2008).

One of the biggest challenges in siting new plants is resistance from local communities. Citizen groups argue that power plants are a source of numerous negative local externalities, including visual disamenities and noise. This paper evaluates these claims using evidence from the housing market. If households value these disamenities, then power plant openings should lead to a decrease in the price of housing in the immediate vicinity of plants. In addition, plant openings should be associated with changes in local demographics as households sort across neighborhoods based on their willingness to pay to avoid living near a plant. This paper tests these predictions using evidence from 92 large power plants that opened in the United States between 1993 and 2000.

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The main empirical challenge in such a study is constructing a counterfactual for the locations where power plants were opened. Power plant siting is a highly political process, and the paper shows that plants tend to be opened in locations near neighborhoods with housing and demographic characteristics that differ from the rest of the United States. In order to better control for these differences, the analysis focuses on power plant openings rather than cross-sectional comparisons between locations with and without plants. This makes it possible to control for a rich set of demographic and housing characteristics from 1990, before the plants were opened. Some specifications also include neighborhood characteristics from 1970 and 1980 to control for differential time trends. In addition, propensity score weighting is used to equate the mean characteristics of neighborhoods in the sample with the mean characteristics of the neighborhoods near where plants were opened. This approach for mitigating omitted variables concerns is not a panacea, but it offers considerable advantages over a conventional cross-sectional analysis and yields reasonable results across a range of different specifications and validity tests.

The results indicate modest declines in housing values and rents within 2 miles of plants. In the preferred specification, housing values decrease by 4%–7%. Results are similar for rents, consistent with commensurate changes in current and expected future amenities. The analysis also sheds light on the evolution of neighborhood demographics near plants. Power plant openings are associated with statistically significant decreases in mean household income, educational attainment, and the proportion owner-occupied. These changes are consistent with taste-based sorting in which willingness to pay to avoid living near a plant varies across households. Again, however, the magnitude of the effects is small. For example, the analysis indicates that within 2 miles of plants, the proportion owner-occupied decreases by 2 to 5 percentage points compared to a mean of 68%.

The baseline estimates imply an average housing market capitalization of $13.2 million per plant. This is small compared to, for example, the cost of constructing new plants and reflects the fact that most plant openings during this period occurred in locations with low population density. It is important to emphasize that this capitalization captures only some of the external costs from power plants. Power plants are, for example, a major source of nitrogen oxides and other criteria pollutants that have negative impacts on human health (Chay & Greenstone, 2003; Currie & Neidell, 2005). However, under normal operating conditions, the vast majority of these pollutants are diluted in the atmosphere and carried far away, resulting in relatively modest disproportionate impacts in the immediate vicinity of power plants. A comprehensive analysis of the negative externalities from power plants

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would need to, in addition, measure these broader welfare consequences.

This study is germane to an extensive literature that examines the impact of locally undesirable facilities on housing markets. Previous studies have examined hazardous waste sites (Gayer, Hamilton, & Viscusi, 2000; Greenstone & Gallagher, 2008), waste incinerators (Kiel & McClain, 1995), nuclear power plants (Nelson, 1981; Gamble & Downing, 1982), coal-burning power plants (Blomquist, 1974), and facilities that report to the Toxic Release Inventory (Bui & Mayer, 2003; Oberholzer-Gee & Mitsunari, 2006; Banzhaf & Walsh, 2008). Other studies have used similar methods to examine environmental public goods more generally, including air quality (Chay & Greenstone, 2005; Bayer, Keohane, & Timmins, 2009) and water quality (Leggett & Bockstael, 2000). This paper is the first large-scale study of power plants.

A key feature of this study is the use of a restricted version of the U.S. decennial census. These data, which must be accessed at a census research data center under authorization from the Census Bureau, include all of the demographic and housing characteristics in the decennial census and identify households at the census block, the smallest geographic unit tracked by the Census Bureau. This precision is important for the analysis because the impact of many of the externalities from power plants is highly localized. In addition, the large (one in six) national sample ensures broad geographic coverage even in nonurban areas.

The format of the paper is as follows. Section II briefly reviews the hedonic price method and discusses the primary predictions of the model. Section III reviews relevant background about power plants, focusing on externalities that are likely to be important to households living in the immediate vicinity of a plant. Sections IV and V describe the data and results, and section VI offers concluding remarks.

II. Analytical Framework

A large literature uses the hedonic price method to test whether households value nonmarket amenities. Dozens of studies dating back at least to Ridker and Henning (1967) have used data from the residential housing market to estimate the association between housing prices and environmental quality. This section briefly reviews the relevant features of the hedonic model. For a more complete description, see Freeman, 2003. The model provides two main testable implications: (a) a decrease in environmental quality will cause housing prices and rents to decrease, and (b) households will respond to a decrease in environmental quality with taste-based sorting.

In the standard hedonic model, a differentiated good is described by a vector of characteristics $(z_1, z_2, \ldots, z_n)$. For a house, these characteristics include structural attributes, neighborhood amenities, local environmental quality, and other factors. Prices are determined by equilibrium interactions between home buyers and sellers. The equilibrium relationship between prices and characteristics is the hedonic price schedule (HPS):

$$P(z_1, z_2, \ldots, z_n).$$

FIGURE 1.—A HEDONIC MARKET FOR ENVIRONMENTAL QUALITY

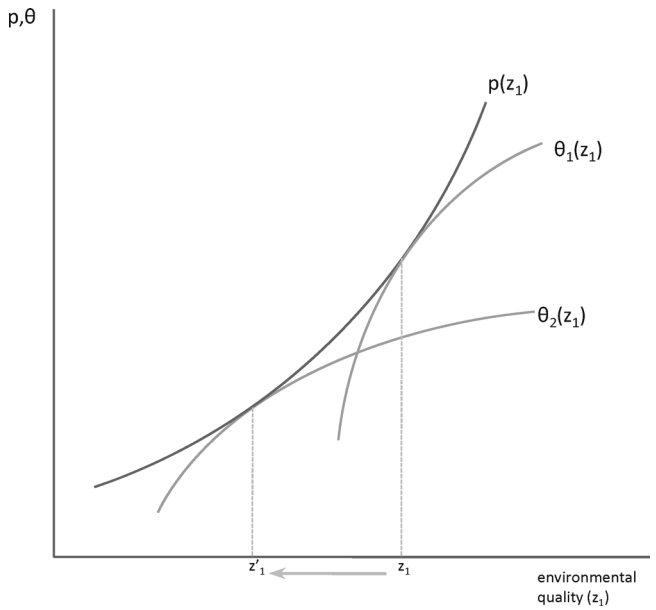


Figure 1 plots the HPS as a function of one particular characteristic, z_1, holding constant the level of all other characteristics. Suppose z_1 is a measure of local environmental quality such as distance to the nearest power plant. If buyers value this characteristic, then houses in locations with low environmental quality must have lower prices than equivalent houses in other locations in order to attract households to these locations. The preferences of buyers are represented by their bid function, denoted θ, an indifference curve in (p, z_1) space. Utility maximization occurs at the point where the bid function is tangent to the HPS. The figure depicts bid functions for two types of households. Type 1 households have a strong taste for environmental quality and choose to consume a relatively high level of z_1, whereas type 2 households have weaker tastes for environmental quality and choose a lower level. As Rosen (1974) first pointed out, at each point on the HPS, the marginal price of a characteristic is equal to the marginal willingness to pay (MWTP) of households that choose to locate at that point.

For nonmarginal changes in amenities, the observed price differential is equal to a weighted average of MWTP for households that choose to locate between the two points. To see this, consider a decrease in environmental quality from z_1 to z_1', as indicated in figure 1. The observed price differential between z_1 and z_1' understates the MWTP of household 1 and overstates the MWTP of household 2. The observed differential is equal to the weighted average of MWTP for households that sort themselves into the range between z_1 and z_1'. It is important to note that this is not the population average MWTP. However, from a policy perspective, the population

average MWTP is often not particularly relevant. Policymakers are typically evaluating interventions that have an impact on a set of locations with a particular level of amenities often very different from the distribution of amenities in the population.[1]

In the thought experiment described above, it is assumed that the HPS does not shift in response to the decrease in environmental quality. Large-scale national changes in environmental quality will cause the entire HPS to shift as equilibrium prices adjust to a new portfolio of housing alternatives. In such cases, observed price differentials are best interpreted as the difference between two equilibrium prices rather than a single equilibrium differential. See Sieg et al., 2004, who use a general equilibrium approach to study the effect of air quality on housing values. For power plant openings, however, the assumption of a constant HPS is likely to be a good approximation because only a tiny fraction of the U.S. housing market is affected. The power plant openings between 1993 and 2000 occurred in just 92 of 65,433 total U.S. Census tracts.

A measure of the implied change in total welfare from a local decrease in environmental quality can be calculated by multiplying the observed equilibrium price differential by the number of local residential housing units. This measure of welfare change assumes no change in the HPS, that there is a parallel shift in the demand curve, and that housing supply is perfectly inelastic. This last assumption is reasonable in the short run because housing is durable. In the long run, a decrease in local housing demand will also decrease the quantity of housing as older homes are razed. See Greenstone & Gallagher, 2008, for a detailed discussion of measuring welfare changes using the hedonic price method.

In response to a decrease in environmental quality, there will also be a change in the composition of local neighborhoods. Again consider a decrease in environmental quality from z_1 to z_1' as indicated in figure 1. After the decrease, type 1 households find themselves in a neighborhood with a suboptimally low level of environmental quality, and these households can increase utility by moving to a neighborhood with the level of quality that they selected originally. After the decrease and subsequent sorting, households in the neighborhood will be those with relatively weaker tastes for environmental quality. Thus, for example, if environmental quality is a normal good, then household income will tend to go down after a decrease in environmental quality. Documenting this taste-based sorting is of significant independent interest (see Banzhaf & Walsh, 2008).

III. Background: The Local Impact of Power Plants

Several local externalities are likely to be important for households living in the immediate vicinity of power plants. Power plants are large industrial facilities that can be seen from a distance because of their tall stacks. These visual disamenities are especially acute for the large plants (more than 100 megawatts) that are the subject of this analysis. Another local externality from power plants is noise pollution. Fossil fuel plants produce electricity using giant engines that generate high levels of noise and vibration. Natural gas plants use turbine engines, which can be particularly noisy. Air intake systems and cooling fans also generate noise. Although available technologies help mitigate these problems, it is not uncommon for noise from power plants to be heard far away, particularly when plants are being tested or cleaned. Another potential source of negative externalities from power plants is traffic from fuel deliveries. Whereas natural gas is delivered by pipeline, coal typically arrives by train, truck, or barge. Coal plants in the United States use over 1 billion tons of coal annually (over 690,000 tons per generator).[2] These deliveries require thousands of trips at all hours of the day, generating noise and traffic as well as fly ash from coal processing.

Each year power plants in the United States emit 8 million metric tons of sulfur dioxide and 3 million metric tons of nitrogen oxides, as well as other criteria pollutants (U.S. Department of Energy, 2010b). Under normal conditions, however, the vast majority of these emissions are diluted in the atmosphere and carried far away. Studies using regional atmospheric models (Levy & Spengler, 2002; Levy et al., 2002; Mauzerall et al., 2005) find little evidence of disproportionate impact on neighborhoods in the immediate vicinity of the plant. For example, Levy and Spengler (2002) find that exposure to health risks from sulfur dioxide and nitrogen oxides decreases approximately linearly between 0 and 500 kilometers from the source of emissions, with more than half of the social costs from emissions borne 100 kilometers or more from the source.[3]

Power plants also emit low levels of uranium, thorium, and other radioactive elements, as well as mercury and other heavy metals. These toxic pollutants have been associated with serious health problems including cognitive impairment, mental retardation, autism, and blindness (U.S. Departmental of Health and Human Services, 2007). Although emitted in far smaller quantities than the criteria pollutants described above, these emissions have a potentially larger impact on local communities because large airborne particles typically settle out from the air relatively close to their emission

[1] Rosen (1974) explains that in a second stage, the HPS could be used together with quantities and additional information about buyers and sellers to identify the underlying MWTP function. Although for evaluating many policy interventions, it would be important to know the entire MWTP function, the overwhelming majority of hedonic studies have focused on the HPS. Identification of this MWTP function continues to be an active area of research. See Ekeland, Heckman, and Nesheim (2004) and Bajari and Benkard (2005).

[2] U.S. Department of Energy (2010b) ES1. As a point of reference, a train car can hold approximately 100 tons of coal. Therefore, a typical four-generator power plant uses about 75 train cars of coal per day.

[3] In a related paper, Kahn (2009) examines the proximity between power plants and population centers. Kahn finds that Census tracts within 2.5 miles of the 100 dirtiest power plants in the United States have slower population growth than other tracts, consistent with a national migration pattern toward the South and West where electricity tends to be produced using newer, cleaner plants.

source.[4] Moreover, a small but nonnegligible amount of toxic emissions is released at ground level. Power plants in 2006 reported 1.1 million pounds of so-called fugitive emissions.[5]

Power plants also generate immense quantities of ash and other residues. When fossil fuels are burned, the noncombustible portion of the fuel is left behind, along with residues from dust-collecting systems, sulfur dioxide scrubbers, and other emissions abatement equipment. These residues consist mostly of silicon, aluminum, and iron, but they also contain lead, cadmium, arsenic, selenium, and mercury. Many plants landfill these residues on site. If they are managed improperly, particles can be picked up by wind and transported locally or enter drinking water supplies.

In short, power plants are the source of numerous local externalities. The baseline empirical specification examines neighborhoods within 2 miles of power plants. This will tend to include the entire area affected by visual disamenities, noise, traffic, fugitive emissions, and fuel residue. For some of these local externalities, the impact is typically even more localized. For assessing the total welfare change, however, it is important to choose an area that is large enough so that it includes the entire relevant area. Estimates will also be presented of the gradient of the HPS with respect to distance. This more flexible approach provides an opportunity to empirically assess the impact of plants at different distances.

IV. Data

A. *Power Plant Characteristics*

Power plant characteristics come from the U.S. Environmental Protection Agency's Emissions and Generation Resource Integrated Database (eGrid) for 2007. This database is a comprehensive inventory of the generation and environmental attributes of all power plants in the United States. Much of the information in eGrid, including plant opening years, comes from the U.S. Department of Energy's *Annual Electric Generator Report* compiled from responses to the EIA-860, a form completed annually by all electric-generating plants. In addition, eGrid includes plant identification information, geographic coordinates, number of generators, primary fuel, plant nameplate capacity, plant annual net generation, and whether the plant is a cogeneration facility. The geographic coordinates in the eGrid data were verified using aerial photos from Google Maps and are highly accurate.

[4] U.S. Environmental Protection Agency (2004). Also, U.S. Environmental Protection Agency (1997) reviews the evidence on mercury transport, reporting evidence from environmental monitoring studies that suggest that measured mercury levels are higher around stationary industrial and combustion sources known to emit mercury.

[5] U.S. Environmental Protection Agency, Toxic Release Inventory, Explorer (Version 4.7), Releases: Chemical Report (Electric Utilities, NAICS 2211). As a point of comparison, 670 million pounds of toxic chemicals were released in 2006 through "point source" air emissions, that is, through gas stacks.

The sample of plants used for the main results includes all fossil fuel plants that began operation between 1993 and 2000. This choice of years is motivated by the use of the 1990 and 2000 decennial census data described in section IVB. Plant construction typically takes at least two years, making plant openings from 1991 and 1992 less valuable because information about these plants was presumably widely available and capitalized into housing prices by 1990. In order to evaluate the sensitivity of the results to this choice, results are also presented for plants opened between 1993 and 1999 and between 1994 and 2000.

The analysis includes all non-cogeneration fossil fuel plants of 100 megawatts or more that were opened during this period. Plants smaller than 100 megawatts are excluded because they tend to be built simultaneously with existing or expanding facilities such as industrial plants. Because the objective of the study is to disentangle the disamenities from power plants, it makes sense to concentrate on these large plants that tend overwhelmingly to be independent facilities. Similarly, cogeneration plants (those that produce both electricity and heat, typically in the form of steam) are excluded because they tend to be constructed simultaneously with industrial plants, large commercial buildings, and other facilities. The sample is restricted to plants in new locations. Existing facilities that increase the number of generators on site and plants that change their primary energy source (for example, switch from coal to natural gas) are excluded. Changes in capacity and emissions levels may indeed affect the local desirability of power plants, but including these changes in the analysis would make the results difficult to interpret. Moreover, these changes often occur simultaneously with other changes at the plant, complicating the interpretation of results.

The resulting sample contains 92 plants. Figure 2 illustrates the geographic distribution. For validity tests, alternative samples were also constructed that describe all plants opened during the 1970s and 1980s and from 2003 to 2006.

B. *Demographic and Housing Characteristics*

Demographic and housing characteristics come from restricted census microdata for the decennial census from 1990 and 2000. The primary advantage of these data is their geographic detail. These data identify households at the Census block, the smallest geographic unit that the Census Bureau uses. An alternative to restricted census microdata would have been to use publicly available aggregate data for 1990 and 2000. Although basic neighborhood characteristics about population, age, and race from the short-form survey are available at the Census block level, most of the more detailed information from the long-form survey, for 2000 is available only at the Census block group level. Because of the focus on highly localized amenities, it is critical to use the most disaggregated data available.

The Census Bureau's Census 2000 Block Relationship Files were used to create geographic identifiers linking 1990

FIGURE 2.—MAIN SAMPLE: POWER PLANTS OPENED 1993–2000 (92 PLANTS)



Census blocks with 2000 Census blocks. For expositional simplicity, these linked units will be referred to as Census blocks, and in cases where there is a one-to-one matching, these units are indeed Census blocks. In cases where Census block definitions changed and the relationship is one-to-many, many-to-one, or many-to-many, geographic identifiers correspond to the smallest consistent geographic unit across the two surveys.[6]

The restricted data are complemented with tract-level data from the Geolytic's Neighborhood Change Database for 1970 and 1980. The Geolytics data were constructed to form a panel of Census tracts based on year 2000 Census tract boundaries. Census tracts are the smallest geographic unit that can be matched across the 1970 to 2000 Censuses, though in 1970 and 1980, nonurban areas were not tracted, so demographic and housing characteristics are not available for all tracts. The Geolytics data are valuable because the 1970 and 1980 characteristics can be used to control for time trends. These data are too coarse, however, to extend the analysis to examine plants opened during the 1970s or 1980s. Census tracts are designed to have between 2,500 and 8,000 residents. As a result, the land area in tracts varies widely, and in nonurban areas, where power plants tend to be sited, tracts can be quite large. The average land area of Census tracts with a power plant from the sample is 193.5 square miles (median 55.7 square miles). This is the land area equivalent to a circle with a radius of almost 8 miles.

Both the Geolytics data for 1970 and 1980 and the restricted data for 1990 and 2000 provide a rich set of housing and demographic characteristics. The housing characteristics used in the analysis are total owner-occupied housing units; total renter-occupied housing units; percentage of total housing units that are owner occupied; percentage of total housing units that are occupied; percentage of housing units with zero, one, two, three, four, and five or more bedrooms; percentage of total housing units that are single-unit detached; percentage of total housing units that are single-unit attached; percentage of total housing units that consist of two, three or four, and five or more units; percentage of total housing units that are mobile homes; percentage of total housing units built within the past year, two to five years ago, six to ten years ago, ten to twenty years ago, twenty to thirty years ago, thirty to forty years ago, and more than forty years ago; and percentage of total housing units with all plumbing facilities. Demographic characteristics include mean household income, percentage of total persons with income below the poverty line, percentage of households with public assistance income last year, population density, percentage of population black, percentage of population Hispanic, percentage of population under age 18, percentage of population age 65 or older, percentage of population over age 25 without a high school diploma, and percentage of population over age 25 with a college degree.

Housing values and rents in the Census data are self-reported. With any self-reported information, one may be concerned about whether households answer accurately. Housing values are self-reported in response to a question that prompts respondents to report how much they think their home would sell for if it were for sale. Particularly for owners who purchased their homes many years ago, this may be

[6] It would have been valuable to expand the analysis to include block-level data from the 1980 Census. The Census Bureau, however, completely redesigned census geography with the 1990 Census, and nothing comparable to the Census 2000 Block Relationship Files is available for matching 1980 and 1990 Census blocks or Census block groups. Moreover, there are serious concerns about the reliability of the Census block coding in the 1980 Census. By the Census Bureau's own admission, the geographic coding in 1980 was replete with "errors, omissions, and inconsistencies," particularly with regard to Census blocks and block groups. See U.S. Bureau of the Census (1994, p. 11–18).

TABLE 1.—EXAMINING NEIGHBORHOODS BEFORE POWER PLANTS WERE OPENED, MEAN CHARACTERISTICS, 1990

	(1) Within 2 Miles of a Power Plant Site	(2) Rest of the United States	(3) Rest of the United States, Reweighted	(4) *p*-Value: Column 1 versus Column 2	(5) *p*-Value: Column 1 versus Column 3
Demographic characteristics					
Household annual income (1,000s)	30.4	33.5	30.4	.00	.87
Household size (persons)	2.49	2.44	2.49	.00	.99
Number of individuals under 18 per household	.67	.64	.67	.00	.99
Number of individuals over 65 per household	.31	.33	.31	.00	.99
Proportion household head completed high school	.70	.77	.70	.00	.99
Proportion household head completed college	.25	.29	.25	.00	.99
Proportion household head black	.10	.07	.10	.00	.99
Proportion household head hispanic	.20	.16	.20	.00	.98
Housing characteristics					
House value (1,000s)	86.0	92.4	91.3	.00	.00
Monthly rent	459.8	470.6	460.3	.00	.89
Proportion occupied	.92	.90	.92	.00	.98
Proportion owner occupied	.58	.68	.58	.00	.98
Proportion 0–2 bedrooms	.45	.36	.45	.00	.98
Proportion 3–4 bedrooms	.50	.59	.50	.00	.97
Proportion built last 5 years	.04	.07	.04	.00	.98
Proportion built last 10 years	.08	.14	.08	.00	.98
Proportion complete plumbing	.99	.99	.99	.00	.99
Proportion 1 or more acres	.08	.16	.08	.00	.99
Proportion 10 or more acres	.03	.11	.03	.00	.99
Proportion multi-unit	.31	.13	.31	.00	.97

Columns 1–3 report the means of the variables listed in the row headings for the group listed at the top of the column. Column 1 describes demographic and housing characteristics for neighborhoods within 2 miles of sites where 100+ megawatt power plants opened in the United States between 1993 and 2000. Columns 2 and 3 describe characteristics for neighborhoods farther than 2 miles away. In column 3, observations are weighted using propensity weights. Columns 4 and 5 report *p*-values from tests that the means in the subsamples are equal.

difficult to answer. In contrast, rent is presumably not subject to the same degree of misreporting as housing values because of the saliency of rent payments. Another potential problem with housing values is that they are reported for twenty categories. In the empirical analysis, housing value is treated as a continuous variable using the midpoint of the range. Again, rental rates are less problematic. In 1990 rent was categorical, but the number of categories was larger (26 categories), and in 2000, rent was a write-in response.

V. Results

A. *Examining Covariate Balance*

Table 1 compares neighborhoods where power plants were opened with neighborhoods in the rest of the United States. Column 1 reports mean demographic and housing characteristics in 1990 for Census blocks for which the block centroid is within 2 miles of where a 100+ megawatt power plant opened between 1993 and 2000. Column 2 describes characteristics for all other Census blocks. Examining neighborhoods prior to when plants were opened is valuable because it sheds light on the siting process for plants and provides evidence on the validity of the rest of the United States as a comparison group.

Mean demographic and housing characteristics within 2 miles of a power plant site are significantly different from mean characteristics for the rest of the United States. Mean household income is lower, household size is higher, and household heads are less likely to have completed high school or college. In addition, the proportion of households for which the household head is black or Hispanic in the neighborhoods within 2 miles is higher.[7] Column 4 reports *p*-values from tests that the mean characteristics are equal in columns 1 and 2. The null hypothesis of equal means is rejected in all twenty cases.

These differences underscore the importance of controlling for observable characteristics in the analysis that follows. The main results control for these characteristics and all the other housing and demographic characteristics listed in the previous section, as well as county fixed effects. Some specifications also include 1970 and 1980 neighborhood characteristics to control for differential time trends. In addition, Census blocks farther away than 2 miles are weighted using propensity scores. The idea of propensity score weighting is to reweight the observations in the rest of the United States to balance the mean characteristics of neighborhoods within 2 miles. Propensity scores were estimated using a logit regression where the dependent variable is 1(within 2 miles), an indicator variable equal to 1 for Census blocks within 2 miles. Regressors include all variables in table 1 except for housing values and rents, which are often not both available for a single Census block. Cubics were used for all variables that are not proportions (household income, household size, number of children, and number of individuals over

[7] This last finding is consistent with evidence from a substantial environmental justice literature (see, Been, 1994; Oakes, Anderton, & Anderson 1996, Been & Gupta, 1997; Helfand, 1999; and Saha & Mohai 2005).

TABLE 2.—THE EFFECT OF POWER PLANTS ON HOUSING VALUES AND RENTS WITHIN 2 MILES

	Housing Values			Rents		
	(1)	(2)	(3)	(4)	(5)	(6)
	−.054	−.071	−.041	−.035	−.044	−.030
	(.023)	(.013)	(.017)	(.013)	(.016)	(.015)
1990 dependent variable	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effects	No	Yes	Yes	No	Yes	Yes
Housing characteristics from 1990	No	Yes	Yes	No	Yes	Yes
Demographic characteristics from 1990	No	Yes	Yes	No	Yes	Yes
Housing characteristics from 1970 and 1980	No	No	Yes	No	No	Yes
Demographic characteristics from 1970 and 1980	No	No	Yes	No	No	Yes
Number of census blocks (millions)	2.4	2.4	1.1	0.8	0.8	0.4
R^2	.55	.64	.72	.42	.52	.52

This table reports estimated coefficients and standard errors corresponding to six regressions. The dependent variable in columns 1–3 is the mean housing value (in logs), and the dependent variable in columns 4–6 is the mean rental price (in logs). The sample includes all Census blocks in the United States. The variable of interest is an indicator for Census blocks within 2 miles of 1 of 92 large (100+ megawatt) power plants opened between 1993 and 2000. Housing and demographic characteristics are listed in section IVB. Observations are weighted using propensity scores, and standard errors are block bootstrap by Census tract with 100 replications.

age 65). Then, following Rosenbaum (1987), the propensity scores from this regression were used to reweight the observations in the rest of the United States by the relative odds, $\frac{p(X_{b1990})}{1-p(X_{b1990})}$, where $p(X_{b1990})$ is the conditional probability of being within 2 miles given X_{b1990}, the complete set of housing and demographic characteristics in 1990.

Column 3 reports means characteristics from the reweighted sample. After reweighting, means for all covariates are virtually identical to the means in column 1, and the null hypothesis of equal means cannot be rejected for any of the conditioning variables. Propensity weighting reduces the potential scope for functional form misspecification in the estimating equation. Moreover, the process of estimating a propensity score reveals the degree to which there are observations in the rest of the United States that are similar to observations within 2 miles. The histograms of the estimated propensity scores reveal a high degree of overlap between the two groups. Although the mean propensity score is higher in the within-2-mile group, there are hundreds of thousands of Census blocks in the rest of the United States with propensity scores higher than the median propensity score in the within-2-mile group and tens of thousands of Census blocks with scores higher than the 95th percentile propensity score in the within-2-mile group.

B. *Baseline Estimates*

This section presents baseline estimates of the effect of power plants on housing values and rents. The approach is described by the following system of equations:

$$y_{b2000} = 1\textit{(within two miles)}_{b2000}\alpha + X'_{b1990}\beta + \epsilon_{b2000}, \quad (1)$$

$$1\textit{(within two miles)}_{b2000} = X'_{b1990}\gamma + \eta_{b2000}, \quad (2)$$

where y_{b2000} is the mean housing value for 2000 in Census block b (in logs). Results are also reported for the mean rental price. The indicator variable $1\textit{(within two miles)}_{b2000}$ equals 1 for Census blocks in which the block centroid is within 2 miles of where a 100+ megawatt power plant opened between 1993 and 2000. The coefficient of interest, α, is the price differential associated with homes within 2 miles of a plant, controlling for block-level control variables, X_{b1990}. This vector is restricted to variables measured in 1990 or before because variables measured in 2000 may be endogenous and reflect the impact of plant openings. In section VF, several neighborhood characteristics are examined as alternative dependent variables.

As illustrated in equation (2), power plant siting decisions or equivalently, $1\textit{(within two miles)}_{b2000}$, are postulated to be a function of location characteristics potentially including all of the characteristics in X_{b1990}. Least squares estimation of equation (1) is consistent if $1\textit{(within two miles)}_{b2000}$ is exogenous conditional on X_{b1990}—that is, if $E[\epsilon_{b2000}\eta_{b2000}] = 0$, or that unobserved determinants of housing prices and rents are not correlated with power plant siting decisions after controlling for X_{b1990}. Estimation is consistent if, for example, power plant siting during the 1990s is a function of housing prices, household income, educational attainment, housing characteristics, or any other characteristic included in X_{b1990}. This identifying assumption is likely to be a reasonable approximation given the rich set of household and demographic characteristics available in the Census data, particularly after controlling for county fixed effects. Nonetheless, it will be important in the following sections to evaluate the robustness of these results to alternative specifications and validity tests.

Table 2 reports least squares estimates of α for housing values and rents from three specifications. Columns 1 and 4 report estimated coefficients and standard errors from a specification that controls only for the 1990 dependent variable. Thus, the specification in column 1 controls for the mean housing value for 1990 (in logs), and the specification in column 4 controls for the mean rental price for 1990 (in logs). In this specification, the impact on housing values is −.054, or −5.4 percent. The estimate for rents is also negative, with a point estimate of −.035. Columns 2 and 5 add the complete set of housing and demographic characteristics from 1990 as well as county fixed effects. After controlling for these additional covariates, the coefficients for housing values and rents change to −.071 and −.044, respectively. Columns 3 and 6

add tract-level housing and demographic characteristics from 1970 and 1980 to control for within-county differential time trends. Including these lagged control variables reduces the number of observations because data are not available for nonurban Census tracts in 1970 and 1980 and decreases the point estimates somewhat. Overall, the point estimates indicate a decrease of 4%–7% for housing values and 3%–4% for rents.

Standard errors in table 2 and throughout the rest of this paper are estimated using block bootstrap by Census tract with 100 replications. In contrast to the point estimates, which are estimated using the complete sample of Census blocks, the bootstrap standard errors are estimated using all Census blocks within 2 miles of a plant and a 5% random sample of all other Census blocks. For each bootstrap sample, the propensity score logit regression is reestimated in order to account for the variance component due to estimation of the propensity scores. The confidence intervals are fairly wide. For example, the 95% confidence interval for the estimate in column 1 ranges from −.008 to −.099. Nonetheless, the estimates in all six specifications are statistically different from 0 at the 5% significance level. It is also possible to rule out empirically relevant hypotheses on the high end. For example, the null hypothesis of a 10% decrease can be rejected at the 5% significance level in all six specifications.

C. *Total Change in Local Welfare*

The estimates in table 2 can be used to calculate a measure of the total change in local welfare from power plant openings. In 1990 approximately 205,000 housing units were within 2 miles of locations where power plants would be opened between 1993 and 2000. The mean housing value from table 1 implies that the average total value of the housing stock within 2 miles of a plant site is $322 million in year 2008 dollars. Multiplying this by the estimate from column 3 in table 2 yields an average housing market capitalization within 2 miles of a plant of $13.2 million. Although not negligible, this measure of the total change in local welfare is small compared to the capital costs of a new plant. For example, to build a new coal-burning power plant costs approximately $2,000 per kilowatt of capacity, so even a relatively small (100 megawatt) plant costs $200 million. Natural gas plants are somewhat less expensive, costing approximately $1,000 per kilowatt of capacity, or $100 million for a 100 megawatt plant (U.S. Department of Energy, 2009). Another point of comparison is the cost of building electricity transmission. The typical cost of a large-capacity (435 kilovolt) transmission line is $800,000 per mile (Hirst & Kirby, 2002).

When interpreting this measure, it is important to keep in mind that local housing market capitalization is a valid measure of the change in local welfare only under the assumptions outlined in section II. These include that there is a parallel shift in the demand curve and that housing supply is perfectly inelastic, for example. Also, it is important to highlight that this measure of the change in local welfare reflects the impact on residential property but not the impact on industrial, commercial, or undeveloped property and thus may understate the total local welfare change. While some industrial uses may not be substantially affected by power plant proximity, commercial property and, perhaps more important, undeveloped property will be affected. In addition, it is important to point out that while the results imply moderate welfare impacts on average, there are large differences across plants in the implied market capitalization. Some of the plants opened during this period are located in almost completely uninhabited areas, whereas others are located in relatively highly populated areas. Finally, when interpreting this measure, it is important to remember that the local housing market capitalization reflects only some of the externalities from fossil fuel power plants. Power plants emit sulfur dioxide and nitrogen oxides, as well as large quantities of carbon dioxide, the principal greenhouse gas associated with climate change. Most of the impacts of these pollutants are experienced far away from plants and are not captured in this estimate.

D. *Semiparametric Estimates*

Figures 3 and 4 plot semiparametric estimates of the gradient of housing values and rents with respect to distance to the nearest power plant. First, equation (1) was estimated without the 1*(within two miles)* indicator. The complete set of 1990 housing and demographic characteristics was used along with county fixed effects as in columns 2 and 5 in table 2. Second, the gradient with respect to distance was estimated using local linear regression with an Epanechnikov kernel and a 1 mile bandwidth.

For housing values, the point estimates start between −.10 and −.05 at the plant and then converge to 0 between 1 and 4 miles. Beyond 4 miles, the estimates are consistently very close to 0. For rents, the estimates start near −.10 at the plant and reach 0 near 2 miles. Farther away from the plant, the rent gradient is consistently close to 0 except for a slight increase between 8 and 10 miles. The figures also plot 95th

FIGURE 3.—SEMIPARAMETRIC ESTIMATES OF THE EFFECT OF POWER PLANTS ON HOUSING VALUES

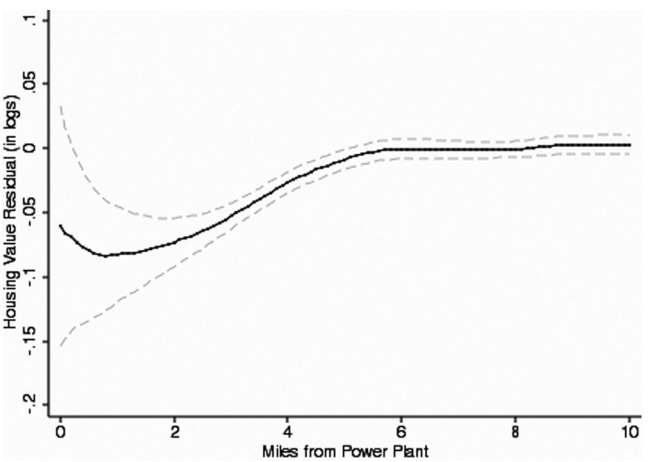
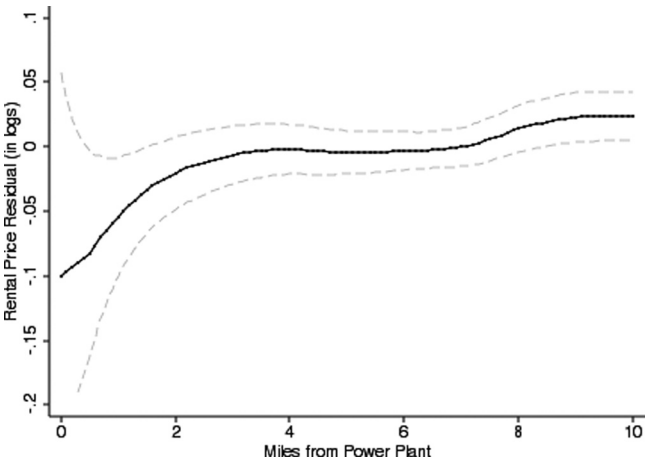


FIGURE 4.—SEMIPARAMETRIC ESTIMATES OF THE EFFECT OF POWER PLANTS ON RENTS



percentile confidence intervals estimated using block bootstrap by Census tract with 100 replications. The estimates are sufficiently imprecise, particularly for rents, to make it impossible to make definitive statements about the exact shape of the gradient. Nonetheless, for both housing values and rents, it is possible to rule out the null hypothesis of a 0 effect for at least part of the 0–2 mile range.

The lack of evidence of a housing market impact beyond a few miles is interesting because one might have expected there to be indirect effects such as household mobility. Suppose power plants cause households to move out of neighborhoods in the immediate vicinity of the plant but labor market and other considerations make it undesirable for these households to move far away. These estimates provide no evidence of such spillover effects. Still, the gradients are not precisely estimated enough to rule out relatively small effects. The gradients are also valuable because one might have been concerned that the impact of local externalities was obscured by employment or tax revenue effects. According to the U.S. Bureau of Labor Statistics (2008), there were 35,000 power plant operators in the United States in 2006. Employment from power plants increases demand for local housing, causing a positive (and potentially offsetting) effect on housing values and rents. Similarly, power plants are typically a substantial source of local tax revenue. The estimated gradients provide an opportunity to evaluate these factors because whereas many of the externalities from plants are highly localized, increased employment and property tax revenues affect all households within a given labor or housing market. The lack of a distinguishable positive impact beyond a few miles provides no evidence of employment or tax revenue effects, though again, the estimates are not precise enough to rule out small effects.

Overall, the semiparametric estimates are consistent with the results in table 2 and provide some support for the baseline empirical specification that focuses on Census blocks within 2 miles of a plant. The rent gradient suggests larger effects within 1 mile, consistent with larger negative externalities. However, the lack of statistical precision makes it difficult to make definitive statements about the exact shape of the gradient within 2 miles. Moreover, for both housing values and rents, most of the total impact appears to occur within 2 miles. This is particularly the case for rents in which point estimates converge to 0 almost exactly at 2 miles. For neither housing values nor rents is the gradient particularly steep at 2 miles, suggesting that minor changes in the specification used in table 2 would be unlikely to substantially change the results.

TABLE 3.—THE EFFECT OF POWER PLANTS ON HOUSING VALUES AND RENTS WITHIN 2 MILES: ALTERNATIVE SPECIFICATIONS AND VALIDITY TESTS

	(1) Housing Values	(2) Rents
A: Alternative Specifications		
Plants opened 1993–1999 (50 plants)	−.058	−.049
	(.017)	(.013)
Plants opened 1994–2000 (89 plants)	−.073	−.044
	(.020)	(.018)
Natural gas plants only (85 plants)	−.072	−.044
	(.017)	(.014)
Large-capacity plants only (46 plants)	−.093	−.056
	(.030)	(.022)
Small-capacity plants only (46 plants)	−.060	−.032
	(.019)	(.017)
B: Validity Tests		
Power plants opened during the 1970s (139 plants)	.013	−.020
	(.018)	(.010)
Power plants opened during the 1980s (60 plants)	−.004	.039
	(.030)	(.042)
Power plants opened 2003–2006 (96 plants)	−.031	.011
	(.015)	(.010)
C: By Type of Household		
Downwind households only	−.048	−.023
	(.033)	(.021)
Upwind households only	−.080	−.051
	(.018)	(.015)
Low-income (bottom tercile) households only	−.101	−.073
	(.042)	(.026)
Medium-income (middle tercile) households only	−.067	−.020
	(.023)	(.018)
High-income (top tercile) households only	−.027	.006
	(.017)	(.022)

This table reports estimated coefficients and standard errors corresponding to 26 separate regressions. The dependent variable in column 1 is the mean housing value (in logs), and the dependent variable in column 2 is the mean rental price (in logs). All specifications include the 1990 dependent variable, county fixed effects, and the complete set of 1990 housing and demographic characteristics as in table 2, columns 2 and 5. The sample includes all Census blocks in the United States. Observations are weighted using propensity scores, and standard errors are block bootstrap by Census tract with 100 replications. Large plants are those for which the nameplate capacity exceeds the median in the sample (380 megawatts).

E. Alternative Specifications and Validity Tests

Table 3 reports results for alternative specifications and validity tests. For each regression, the table reports the estimated coefficient and standard error corresponding to 1*(within two miles)*. All specifications are weighted using propensity scores and include county fixed effects and the complete set of housing and demographic characteristics from 1990 as in table 2, columns 2 and 5.

Panel A reports estimates from alternative sets of plants. First, results are reported separately for plants that opened between 1993 and 1999 and plants that opened between 1994

and 2000. An unusually large number of plants were opened in 2000, and it is reassuring that the results are not unduly sensitive to exclusion of the plants opened in that year. Second, results are reported from restricting the sample of plants to include only natural gas plants. Between 1993 and 2000, 85 of the 92 plant openings were natural gas plants, and restricting the sample to these plants does not meaningfully change the estimates. It would have been interesting to report results separately for coal plants, but there were too few coal plant openings between 1993 and 2000 for the estimates to meet Census disclosure requirements, which prevent reporting coefficients based on a small number of observations. Finally, estimates are reported separately for large and small plants. Large plants are defined as those for which nameplate capacity exceeds the median nameplate capacity in the sample (380 megawatts). The point estimates indicate moderately larger effects for big plants for both housing values and rents, though the differences are not statistically significant. It would have been valuable to more fully characterize this relationship between plant size and local impact or, alternatively, report estimates separately by plant. Further disaggregation would not, however, meet Census disclosure requirements.

Panel B reports estimates from three validity tests. Instead of plants opened between 1993 and 2000, these specifications examine plants opened during the 1970s and 1980s and from 2003 to 2006. Because these plants were either already open in 1990 or not yet opened in 2000, there should be no housing market effect in 2000 after controlling for 1990 characteristics.[8] As expected, the estimates are close to 0, with no consistent pattern. This lack of evidence of a relationship between these openings and housing prices or rents is reassuring because it suggests that the results for plants opened between 1993 and 2000 are not driven by unobservable factors associated with the type of locations where plants tend to be sited.

Panel C reports alternative specifications aimed at describing how estimates vary for different types of households. First, the effect of 1*(within two miles)* was estimated separately for Census blocks upwind and downwind from plants.[9] The results provide no evidence of a disproportionate impact on homes downwind of plants. If anything, there would appear to be somewhat larger effects on upwind households, but the differences are not statistically significant. Second, the effect of 1*(within two miles)* was estimated separately by income tercile. The estimates are decreasing in income, with the largest effects for Census blocks that in 1990 were in the bottom income tercile. Again, however, these results should be interpreted with some caution because of the lack of statistical precision.

F. Neighborhood Characteristics and Housing Supply

Table 4 describes the effect of power plants on neighborhood characteristics within 2 miles. As described in section II, households will respond to a decrease in local environmental quality with taste-based sorting. Households that place a high value on local environmental quality will move away, while households that value local environmental quality less will move in. The table reports estimates for twelve dependent variables, including household income, educational attainment, demographics, housing unit characteristics, housing supply, and total population using three different specifications, all identical to the specifications used in table 2.

Panel A reports coefficients for household income and educational attainment. Power plant openings are associated with between a $2,000 and $4,200 decrease in household annual income within 2 miles of the plant. This effect is statistically significant at the 2% level in all specifications though modest in size relative to the 1990 mean. Results for educational attainment are similar. In columns 1 and 2, plant openings are associated with declines in the proportion completed high school and proportion completed college. However, the point estimates change considerably when housing and demographic characteristics from 1970 and 1980 are included. This could indicate that the results in columns 1 and 2 are influenced by within-county differential time trends, or it could simply reflect the fact that the estimates in column 3 come from the smaller, more urban sample for which data are available for 1970 and 1980.

Panel B reports coefficients for demographic characteristics. The estimates indicate an increase in the number of individuals under age 18 and a decrease in the number of individuals over age 65, as well as increases in the proportion of household heads who are black or Hispanic. Estimates for proportion Hispanic are positive and statistically significant at the 1% level in all three specifications. As with educational attainment, the results in this panel are sensitive to whether the specification includes characteristics from 1970 and 1980.

Panel C reports coefficients for housing unit characteristics. The estimates for the proportion of housing units that are occupied are close to 0 and not statistically significant, providing no evidence of an increase in vacancies. For the proportion of housing units that is owner occupied, the estimates are negative and statistically significant at the 1% level across specifications, indicating a modest progression toward rental properties.

Finally, panel D reports coefficients for housing supply and total population. All estimates are small relative to the mean and not statistically significant. The coefficients are estimated with enough precision to rule out reasonably small changes in the number of housing units and total population. The lack of evidence of a change in housing supply is perhaps not

[8] This type of validity test has been used effectively in other contexts. For example, Busso and Kline (2008) use empowerment zones awarded in 1999 and 2001 as a point of comparison for empowerment zones awarded in 1994.

[9] Prevailing wind direction comes from the National Oceanic and Atmospheric Administration (1998) for 321 locations in the United States summarizing over sixty years of data from weather stations. The prevailing wind direction for each plant site is determined using the closest available weather station.

TABLE 4.—THE EFFECT OF POWER PLANTS ON LOCAL NEIGHBORHOOD CHARACTERISTICS WITHIN 2 MILES

	(1)	(2)	(3)
A: Household Income and Educational Attainment			
Household annual income (1,000s)	−1.98	−4.19	−2.01
(1990 mean: 33.5)	(0.78)	(0.93)	(0.83)
Proportion household head completed high school	−.052	−.032	−.013
(1990 mean: .77)	(.009)	(.009)	(.009)
Proportion household head completed college	−.017	−.009	.006
(1990 mean: .29)	(.009)	(.010)	(.008)
B: Demographics			
Household size (persons)	.070	.035	−.025
(1990 mean: 2.44)	(.030)	(.034)	(.035)
Number of individuals under 18 per household	.027	.015	.006
(1990 mean: .64)	(.005)	(.005)	(.005)
Number of individuals over 65 per household	−.034	−.016	−.008
(1990 mean: .33)	(.005)	(.007)	(.008)
Proportion household head black	.012	.005	.002
(1990 mean: .07)	(.005)	(.006)	(.005)
Proportion household head Hispanic	.052	.053	.028
(1990 mean: .16)	(.011)	(.013)	(.010)
C: Housing Unit Characteristics			
Proportion occupied	.008	−.005	−.004
(1990 mean: .90)	(.003)	(.005)	(.005)
Proportion owner occupied	−.049	−.038	−.020
(1990 mean: .68)	(.006)	(.007)	(.007)
D: Housing Supply and Total Population			
Total housing units per Census block	−.732	−.573	−.515
(1990 mean: 31.0)	(.402)	(.819)	(.838)
Total population per Census block	−.409	−.092	−1.33
(1990 mean: 73.5)	(1.16)	(2.20)	(2.36)
1990 dependent variable	Yes	Yes	Yes
County fixed effects	No	Yes	Yes
Housing and demographic characteristics from 1990	No	Yes	Yes
Housing and demographic characteristics from 1970 and 1980	No	No	Yes

This table reports estimated coefficients and standard errors corresponding to 36 separate regressions. The row headings list the dependent variable used in each regression. The sample includes all Census blocks in the United States. The variable of interest is an indicator for Census blocks within 2 miles of 1 of 92 large (100+ megawatt) power plants opened between 1993 and 2000. Housing and demographic characteristics are listed in section IVB. Observations in all specifications are weighted using propensity scores and standard errors are block bootstrap by Census tract with 100 replications.

surprising because housing is durable, so a decrease in local amenities typically does not lead to an immediate decrease in housing supply. Moreover, the direct effect of power plants on the local supply of available land is likely to be relatively small. Even the largest power plants use at most only a few hundred acres, including all generators, the network switchyard, cooling towers, and parking, typically representing less than 2% of the total land area within a 2-mile-radius circle around the plant.

VI. Conclusion

Electricity consumption in the United States is forecast to continue to increase over the next several decades. Although wind, solar, and other alternative sources of electricity production receive a great deal of attention from policymakers, the low cost of fossil fuel electricity generation all but guarantees that it will play a central role in meeting this growing demand. At the same time, siting of power plants has become more difficult than ever before, in large part because the need for new facilities is most severe in places with large and growing populations. Policymakers face difficult, often politically contentious, decisions about where to site plants and must balance many factors. Although local amenities are typically one of the important factors considered in this process, the lack of reliable empirical evidence about the magnitude of these costs has limited the use of cost-benefit analysis.

This paper is the first large-scale effort to assess the impact of power plants on local housing markets. Across specifications, the results indicate 3%–7% decreases in housing values and rents within 2 miles of plants, with the semiparametric estimates suggesting somewhat larger decreases within 1 mile. In addition, there is evidence of taste-based sorting, with neighborhoods near plants experiencing statistically significant decreases in mean household income, educational attainment, and the proportion owner-occupied. Overall, however, the analysis suggests that the total local impact from power plant openings during the 1990s was relatively small because plants tended to be opened in locations where the population density is low.

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Nuclear Power Plants and the Value of Agricultural Land

Sherman T. Folland and Robbin R. Hough

I. INTRODUCTION

A serious nuclear reactor accident could entail substantial detrimental consequences to the environment. Consequently, it might be expected that nuclear risks at any plant would be capitalized in the reduction of the value of assets located nearby. Two studies in the United States, however, found no consistent significant effects of proximity to a nuclear reactor on the price of local housing. Nelson (1981) found that no significant reduction in nearby housing prices occurred following the accident at Three Mile Island. Gamble and Downing (1982) investigated the effect of proximity to a nuclear plant on housing sale prices near five sites and found predominantly insignificant effects.

However, unlike the presumption of these studies, it may be that the external effects extended to a larger geographic area and differentially affect different assets. Thus, the correlation of individual housing values and distance—e.g., within the 20-mile radius examined by Gamble and Downing—may be relatively unimportant at the same time as the interarea effects are substantial. The study presented here examines agricultural land values in a cross section of 494 market area regions constituting the United States. The hypothesis of a nuclear externality is tested by estimating a reduced form equation of the equilibrium average price of an acre of farmland in which the presence of a reactor is indicated by one or more dummy variables.

The next section presents the theoretical model and develops the econometric specification. Next the data are described and then the results are reported. A discussion of possible confounding effects including tests of alternative hypotheses is next. A conclusion section closes the paper. The major finding is that a significant negative externality on the value of agricultural land on a scale meaningful for energy policy is consistent with these empirical analyses.

II. A THEORETICAL MODEL

The Price of Land

Let the owner of land be an investor who owns a portfolio of assets consisting of land and one other conglomerate asset whose return is market determined and is unaffected by the presence of nuclear power in the region. The owner may also be an operator, but, as owner, holds assets because of their returns both in dividends and in appreciation in price.[1] To focus on nuclear risk, assume that the owner adjusts for risks unrelated to nuclear power by adjusting his/her discount factor. Investors are assumed to be risk averse.

Under conventional assumptions, the market price of land will be determined by the capital asset pricing model. That is, the price of land will equal the discounted present value (*DPV*) of the stream of cash flows. The cash flows in this case will be the rents received. Thus,

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[1]Other factors besides nuclear power may affect the price of land over time, in particular, the encroachment of urban areas tends to drive up the price of land. If the land in question is applicable for urban development in the future, one can assume that the current price of land capitalizes the future value of use for development. But for simplicity, one may assume that such factors remain constant during the analysis.

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$$P = \sum_{t=0}^{\infty} \delta^t r_t, \qquad [1]$$

where δ is the discount factor; that is, $\delta = 1/(1 + i)$ where i is the required return.

To introduce the nuclear risk, it is illuminating to introduce the specific effect, the effect that a serious nuclear accident will reduce land rent to zero more or less permanently. Inasmuch as the nuclear accident is probablistic, an appropriate specification of the land price involves expectations, that is let $P = E(\Sigma\delta^t r_t)$. To describe the latter term more explicitly, first describe the discounted present value of cash flows from the land up until year m, the year the meltdown accident occurs as

$$DPV(m) = \sum_{t=0}^{m} \delta^t r_t. \qquad [2]$$

Then let $f(m, N)$ be the probability that the nuclear reactor will live until exactly year m (where N indicates the presence and degree of the nuclear risk). Then the expected value in question is as follows:

$$P = E(\Sigma\delta^t r_t) = \sum_{m=0}^{\infty} DPV(m) \cdot f(m, N). \qquad [3]$$

Given these considerations, the determinants of the equilibrium price of land are as follows. First, the price depends on the land rent, thus the price of output and the fertility of the soil increase the price of land whereas the transportation costs decrease it.[2] More importantly, the nuclear effect enters not by altering the rental rate of land, but by altering the probability of receiving that rent.[3] Note that $DPV(m)$ is an increasing function of m and that the entrance of nuclear risk shifts probabilities under f relatively from later dates to earlier ones. Thus, the nuclear risk unambiguously lowers the equilibrium price of land.[4]

The Process by Which the Price of Land Changes

Suppose first that when the nuclear reactor enters the region the information becomes available regarding the probabilities of meltdown. The market efficiently processes this information and the equilibrium market price is reduced. A familiar problem is that with symmetric and complete information, the buyer will not purchase at any price higher than the new equilibrium value and the seller is likewise indifferent between holding and selling. Under this construction there is no advantage in switching to renting or toward purchasing the other asset. The actual process of price adjustment may be spread over time if the information becomes known only sporadically through several announcements pertaining to the reactor.

The relaxation of two assumptions affords more realism. In particular, let people differ in their degree of risk aversion, and, more important, let people differ in their beliefs about the probability of a meltdown. The latter view is realistic in light of the controversy surrounding the risks of nuclear power. Here the expected value of discounted cash flows will differ between potential buyers and sellers. Relatively more risk averse and pessimistic owners

[2] This is a straightforward result of a simple model of land rent. Let the farmer maximize profits, $\pi = pq(L, \alpha) - rL - Tq(L, \alpha)$, where p is the exogenous price of output delivered at the regional market center; output, q, is a function of the amount of land, L, rented at price r, and a parameter, α, representing the productivity of the land. Let T be the per unit transportation cost. If land supply is fixed, it is simple to show that the equilibrium rent increases in p and α and decreases in T.

[3] The reactor does not affect the technical relations or the price of transportation or output. The primary threat of a reactor failure is to the owner not the renter. For the renter, the best way to farm in the presence of a reactor is the same as before.

[4] It may occur to some readers that while the qualitative effect of nuclear power on land prices is negative, the magnitude of these effects may be too small to observe. Although this issue is inevitably an empirical one, simulations were run to determine if observable effects would be generated from accident probabilities in a credible range. These simulations indicated that price effects of the size of those estimates reported later are consistent with landowner beliefs that an accident would occur once in 250 to 500 years. Thus, the estimates here are consistent with rather small probabilities of a serious accident. The simulation method and results are available upon request.

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will have an incentive to sell to less risk averse and more optimistic buyers. The seller will have both the incentive to sell and the incentive to rent the land back from the buyer and farm as before, shifting his portfolio into the conglomerate other asset. The effect on land prices is nevertheless qualitatively the same. They will fall with the announcements regarding the introduction of the reactor.

Finally, an additional element of realism is introduced by noting that the subjective probabilities of a nuclear accident will tend to increase over time as the reactor ages. This is due to both the perception and the reality that older capital equipment is more inclined to malfunction.[5] As subjective probabilities grow in the direction of a greater likelihood of a nuclear accident in a given year, this will have the effect of reducing the equilibrium price of land further. This effect is analogous to the fact that the market value of a capital asset will decline as it depreciates. Together with the reality of sporadic announcements regarding the reactor initially, the effect of gradual change in the subjective probabilities of an accident will be that the price of land in the vicinity of the reactor will fall gradually over time.[6]

An Econometric Model

As an econometric approach, a simple demand and supply model is proposed. Let the demand for agricultural land in a region be a log-linear function of price, transportation costs, land productivity, and nuclear risks. In addition, demand for land will be increased at the urban fringe due to competing uses for land for residential and commercial development.[7] Treating lowercase variables as logarithms demand for land becomes

$$Q_d = a_p \cdot p + \Sigma\, a_i \cdot x_i, \qquad [4]$$

where p is the price of land, and the x_i represent the other demand variables. Letting the supply of agricultural land in the region be in fixed quantity, $Q_s = l_o$, it follows that

$$p = (-l_o/-a_p) + \Sigma\,(a_i/-a_p) \cdot x_i, \qquad [5]$$

where $-a_p$ is positive. The prior discussion in this section implies a sign for each coefficient. Land productivity factors will be positive, transportation costs negative, and finally, the hypothesis of a nuclear externality implies a negative coefficient for the presence of a nuclear reactor.

III. THE DATA

The model requires that the price equation be estimated across relatively large geographic areas which approximately represent regions affected by the nuclear externality. The Basic Trading Areas (BTA) developed by Rand McNally and Company are suitable for this purpose. The Rand McNally areas are constituted as groups of counties constructed to reflect patterns for retail trade. These BTAs are devised without regard to state boundaries, and the 494 such areas exhaustively account for the United States. The average size of the areas in the sample is 3,195 square miles.[8] In addition, Rand McNally associates each BTA with a supra BTA major trading center of which there are 50 in the United States.

Data for agricultural and other variables at the BTA level were generated by aggregating county and city data to the BTA. County and city data were obtained from the U.S. Department of Commerce *County and City Data Book, 1983*. Agricultural

[5] A related phenomenon probably exists across regions in that newer reactors will be of somewhat safer design than the older reactors.

[6] While the model presented captures one self-consistent account of the matter, it is nevertheless clear that a disamenity model based on subjective perceptions of the effect of the reactor's presence on health and quality of life would also generate effects on the long-run value of land.

[7] For discussions of agricultural land pricing at the urban fringe see Shonkwiler and Reynolds (1986); Dunford, Marti, and Mittelhammer (1985); and Chicoine (1981).

[8] To get some feel for the size of these areas, consider that if the areas were circular (which they are not) and if a reactor were perfectly in the center of the area, the radius around the reactor would be approximately 32 miles.

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variables represent data from the 1978 Census of Agriculture. The available variables are approximations to the concepts posed in the model.

The price of land in each area, *PRICE*, is approximated by the reported average value of all agricultural land and buildings per acre. The supply of land is measured by the total number of acres (*LAND*) in farms in the region and alternatively by the average farm size (*AVEFARM*). Productivity is proxied by *VALPROD*, which is the value of farm products per acre. Competing uses of land for urban development are indicated by population density, *DENSITY*, which values are derived from the 1980 Census of population. Transportation costs are assumed to be increasing in the *DISTANCE* from the basic trading area to the supra regional market center. In addition, the existence of a *PORT*, is taken as an indication of lower transportation costs.

Data on the presence of nuclear reactors were generated from *Nuclear Power Reactors in U.S.*, published by the Technical Information Center, U.S. Energy Department for reactors in operation as of December 31, 1981. These data include the number of reactors at each site and the starting date of operation. Each nuclear reactor site within the United States in operation by 1978 has been included in the data set. The presence of one or more nuclear reactors in the area is indicated by the dummy variable, *NUCLEAR*.

IV. RESULTS

Two log-linear versions of the reduced form price equation were estimated by ordinary least squares. The results are reported in the first two columns of Table 1.[9] Each of the variables takes the hypothesized sign and is significant. Of interest here, the nuclear dummy variable takes a significant negative coefficient in each equation. The size of the nuclear coefficient implies a reduction in land values of approximately 10 percent.

The Breusch-Pagan test statistic indicated significant heteroscedasticity, therefore both equations were reestimated under estimated generalized least squares (EGLS). These estimates, shown in Equations [3] and [4], revealed only minor changes in coefficients and t-values, indicating that heteroscedasticity was not a serious problem.

Each equation performs well in that all coefficients take the predicted sign and most are easily significant at the 5 percent level. By theory, the fixed supply of land enters negatively, hence *AVEFARM* and *LAND* are appropriately negative in all equations. Reflecting that transportation costs increase with distance to the market center and decrease with the availability of a port, the variables *DISTANCE* and *PORT* each take the correct sign in all equations. The productivity factor, *VALPROD*, increases the value of the land and has a highly significant positive coefficient. The significant positive coefficient for *DENSITY* is consistent with previous studies of land pricing at the urban fringe (Dunford, Marti, and Mittelhammer 1985). Finally, the point estimates of *NUCLEAR* suggest a sizeable effect with land values approximately 10 percent lower than similar areas without a reactor. The sample average land value is $992, thus on average a 10 percent reduction corresponds to a difference of about $100 per acre.

V. DISCUSSION OF POSSIBLE CONFOUNDING FACTORS

As with any econometric result, it is possible that the result arises for reasons other than those presented in the theory. The present section investigates several possibilities.

Factors That Create Noise

These results are fairly strong in that many of the confounding factors work

[9] Two linear versions of the price equation were also estimated; though not reported here, these performed similarly in most respects. The linear versions also generate the correct signs and significant t-values for the coefficients, but they perform less well in terms of R^2 and the OLS linear versions are highly heteroscedastic. For these reasons the log-linear versions are featured in the paper. Results for the linear versions are available on request.

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TABLE 1
LOG-LINEAR REGRESSION RESULTS FOR THE EQUILIBRIUM PRICE EQUATIONS

	OLS		EGLS	
Equation	(1)	(2)	(3)	(4)
LAND	—	−0.5444	—	−0.05141
		(−4.06)		(−3.75)
AVEFARM	−0.17684	—	−0.17315	—
	(−7.32)		(−7.48)	
DISTANCE	−0.02122	−0.03507	−0.01802	−0.02722
	(−1.77)	(−2.67)	(−1.83)	(−2.50)
PORT	0.17123	0.10866	0.16158	0.07542
	(3.70)	(2.24)	(3.31)	(1.48)
VALPROD	0.35922	0.41173	0.35485	0.42650
	(18.30)	(21.34)	(18.50)	(22.70)
DENSITY	0.12386	0.15794	0.12710	0.15986
	(6.25)	(7.74)	(6.77)	(8.05)
NUCLEAR	−0.11752	−0.13437	−0.09095	−0.10283
	(−2.28)	(−2.52)	(−2.09)	(−2.37)
CONSTANT	5.63515	5.06073	5.60599	4.91127
	(24.25)	(19.49)	(25.16)	(18.41)
Adjusted R^2	.794	.779	.808	.800
F	314.32	286.96	337.41	318.92
n	494	494	494	494

Note: *t*-values in parentheses. Critical values of *t* for a one-tailed test are 1.645 at the 5 percent level and 2.326 at the 1 percent level.

against the hypothesized results. The areas are not of equal size, they are not circular centering around the reactor. In addition, prevailing wind direction is not incorporated.

Similarly, the dependent variable is subject to some possible measurement error. Value of land in these data is the reported value of agricultural land and buildings within an area. Variations in reporting error may exist but are probably unrelated to the presence of a reactor and they do not introduce bias. Variations in the relative proportion of value incorporated in buildings are probably minor and are accounted for by included variables. For example, the value of buildings may be allowed to run down near urban centers when the land is being considered for urban development. This factor would have effect for all land near metro centers, not just areas with reactors, and the variable, *DENSITY*, would account for this factor.

The Relative Effect of Multiple Reactors

The logic of the model would suggest that multiple reactors present a greater nuclear risk than single reactors. To test for this effect, an additional variable representing the number of nuclear reactors in the area was added to each equation with the nuclear dummy still present. In each case, the number of reactors did not contribute significantly to the equation. It must be concluded that it is not the number of reactors by which nuclear risk is measured but the presence of any reactor.

The Nature of the Causation

It is theoretically possible that the negative coefficient for *NUCLEAR* is the result of the power company's site selection process. The company may deliberately select a site that would generate little opposition to the reactor and consequently choose land that has lower opportunity costs and lower price.

The present data, however, afford a simple test of this alternative hypothesis. If the alternative hypothesis were true, then there would be no reason for the land price to change downward subsequent to introduction of the reactor. If instead, the nuclear externality hypothesis were true, land price

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TABLE 2
OLS REGRESSION RESULTS FOR OLD AND NEW REACTORS

	Linear		Log-linear	
Equation	(1)	(2)	(3)	(4)
LAND	—	−0.00002	—	−0.05471
		(−2.67)		(−4.07)
AVEFARM	−0.02951	—	−0.17602	—
	(−2.44)		(−7.26)	
DISTANCE	−0.52205	−0.49747	−0.02186	−0.03558
	(−3.56)	(−3.36)	(−1.82)	(−2.71)
RATIO	−380.025	−387.866	—	—
	(−5.28)	(−5.41)		
PORT	117.429	105.717	0.17691	0.10911
	(1.70)	(1.53)	(3.70)	(2.25)
VALPROD	2.49869	2.47588	0.35701	0.40882
	(15.90)	(15.67)	(18.13)	(21.12)
DENS	1.31819	1.30956	0.12770	0.16280
	(13.12)	(13.03)	(6.37)	(7.89)
OLDNUCLEAR	−536.818	−539.157	−0.15718	−0.21772
	(−3.76)	(−3.78)	(−1.62)	(−2.17)
MIDNUCLEAR	−258.475	−244.751	−0.16650	−0.16777
	(−2.49)	(−2.36)	(−2.23)	(−2.16)
NEWNUCLEAR	−137.982	−125.484	−0.04863	−0.05511
	(−1.11)	(−1.01)	(−0.55)	(−0.60)
CONSTANT	767.231	790.278	5.62772	5.00627
	(13.82)	(13.97)	(24.10)	(19.46)
Adjusted R^2	.660	.661	.794	.779
F	105.80	106.19	235.74	215.65
n	494	494	494	494

Note: *t*-values in parentheses. The additional variable used in the linear regressions is the *RATIO* of cattle products to total product in the area. Critical values of *t* for a one-tailed test are 1.645 at the 5 percent level and 2.326 at the 1 percent level.

would fall as reactor announcements are made and subsequent further reductions would occur as the reactors age.

To investigate this issue, Table 2 presents the OLS estimates of both linear and log-linear forms of the price equation with dummy variables representing nuclear plant site by age of the plant. Plants were designated old, middle, and new by date of beginning operation, with the age categories approximately at five-year intervals. The results are clearly consistent with the gradual effect hypothesis.

Land Price Dynamics of the 1970s

It has been suggested that during the 1970s, a period of rapid growth in agricultural land prices, the areas of most rapid price growth may have also been predominantly areas without nuclear reactors. If this occurred for reasons extraneous to nuclear power, the results of these model estimates could be an artifact of 1970s price dynamics.

To investigate this possibility, Department of Agriculture state aggregate[10] data was assembled on land prices in time series cross section. It is clear from any review of these data that the period from 1973 to 1979 was a period of extraordinary change. The question of interest is whether the *NUCLEAR* variable is negatively correlated with areas of abnormally high increases in values for land. A review of the annual average growth rates of land values by state, however, does not reveal such a relationship. In addition to casual observation of these data, a regression was estimated employing the average annual growth rate in

[10] Comparable data were not available by the Rand McNally regions used in the main body of our study.

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land prices by state as the dependent variable and the number of nuclear plants by state as the independent variable. The coefficient of the nuclear plant variable is insignificant with a *t*-value of − 0.11. Thus, the alternative hypothesis of extraneous land price dynamic effects can be rejected as an explanation for the present findings.

VI. CONCLUSION

Average land values in market areas which contain a nuclear power plant are significantly lower than in similar areas which do not. The effect is stronger for areas where the reactor has been in operation a longer period of time. The results are consistent with the view that the risks associated with nuclear power create a negative external effect that is perceived by owners of land within the area and is incorporated in their decision calculus regarding the price they are willing to pay for land. As with any initial econometric result, these results must be considered tentative, pending the normal process of verification by other studies and other data sets. However, the results obtained here are robust to alternative specifications and considerations of alternative hypotheses. At present, they must be reported as significant facts which are potentially important to energy policy. As such they suggest the need for further research on this issue at the interregional level.

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EXTERNALITIES OF NUCLEAR POWER PLANTS: FURTHER EVIDENCE*

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ABSTRACT. Several prior studies found no detrimental external effects of nuclear power plants when estimating the distance gradient for housing prices within a hedonic model. Other papers found significant negative effects of nuclear power when studying real asset prices in cross sections of broad market areas.We suggest a resolution and verify that an installation effect occurs after controlling for the tendency of facility builders to seek out cheap land. The study assembles a panel of all commercial market areas, including indicators for nuclear facilities, in the contiguous United States observed 11 times over roughly equal intervals covering the span from 1945 to 1992.

1. INTRODUCTION.

The harm done to farmers by nearby nuclear facilities in the United States, must be the perception of risk, real or imagined, because history rarely involves a serious accident of relevance to the farmer. It is an understandable perception, because a nuclear leakage may cause him damage in two ways. First, as a businessman he may perceive the added risk as a depreciation of the expected present value of the profit stream from the land. Second, as spouse and parent he may worry about health consequences, a disamenity of living downwind from the facility. He may not be fully aware of agencies that insure him, or, as Tyran and Zweifel (1993) conclude, the available insurance may not fully cover the anticipated loss. In any case, a decline in land prices begins upon an announcement of the installation (Galster, 1986). Under one scenario, the expected present value of the land depreciates, the small probabilities of the land's diminishment acting much like physical depreciation factors. Under a second

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scenario, exit of human beings from the area operates to cause supply to exceed demand at prenuclear land prices.

Without question, some people perceive a substantial risk. They may be rational or irrational in these perceptions; the issue of just compensation becomes muddied. Compensation is sometimes provided through the courts in cases where scientists are close to unanimous in denying the scientific validity of the claim. Our focus is whether farmers and other landowners express their risk perceptions in observable ways, beyond the subjective responses to hypothetical survey questions. Selling farmland at a reduced price or leaving the area are responses that can be measured with reliable econometric tools.

Previous empirical research is mixed on this issue, two designs being prevalent. Nelson (1981), Gamble and Downing (1982), and Clark et al. (1997) assembled data from selected market areas that contained a nuclear facility. These researchers built a hedonic model of housing prices that estimated the distance gradient (distance from the property to the nuclear facility) for each study area. A positive gradient supports the externality hypothesis. The distance coefficients (or gradients) were generally insignificant and sometimes took the "incorrect" sign. A negative gradient suggests the alternative hypothesis—that nuclear facilities may raise asset values through association with economic growth and broadening of the tax base. Viewed from the perspective of the distance-gradient studies alone, the hypothesis of a negative nuclear externality appears to be baseless.

However, there are two reasons why the design of these three studies is not a sufficient test of the externality hypothesis. First, these few studies are really single cases (or involve very few cases) even when hundreds of residential homes are evaluated. The public perceptions regarding reactor safety may be general, affected by or dependent on the broadcast media, which conveys the views of experts, community leaders, and news of energy company behavior. In one locality the company's reputation may purvey excellent safety whereas in another there may even have been an accident.

One of us lived for several years within view of Three Mile Island after the time of its well-known accident, an area that was included in two of the above studies. Continued residence by tens of thousands of people in that vicinity seems to suggest anecdotally that there was no external effect. However, other anecdotes abound. The threatened leakage had been terrifying to pregnant women, some of whom sought safety far from the area either in miles or to areas protected by natural mountain barriers. Further, the reactors were quickly shut down and, ironically, some people perceived the area to be safer in the shutdown period directly following the accident than it was before the accident.

Second, one may err by embedding hypotheses that prescribe how the local people perceive distance to relate to risk. Should someone living 5 miles from the reactor site feel more at risk than someone living 15 miles away? The embedded hypothesis that the nuclear externality would necessarily affect the distance gradient could prove false, the risk being experienced generally

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throughout the area. *Acceptance distances*, the distances from a nuclear reactor that laymen state they would accept when choosing a residence location sometimes average as high as 60 miles (Krupnick, Markandya, and Nickell, 1993).

To complement the distance-gradient research, Folland and Hough (1991) studied a cross section of broad market areas across the United States drawn from 1978–1980. They found a significant negative coefficient for a nuclear dummy and other nuclear variables suggesting a negative nuclear externality. Clark and Nieves (1994) also studied broad areas in cross-section, and found reductions in land rents as well as higher wages in nuclear areas, so both results support a negative external effect. Thus, the two approaches seem to reach opposite conclusions: within a nuclear area, real asset prices are unaffected by proximity to the plant; between markets in cross section, those with nuclear plants tend to record significantly lower asset prices, ceteris paribus. These results are not logically inconsistent, but a resolution would be welcome.

2. THEORY: FARMLAND ASSETS DEPRECIATE WITH THE NUCLEAR RISK

Potential nuclear externalities can be theorized in two ways: (1) by amenity models that describe the psychological or health effects of the exposure to the risk of an accident or to distaste from the reactor's presence, and (2) by asset-depreciation models that describe the loss in value of a location-specific property. We take the asset-depreciation approach in part because it has been the less developed in this literature and in part because the owner of a real asset may not reside in the area studied but may nevertheless respond to nuclear announcements. In the following section we present a theoretical model and define the terms and their relationships in an assets model. This is followed by a description of the data and the econometric approach.

For a given market period, which is treated as a year and encompasses an agricultural season, the quantity of land within an agricultural market area available for farm use is assumed to be fixed $L_S = L_O$. On the urban fringe, a small fraction of the land will be developed for residential use within each year, and this process implies that the supply of farming land will decline with time. However, the fraction of land that is already zoned and ready to be converted to urban use during the year will generally not be sufficiently large to affect considerably the market price of agricultural land during the same year. Nevertheless, the magnetic attraction of the encroaching city will draw land into urban use over time, and the future selling price will become capitalized into the price of farmland before conversion occurs.

The farming process is split conceptually into land title holding (the landlord function) and farm operating (the tenant function). The fixed supply of land is the same for markets, land buying, and land renting, and we assume that both markets clear during the year. The demand for rental land is determined by the tenant's attempt to maximize profit from the sale of amount Q agricultural product, for example grain, at price p_G; the tenant incurs costs C that are

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increasing in output and are conditioned by parametric input rental prices for capital r, and land p_L. The farmer also must pay transport costs γ for each unit of product shipped to the major trading center. These unit transport costs increase with the distance to the major trade area center D and the freight transportation price per mile of distance p_D. The farmers profit function is then

$$\prod = p_G Q - C(Q; r, p_L) - \gamma(D, p_D)Q \tag{1}$$

The equilibrium farmland rental price $\bar{p}_L$ then becomes

$$\bar{p}_L = \left[p_L \, st \, \Pi = \Pi^* \; \forall \; tenants, and \; L_D(p_L) = L_{So} \right] \tag{2}$$

where the asterisk indicates the maximum profit, and L_D indicates the combined tenants demand function for farmland, treating all tenants as similar profit maximizers and assuming that nonnegative profits are attainable. Equation (2) states that the equilibrium land rental price for the period will be that rate that clears the rental land market given that all tenants have accepted the rental price as a given and have adjusted to it so as to maximize their profits.

Let this equilibrium rental price of farmland be the landlord's sole return on the property while he holds it. The landlord's demand for owning land is then dependent on the discounted present value of these returns as amended, truncated, or adjusted by the nuclear risk. This present value is then the landlord's reservation price for land, the highest price that he would be willing to pay under the conditions of no speculation regarding possible urban encroachment. To generate this reservation price we first define a truncated return

$$\hat{R}_{t,k} = \int_{t}^{t+k} e^{-bt} \bar{p}_L \, dt \tag{3}$$

where discounted returns from land purchased in period t are truncated if a reactor accident should occur in exactly the kth year following the land purchase and if the accident reduces that land value to zero in perpetuity. The value k is thus the life of the reactor in this specific sense; it depicts each possible "worst case" scenario given that the interval from the purchase to the event of the worst case is variable.

The landlord's reservation price assuming purchase in year t can then be derived given his probability density function f for the occurrence of the worst case in exactly k years

$$P_{D_{Lt}} = \int_{k=0}^{H} \hat{R}_{t,k} \, f(t+k) dk$$

where H is the potential buyer's finite time horizon, which can well exceed his own life span, that is, he can reasonably expect to find a buyer when he decides

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to sell. The function f properly integrates to unity given that we define period H as a time-distant period to represent the case that a reactor event never occurs, such as when no reactor is present. Absence of a reactor implies that for ($k < H$), $f = 0$, and for $k = H$, $f = 1$. By picking a sufficiently time-distant period and provided a discount factor approximating a discounting by the market rate of interest, H is in practicality beyond his horizon, that is, the discounted present value of income foregone because of truncation at H is negligible.

For farmland on the urban fringe, this agricultural reservation price may be outbid by developers. When this happens the agricultural demanders are superceded and represent only the minimum of what the market will bear. We assume that the developer also maximizes profits, and without loss of generality, we further assume that he rents his acquired property for residential use. The additional demand by developers is thus similar in form to the demand by agricultural buyers, though the pattern of encroachment implies that farm purposes are gradually outbid. We emphasize that the developer is a speculator and his optimism becomes capitalized in land prices perhaps well before conversion of the land takes place.

The demand for land title becomes the maximum reservation price for the next acre of land at each level of total land to be considered for purchase. The equilibrium price of land is then the demand price at which the fixed supply equals the demand

$$\overline{P}_{D_L} = \left[P_{D_L} \, st \, L_{D_L}\left(P_{D_L}\right) = L_{So} \right]$$

The introduction of a nuclear power facility into the area implies that years earlier than H come to be given nonzero probabilities. Information of the installation may form complex patterns including pre-announcement rumors, official announcements, and groundbreaking, each prior to installation and operation (Kiel, 1995; Kiel and McClain, 1995). These will reduce the land buyer's expected discounted value of ownership as the information becomes available to him which in turn this reduces the equilibrium land value, that is, $\partial \overline{P} / \partial N < 0$, where N represents the nuclear risk. New information such as news of serious accidents elsewhere may also cause a drop in his valuation of the land.

The other parameter effects stem from the tenant's decision problem. Let the farmer-tenant be a price taker in both output and input markets, then by differentiating the profit function in Equation (1) and dropping the notation for the assumed time period, the necessary condition for profit maximization becomes

$$\Pi_Q = p - C_Q - \gamma = 0 \tag{4}$$

The effects of the cost-raising parameters are illustrated for the case of the capital-input rental price r. Derivations and detailed discussions of all the comparative statics are provided in the Appendix. By totally differentiating the

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profit function in Equation (1) we get Equation (5), which indicates the change in profit that occurs when the parameters change

$$d\Pi = dp_G Q + \left(p_G - C_Q - \gamma\right)\left(Q_r dr + Q_{p_L} dp_L + Q_D dD + Q_{p_D} dp_D + dQ\right) - C_r dr - C_{p_L} dp_L - \left(\gamma_D dD + \gamma_{p_D} p_D\right)Q \tag{5}$$

The parameters p_G, r, dp_L, and dD are exogenous and represent directly or indirectly all the nonnuclear demand-side variables in the empirical model. For example, increased soil fertility has formally the effect of a reduction in an input price r and the presence of a port has formally the effect of a reduction in the carrier price p_D. To derive the effects of a *ceteris paribus* change in input price r we substitute Equation (4) into Equation (5) and set $dp_G = dD = dp_D = 0$. This results in

$$d\Pi = -C_r dr - C_{p_L} dp_L = 0$$

or

$$\frac{d\Pi}{dr} = -C_r - C_{p_L}\frac{dp_L}{dr} = 0$$

Through the reduction in land rental prices, mobility of the tenant's labor and capital will tend to equate profits for similar farms that incur different input price levels. When this occurs, $\frac{dp_L}{dr} = -C_r/C_{p_L} < 0$, and consequently $\frac{d\overline{P}}{dr} < 0$. This and the other predictions from the model are developed in the Appendix, but they are fairly intuitive. Together the model predictions are as follows

$$\frac{\partial\overline{P}}{\partial r} < 0; \quad \frac{\partial\overline{P}}{\partial D} < 0; \quad \frac{\partial\overline{P}}{\partial p_D} < 0; \quad \frac{\partial\overline{P}}{\partial p_G} > 0; \quad \frac{\partial\overline{P}}{\partial N} < 0$$

3. THE DATA AND THE ECONOMETRIC MODEL

We generated a panel of 494 market areas based on the trading areas developed in Rand McNally's Commercial Atlas. These Basic Trading Areas (BTAs) were designed by Rand McNally to represent well-integrated market areas. Within an area, farming generally is focused on a single group of products such as grains, livestock, truck farming, or rangeland, whereas across BTAs the differences range widely. The center of each BTA is identified with the dominant city for local market activities, and these are often, but not uniformly, near the geographic center of the area.

The BTAs are usually groups of three or four counties but occasionally they contain as many as eight or more countries, averaging just over six. These collectively exhaust the contiguous 48 states and create areas roughly 40 miles in radius. In addition, Rand McNally identified just over 50 Major Trading

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Centers. These represent the hub city to which various products from a BTA would go either for processing or for connection to the major transportation avenues including highway, railroad, air, and waterway hubs.

The geographic and market patterns devised by Rand McNally are necessarily imperfect for our purpose, primarily because the individuality and idiosyncrasies of the area, including its terrain, farmland, farmers, and wholesalers, can never be fully perfectly captured by such data as these. However, the data have advantages for interarea studies of nuclear externalities affecting agricultural land. They have greater homogeneity as markets than larger areas selected with political boundaries, and these small areas collectively cover a very large area with a fairly consistent methodology. Furthermore, they are defined with relatively few changes over the period for which nuclear power was at issue. With this panel, we can also investigate whether the results are affected or distorted by failure to collect a sufficient number of variables to describe the individuality of the BTAs; this issue is tested by incorporating a group fixed effect for each BTA in some analyses.

The 11 cross-sections in the panel survey the years 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, and 1992 (see Table 1). In each case agricultural data are derived from the Census of Agriculture made available from the National Archives; data on nuclear power plant location and date of installation are from the Nuclear Energy Commission; the remaining data are demographic and geographic. The demographic data are from the *City and County Data Books*. All data are aggregated to the BTA level. The geographic data included locational coordinates, which were applied to calculate the Distance from the BTA center to the Major Trading Center. The panel data analyses were conducted with Limdep 7.0.

In addition to the *Distance* variable just described, the following variables in the panel are used to represent the parameters in the theoretical model. The *Landtotal* variable measures the fixed land supply L_{Sot}. Over the time period, the supply of agricultural land was encroached on by development on the urban fringe, affecting land prices (Dunford et al., 1985; Chicoine, 1981). To account for this effect, we calculated the population density *Popdensity* from data provided by the *City and County Data Books* for each observation year. Transportation costs to bring produce to the Major Trading Center are represented by *Distance* and *Port*, where *Port* is a dummy variable identifying the presence of a port suitable for shipping products.

No direct measure is available for the agricultural product price or for the fertility and productivity of the local soil, climate, and topography; however, we approach these variables in two ways. First, the *Valueofproduct* per acre, measured in current dollars, becomes a proxy for the combined effect of product price and the soil fertility. Second, a panel analysis included BTA-specific fixed effects as well as observation-period effects, and these capture many of the idiosyncratic characteristics of each area such as climate and terrain and local price levels. Fixed effects for the 11 time periods adjust for time-dependent

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TABLE 1: Descriptive Statistics on the Panel Data

Variables and Definitions	Mean	Standard Deviation	Minimum	Maximum
landprice,* Value of Agricultural Land Per Acre; The Dependent Variable.	5734.9	8643.8	18.4	195875.8
landtotal, Total Land in Agriculture	2154.3	3274.2	2	23415
valueproduct, Value of Agricultural Product per Acre	145929	256484	40	4559723
distance, Distance to Major Trading Center from Coordinates	137.1	132.7	1	826
port, Presence of a Commercial Port in the BTA	0.11	0.31	0.0	1.0
nuclear, Presence of an Operating Nuclear Power Facility	0.061	0.239	0.0	1.0
nuctime, Years from Installation	0.774	3.56	0.0	33.0
popdensity, Population Density	115.9	216.7	1	2558
nearnuclear, BTA Center is < 60 Miles From a Nuclear BTA's Center	0.159	0.366	0.0	1.0
nukcombined, BTA is Either *nuclear* or *nearnuclear*	0.220	0.414	0.0	1.0
timenukcombined, Counts Years from Installation for *nukcombined*.	1.416	4.539	0.0	33.0
Pre, Nuclear BTA in the Years Prior to the nuclear Installation	0.084	0.278	0.0	1.0
Pre1, Nuclear BTA in Years between Contract Permit and Installation	0.061	0.239	0.0	1.0
Pre2, Nuclear BTA in Years Prior to the *Pre1* period.	0.060	0.237	0.0	1.0
period indicator	5.99	3.16	1	11
group indicator	248.6	142.9	1	494

Note: *These data from the Census of Agriculture combine the value of land and buildings. All variables except *port* and *distance* are specific to the time period. The 11 observation years by 494 BTAs generated 5,434 observations, However, invalid data and missing values required the rejection of 73 of these observations resulting in a sample size of 5,361.

factors including the general level of prices in the country. Each model is also tested assuming random effects.

Time trends are very important to the analysis. First, the time-period indicator is set to $t = 1$ for the first observation year, 1945, and counts by observation year so that $t = 2$ for the second observation year, which is 1950, and so on.Second, the variable *Nuctime* is reactor specific and counts by calendar years beginning with the installation year as *Nuctime* = 1.

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Also related to the installation is a dummy variable *Nuclear* that equals one if a plant is present and operating. Thus, *Nuctime* and *Nuclear* together test the central hypotheses; *Nuclear* tests whether installation has a lump sum negative effect on land price, and *Nuctime* tests whether installation continues to alter the land prices over time.

We investigate both linear and loglinear versions of the model and apply the Box-Cox approach to adjudicate between the two. The linear version generates the same signs for the coefficients but performs much less well on goodness-of-fit criteria, and the Box-Cox result is close to the loglinear. Thus, we present the loglinear and Box-Cox results in Table 2 along with a variant to be described as follows. The basic model presented in its loglinear form, with logarithms of the variables represented by lower case lettering, is

$$landprice = a_0 + a_1\, landtotal + a_2\, valueofproduct + a_3\, distance + a_4\, port + a_5\, nuclear + a_6\, nuctime + a_7\, popdensity + u$$

The theoretical model predicts $a_1 < 0; a_2 > 0; a_3 < 0; a_4 > 0; a_5 < 0; a_6 < 0; a_7 > 0$. Estimating the model with panel data has advantages for testing external effects. First, if the externality hypothesis is correct then the nuclear coefficient a_5 must be negative; it is a stronger test than a single cross section because it summarizes the effect for eight reactor observation years (the first year to record an active site was 1959) and three observation years prior to any reactors. Second, the nuclear hypothesis suggests a second related hypothesis, that of a distinct, declining time trend during the years following installation; a negative coefficient for *nuctime* ($a_6 < 0$) gives strong support to the externality hypothesis.

In contrast, the *cheap-land hypothesis* states that the depression in land prices is spurious and occurs well before rumors of or announcements of a reactor; under this hypothesis, the apparent nuclear externality occurs only because energy companies seek out cheap, less populated, and less controversial sites. This can be tested in panel by defining dummy variables preliminary to the reactor's installation. To account for such effects, we define three additional variables: *Pre* equals one in each of the years preceding the reactor installation and zero post installation as well as for nonreactor areas; *Pre1* equals one for nuclear BTAs beginning with the date of the contract permit and is intended to capture an announcement effect; and *Pre2* equals one in nuclear BTAs for all observation years prior to the date of the contract permit and is intended to capture the *cheap-land* effect. These *pre* reactor variables, or ghost reactors, will support the *cheap-land* hypothesis if *Pre* and *Pre2* take negative coefficients, in the latter case when controlling for the announcement effects *Pre1*.

Finally, a finding of a significant positive coefficient a_6 would capture another alternative hypothesis under which an installation is associated with a growth in land prices post installation $a_6 > 0$. This may occur if the power facility stimulates economic growth or improves the tax base. It may also occur where better or fuller information regarding the nature of nuclear power processes reassures residents on nuclear safety issues (Rhodes and Beller, 2000).

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In summary, the hypotheses to be tested are:

H_1: *Ceteris paribus*, the installation of a nuclear power facility in the area causes a permanent decrease in the level of agricultural land prices, that is, $a_5 < 0$.

H_2 *Ceteris paribus*, the installation of a nuclear power facility introduces a new negative trend in land prices, that is, $a_6 < 0$.

H_3: *Ceteris paribus*, the inverse statistical relation of land prices to nuclear facilities reported in studies is only an apparent one and is due to the energy firms' preference for choosing cheap, undeveloped land for installations, that is, *Pre*, *Pre2* < 0.

H_4: *Ceteris paribus*, the installation effect of a nuclear facility is countered over time by the introduction of a new positive time trend so that $a_6 > 0$.

4. RESULTS OF THE BASIC MODEL

Table 2 reports the initial estimates of Equation (1) in panel with fixed period effects applying the Box-Cox transformation and the loglinear form; the third version includes 494 fixed effects representing the BTA groups. Of the fixed-effects (FE), and random-effects (RE) versions, the former was almost always favored based on the Hausmann test, and only the fixed-effects versions are presented. Please note three main features of these data. First, the nuclear

TABLE 2: Basic Model Estimated on Panel Data in Box-Cox, and Loglinear Forms, The Dependent Variable is the Land Price in Logs

	Fixed Period Effects	Fixed Period Effects	Fixed Period and Group Effects
Variable	Box-Cox Model	Loglinear Model	Loglinear Model
landtotal, a_1	–0.540 (–63.2)	–0.560 (–73.9)	–0.477 (–29.8)
valueproduct, a_2	0.297 (65.7)	0.517 (79.3)	0.297 (22.8)
distance, a_3	–0.032 (–4.2)	–0.029 (–7.4)	—*
port, a_4	0.678 (15.1)	0.146 (9.6)	—*
nuclear, a_5	–0.31 (–2.7)	–0.061 (–1.6)	–0.524 (–2.0)
nuktime, a_6	0.014 (1.9)	0.0007 (0.3)	0.221 (1.3)
popdensity, a_7	0.312 (30.3)	0.152 (25.5)	0.163 (10.7)
Adjusted R^2	0.926	0.938	0.976
F-Value for Model	3142.6	4820.8	435.4
Probability for Model	0.000	0.000	0.0000

Notes: Data include 11 observation periods and 494 BTA Groups spanning the era from 1945 to 1992. *t*-values in parentheses. *the *distance* and *port* variables do not change within the BTA over the 11 periods, thus their presence along with group effects for the 494 BTAs would create perfect colinearity in the fixed-group and period-effects model. After creating indicators for group- and period-effects, observations with invalid or missing data were rejected from the original sample of 5,434 resulting in a final sample of 5,361.

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externality is supported consistently by negative coefficients for the *nuclear* dummy, which are each significant given the appropriate one-tail test of confidence at the 95 percent level.

Second, the added hypothesis that the installations will slow the rate of land-price growth is contradicted in this version of the model. However, the alternative hypothesis—that installation stimulates land-price growth does not attain significance in the appropriate two-tail test, though it is consistently positive. The models perform well overall, are easily significant, and they explain a large portion of the variation in land-prices. The other variables take the predicted and plausible signs without exception.

The BTAs are often irregular in shape and smaller in diameter than the 60-mile diameter of the "nuclear acceptance areas" reported by some studies. The BTAs average about 40 miles in diameter, posing the possibility that nonnuclear BTAs may be near enough to nuclear areas for the public to perceive an increased risk.

To investigate this issue we coded the nonnuclear BTAs for each of the 11 observation years as to their distance from the nearest operating reactor, provided that it was within 60 miles of the BTA's central city, and reanalyzed the data. Table 3 shows the reproduced results of the loglinear version of the basic model and compares this with variations treating the nearby BTAs as also affected areas; the second column separates nonnuclear and nearby-nuclear areas and the third column combines them.

TABLE 3: Nearby BTA Effects, and Effects on Combined Nuclear and Nearby BTAs

Variable	*landprice*, Dependent Variable	*landprice*, Dependent Variable	*landprice*, Dependent Variable
landtotal, a_1	–0.560 (–73.9)	–0.563 (–74.0)	–0.563 (–74.2)
valueproduct, a_2	0.517 (79.3)	0.518 (79.4)	0.518 (79.4)
distance, a_3	–0.029 (–7.4)	–0.029 (7.5)	–0.029 (–7.4)
port, a_4	0.146 (9.6)	0.143 (9.4)	0.143 (9.5)
nuclear, a_5	–0.061 (–1.6)	–0.069 (–1.9)	NA
nuktime, a_6	0.0007 (0.3)	0.0006 (0.3)	NA
popdensity, a_7	0.152 (25.5)	0.154 (25.7)	0.153 (25.8)
nearnuclear	NA	–0.047 (–3.6)	NA
nukcombined	NA	NA	–0.036 (–2.6)
timenukcombined	NA	NA	–0.0024 (–1.8)
Adjusted R^2	0.938	0.938	0.939
F-Value for Model	4820.8	4564.1	4836.1
Probability for Model	0.000	0.0000	0.0000

Note: Total observations are 5,361 after rejection of 73 observations with invalid or missing data.

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The nuclear external effect hypothesis embedded with the hypothesis of a 60 miles acceptance distance is strongly supported. All signs remain correct and the *t*-values on nuclear dummies improve sharply. The post-installation time trend changes sign and its *t*-statistic becomes larger in absolute value.

5. LAND PRICES IN FUTURE NUCLEAR AREAS—THE "GHOST REACTORS"

As mentioned, a plausible alternative hypothesis to the nuclear externality states that energy companies seek out cheap land. The panel data offer a convenient test because they contain land values for each nuclear site dating many years before the installation. We created false dummy variables to indicate preliminary land prices, hence "ghost reactors."

The dummy variable *Pre* equals one for a nuclear BTA in years prior to installation, zero otherwise. To test for announcement effects we also split *Pre* into component parts: *Pre1* equals one for all years from and including the year the construction permit was issued, zero otherwise; and *Pre2* equals one in the years prior to the construction permit issuance. A negative coefficient for *Pre* indicates support for the *cheap-land* hypothesis, though it may or may not be contaminated by a negative announcement effect. A negative coefficient for *Pre1* would indicate an external effect via the announcement of the installation; and by removing this we are able to test for a relatively pure cheap-land effect, which would be indicated by a negative coefficient for *Pre2*. Further, if these ghost reactors eliminate the previously measured effect of installation, then we would conclude that the previously measured nuclear externality had been spurious.

In Table 4, the *Pre* variables usually do not attain the usual significance level, but more importantly the *Pre2* estimates are both negative with large absolute values of the *t*-statistics. Notably, the variables added to the basic equation seem plausible on theoretical grounds, and they improve the performance of the hypothesis tests. Rather than declaring the external effects to be spurious, the nuclear effect becomes statistically stronger. By comparing nuclear and nonnuclear BTAs and incorporating the "ghost reactor" effect, the negative nuclear effect is revealed more strongly as both a lump sum decline in land values as well as a continuing, significant negative time trend.

6. NUCLEAR EXTERNALITIES AND VINTAGE OF REACTOR

At first consideration, a significant and negative post-installation trend in land prices suggests that the older installations generate the greatest accumulated effect. However, large changes in time are accompanied by larger changes in technology, information, and public knowledge. We call these possibly omitted factors *vintage effects*. By separating reactors by vintage, we hope to get vintage-dependent information not captured by the panel results.

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TABLE 4: Land Prices in Areas with Future Reactors, the "Ghost Reactors" Test, Loglinear Form

Variable	*landprice*, Dependent Variable	*landprice*, Dependent Variable	*landprice*, Dependent Variable	*landprice*, Dependent Variable
landtotal, a_1	–0.561 (–74.1)	–0.560 (–73.9)	–0.564 (–74.4)	–0.563 (74.2)
valueproduct, a_2	0.517 (79.1)	0.518 (79.4)	0.518 (79.2)	0.520 (79.6)
distance, a_3	–0.029 (–7.5)	–0.030 (–7.6)	–0.029 (–7.5)	–0.030 (–7.7)
port, a_4	0.144 (9.6)	0.147 (9.7)	0.141 (9.4)	0.146 (9.6)
nuclear, a_5	–0.088 (–2.4)	–0.100 (–2.5)	NA	NA
nuctime, a_6	–0.0006 (–0.2)	–0.0007 (–0.2)	NA	NA
popdensity, a_7	0.152 (25.4)	0.153 (25.6)	0.153 (25.6)	0.156 (25.9)
nukcombined	NA	NA	–0.035 (–2.6)	–0.040 (–2.9)
timenukcombined	NA	NA	–0.004 (–2.8)	–0.004 (–2.4)
Pre	0.021 (1.2)	NA	0.014 (0.8)	NA
*Pre*1	NA	0.021 (0.7)	NA	–0.017 (–0.8)
*Pre*2	NA	–0.026 (–1.3)	NA	–0.036 (–1.8)
Adjusted R^2	0.939	0.939	0.939	0.939
F-Value for Model	4565.9	4325.6	4575.9	4336.9
Probability for Model	0.0000	0.0000	0.0000	0.0000

Notes: *t*-values in parentheses. *Pre* is a dummy variable defined equal to one in all years prior to the reactor installation, zero otherwise, and zero for all nonnuclear areas. *Pre* is then separated into *Pre1*, which is coded one during the years beginning with the year of the Contract Permit. *Pre2* is set to one for the years prior to the contract permit for a nuclear BTA.

For this purpose, *oldnuclear* reactors are defined by installation prior to 1970; *midnuclear* reactors were installed from 1970 through 1979; and *newnuclear* reactors were installed after 1979. Previous research by Folland and Hough (1991) reported differential effects by vintage; older reactors showed a somewhat greater negative effect than the newer, presumably safer, reactors. That paper applied a single cross section centered at 1978–1980. The data for our 1978 cross section are consistent with that earlier study. However, the present panel reveals little difference between *oldnuclear* and *midnuclear* vintages as a general rule; and, the newer installations generally show positive effects (see Table 5).

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TABLE 5: Vintage Effects of Nuclear Power Facilities, Loglinear Form

Models: *nuclear* includes near BTAs	*Oldnuclear*	*Midnuclear*	*Newnuclear*	*Nuclear*
Panel, Period Effects, *Pre*	–0.108 (–3.9) [231]	–0.118 (–6.2) [557]	0.066 (2.4) [262]	–0.037 (–2.7) [1050]
Panel, Period Effects, *Pre*1, *Pre*2	–0.070 (–2.7) [231]	–0.085 (–4.8) [557]	0.121 (4.9) [262]	–0.039 (–2.8) [1050]
1959, Cross-section	–0.111 (–1.4) [16]	—	—	NA
1964, Cross-section	–0.110 (–1.3) [16]	—	—	NA
1969, Cross-section	–0.094 (–1.4) [22]	—	—	NA
1974, Cross-section	–0.115 (–2.1) [26]	–0.105 (–2.8) [69]	—	–0.066 (–2.2) [95]
1978, Cross-section	–0.177 (–2.6) [26]	–0.088 (–2.1) [81]	—	–0.087 (–2.4) [107]
1982, Cross-section	–0.152 (–2.3) [26]	–0.065 (–1.6) [81]	0.104 (1.5) [23]	–0.084 (–2.4) [130]
1987, Cross-section	–0.037 (–0.6) [26]	–0.053 (–1.4) [80]	0.068 (1.3) [36]	–0.012 (–0.4) [142]
1992, Cross-section	–0.011 (–0.2) [26]	–0.064 (–1.5) [80]	0.048 (0.8) [38]	–0.017 (–0.5) [144]

Notes: *t*-values in parentheses; number of unique occurrences of a year and a BTA at or near a nuclear power facility are in brackets. *Oldnuclear*, *midnuclear*, and *newnuclear* are dummy variables defining a reactor's presence for reactors of vintage pre-1970, 1970–1978, and post-1978, respectively. *Nuclear* defines the presence of a reactor regardless of vintage. Thus, regressions for *nuclear* are done separately and are omitted (NA = not applicable) for years during which only the "old" vintage reactors were present.

7. DISCUSSION AND CONCLUSIONS

The preponderance of significant, negative estimated effects across all varieties of models strongly suggests a negative nuclear externality and one that appears throughout the major portion of the nuclear era. Part of the observed negative effect on land prices is only apparent, most likely contributed by the actions of energy companies and governments who seek out cheap land for installations. Nevertheless, removing spurious effects leaves a significant negative installation effect.

A one-time adjustment in land asset values consistent with the theoretical account describes profit maximizers adjusting to the introduction of the perceived nuclear risk, much like equity markets adjusting to negative news regarding the future profit streams of a corporation. In the best-performing models we examined, those incorporating both preliminary land-price controls and nearby nuclear areas, the installation also alters the trend of land prices downward. Land prices continue downward after installation in the best-

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performing and most complete models. Finally, the positive effects of recent vintage reactors are significant in the panel models. This result is consistent with several alternative hypotheses, including the idea that the public is more informed about reactor safety as well as the idea that the newer, modern reactors are safer and more safely managed.

Though these data do not resolve each of the questions raised, they reinforce the proposition that the discrepant findings in the literature derive less from error than from the alternative study designs. Comparisons across areas, which reported significant negative effects of nuclear power plant installation, are compatible with studies of variations within areas, which show little or no effect on housing prices due to the distance from the plant. If our conjecture is correct, a meta study reexamining the distance-gradient studies should show different asset-price levels when compared to matched nonnuclear areas.

Further, research that seeks to confirm these and related results may investigate population movements throughout the nuclear era. Although the absence of such movements is not sufficient to prove the absence of a public response to perceived risk, the finding of such movements is a strong confirmation of the externality hypothesis and will help to distinguish between the amenities models of nuclear effects versus the assets-depreciation model. Case studies of nuclear areas may be helpful, also. Selected assets may afford a richer sample for study if they are especially vulnerable to fears of radioactive contamination, for example: food processing; bottling of beer, water, and soft drinks; fisheries; or industries sensitive to elevated water temperatures.

Our data support the proposition that a public perception of nuclear risk causes a change in land prices, and that the reduction continues after installation and is associated largely with the middle and older vintage reactors. The data show an installation effect centering around 10 percent of land value. Inasmuch as the amount of land affected by a given installation may be large, (the effect is significant when applying a 60-mile radius) the loss in value could exceed tens of millions of dollars, an important additional consideration for installation or removal decision making. In the present climate of public opinion, the public logic more plausibly runs toward removal, and the perceived risk of harm from handling or storing nuclear waste may not be easily reversed. In any case, these findings add to the knowledge needed in cost/benefit determinations on the replacement of a perceived risky plant with a perceived safer one. All of these issues concern information as understood by the public, and they are pertinent to assessing the value of improved public information.

Finally, the results add to the importance of welfare economic theory regarding harmful external costs in cases where information is imperfect. Should a misperceived threat of an externality warrant compensation? Is it sufficient to show that the individual consumer has become fully informed and is acting voluntarily? Is it a sufficient defense for an energy company to show that the consumer's perceived fear is unscientific? Nevertheless, negative external effects exceeding 10 percent of asset value are real one-time costs to

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some members of society relevant not only nuclear installation but also to decommissioning (Eyre, 1997; Ballard, Everett and Everett, 1991; Hall, 1990). The economic approach to efficiency requires the recognition of these external costs as well as their internalization into the calculus of nuclear energy decisions.

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APPENDIX

Derivations in Detail for The Predicted Effects:

Define the tenants profit as

$$\Pi = p_G Q - C(Q; r, p_L) - \gamma(D, p_D) Q \tag{A1}$$

where p_G is the price of the farm produce, for example, grain, which is assumed by the tenant to be fixed; Q is the quantity of farm product; costs C which are a

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function of quantity produced are also affected by parametric input prices r and p_L, the rental price of capital and the rental price of farmland (this latter being determined within the system). Transportation cost γ represents the cost of shipping one unit of farm product to the major trading center, and this unit cost depends on the distance D to that center and the per-mile price charged by farm produce carriers p_D. The change in profits that occurs when the parameters change is derived by taking the total differential of (A1)

$$\text{(A2)} \quad \begin{aligned} d\Pi = dp_G Q + \left(p_G - C_Q - \gamma\right)\left(Q_r dr + Q_{p_L} dp_L + Q_D dD + Q_{p_D} dp_D + dQ\right) \\ - C_r dr - C_{p_L} dp_L - \left(\gamma_D dD + \gamma_{p_D} p_D\right)Q \end{aligned}$$

The tenant's profit-maximization goal requires that output be chosen so that the marginal cost equals the marginal revenue, that is

$$\text{(A3)} \quad \frac{\partial \Pi}{\partial Q} = p_G - C_Q - \gamma = 0$$

Letting $dr > 0$ and $dp_G = dD = dp_D = 0$ and substituting (A3) into (A2) yields the change in profits once the land rental price is allowed to adjust

$$\text{(A4)} \quad d\Pi = -C_r dr - C_{p_L} dp_L = 0$$

or

$$\frac{d\Pi}{dr} = -C_r - C_{p_L} \frac{dp_L}{dr} = 0$$

Equality with zero in Equation (A4) obtains when the initial situation is one of long-run equilibrium so that the tenant is just covering his opportunity costs of applying his resources elsewhere, and given free mobility of his capital and labor. Under these conditions the tenant's actions ensure that equality of profits is maintained across the wider region even after one area is affected by an input price rise. The extra cost is inevitably born by the owners of the fixed factor, land. Solving from Equation (A4) implies that $\frac{dp_L}{dr} = -C_r / C_{p_L} < 0$. The equilibrium land-title price consequently falls inasmuch as land price in the model is a monotonic function of rental price, hence, $\frac{d\bar{P}}{dr} < 0$.

Alternatively, letting $dp_G > 0$, and setting $dr = dD = dp_D = 0$, then

$$d\Pi = dp_G Q - C_{p_L} dp_L = 0$$

or

$$\frac{d\Pi}{dp_G} = Q - C_{p_L} \frac{dp_L}{dp_G} = 0$$

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Again, beginning from a long-run equilibrium and assuming free mobility, competitive pressure for higher potential local profits causes changes in land rents, $\frac{dp_L}{dp_G} = Q/C_{p_L} > 0$ though in this case the fixed factor reaps the rewards and local land title prices rise $\frac{d\overline{P}}{dp_G} > 0$.

Next, let $dD > 0$ and $dp_G = dr = dp_D = 0$. Then, substituting as before

$$d\Pi = -C_{p_L} dp_L - \gamma_D dDQ = 0$$

or

$$\frac{d\Pi}{dD} = -C_{p_L} \frac{dp_L}{dD} - \gamma_D Q = 0$$

Mobility of the tenant farmer and his capital will ensure equality of profits for a given investment across the plain. Farms distant from the major trading center have lower prices for rental and title ownership, that is, $\frac{dp_L}{dD} = -\gamma_D Q/C_{p_L} < 0$, and $\frac{d\overline{P}}{dD} < 0$.

Finally, let $dp_D > 0$ and $dr = dp_G = dD = 0$. Then

$$d\Pi = -C_{p_L} dp_L - \gamma_{p_D} Q = 0$$

or

$$\frac{d\Pi}{dp_D} = -C_{p_L} \frac{dp_L}{dp_D} - \gamma_{p_D} Q = 0$$

This reveals a negative effect of transport mileage prices, and indirectly of the nonavailability of convenient transport routes, hubs and ports; that is, $\frac{dp_L}{dp_D} = -\gamma_{p_D} Q/C_{p_L} < 0$. Thus land in remote areas will tend to be cheaper, $\frac{d\overline{P}}{dp_D} < 0$.

Recall from Equation (3) in the text that the landlord's reservation price for land ownership is function of the product of his maximum discounted profits should the event occur at year k and the probability that the facility will function normally until it has a major accident in exactly year k summed over all possible values of k. We have

$$P_{Dt} = \int_{k=0}^{H} \hat{R}_{t,k} f(t+k) dk$$

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where H is the potential buyer's finite time horizon, $\hat{R}$ represents the present value earned by the landowner when he buys the land in year t and its value is destroyed at year $t + k$, and f is the probability density function for the event that the nuclear plant survives to exactly year $t + k$. Now P_D becomes the potential landowner's reservation price for land. To see the effect of a nuclear installation, note that prior to installation the value of f is zero until year H, at which time it becomes unity. Note that $\hat{R}$ is monotonically increasing in k, and that P_D is a weighted average of increasing values of R where the nonnegative weights add up to unity. It follows that no average over R can be greater than the case when all the weight is put on the highest valued R, which is R_H. Thus, the profit-maximization model as developed here implies that installation unambiguously lowers the land values. Hence, $\partial \overline{P} / \partial N < 0$, where N is an indicator of the nuclear risk.

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NUCLEAR POWER PLANTS AND RESIDENTIAL PROPERTY VALUES: A COMMENT ON SHORT-RUN vs. LONG-RUN CONSIDERATIONS

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In their important and controversial analysis published in 1982 in this journal, Gamble and Downing (G-D hereafter) presented statistical evidence for sales values of single-family properties in the vicinity of four nuclear power plants in the Northeast during 1975–1977, and in the vicinity of the Three Mile Island (TMI) nuclear plant during 1977–1979. Based on their analysis, they concluded that there was no significant impact on property values due to proximity to a nuclear power plant, even after the March, 1979, accident at TMI. One may quibble with this study on statistical grounds,[1] but this is not the purpose here. Rather, it will be argued that the G-D research overlooks potentially significant short-run impacts because it implicitly employs a long-run perspective.

A theoretical analysis of urban housing markets employing bid-rent theory [Alonso (1964), Stull (1974)] suggests that the introduction of a land use which imposes negative externalities on (some) proximate residents will produce distinct short- and long-run impacts, depending on: (1) the extent of the externality; (2) the nature and distribution of household preferences; and (3) the degree of household mobility. The analysis, using nuclear power plants as an illustration, follows.

For the introduction of a plant into a community to have an adverse impact on property values in the short run, one must assume that there exists a nontrivial number of households within the zone of the plant-generated externality who would be averse to such. The well-being of these "nonindifferent" households would be reduced, with a concomitant reduction in their bids (or willingness-to-pay) for their current residential sites. Households who were indifferent to any potential negative externalities generated by the plant would have no alteration of their bids, regardless of their proximity to the plant.

The above alteration of bids by nonindifferent households near the plant would upset the equilibrium price gradient in the community. Assuming some intraurban mobility, nonindifferent households would tend to bid up the price of housing outside the zone of externalities until inside-zone and outside-zone price differentials for homes occupied by this group would exactly compensate them for their externality cost.

But this price differential is likely to be reduced over time as further dynamic

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[1]See Bjornstad and Vogt (1984).

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adjustments ensue. Again assuming some intraurban mobility, indifferent households would tend to outbid any nonindifferent ones who remained in the zone of externality, since the former would perceive these inexpensive locations as bargains. If interurban mobility is also assumed, the possibilities for replacing nonindifferent with indifferent households in the zone of externalities are enhanced further. And as such progresses over time, any inside/outside zonal price differential would be eroded.

As for the new long-run equilibrium, if and only if the number of dwellings within the zone of externalities is greater than the number of indifferent households who could occupy them (via moving both from within and from outside the given city), will proximity to the nuclear power plant be associated with lower property prices.

In light of the foregoing conceptual argument, what is likely in actuality? It is posited here that there are substantial numbers of both indifferent and nonindifferent households who are more or less randomly situated in a given area at the inception of a nuclear power plant. This means that there likely would be a short-run impact on property values, although this impact should wane over time and, perhaps, disappear entirely in the long run if indifferent households were not too scarce and/or were reasonably mobile.

How does this bear on the G-D research? The four Northeast plants investigated all began operation by the early 1970s [U.S. Nuclear Regulatory Commission (1984)], but property values were analyzed from 1975–1977. TMI began operation in 1971, but property values were analyzed from 1977–1979. Thus, it is conceivable that many of the dynamic adjustments stemming from possibly sizeable price differentials occurring at the time of start-up had already eroded these differentials by the period of investigation.

An even more convincing argument in this regard can be made if one drops the plant's start-up date as the initiator of the short-run adjustments.[2] A more reasonable position is that households begin adjusting when they first hear a public announcement of the location of a forthcoming nuclear power plant. Some may, e.g., decide to move out "*before* it gets dangerous"or "while I can still get something for my house." Given that all of the plants analyzed by G-D were announced in 1967 or earlier, it is entirely likely that the decade ensuing between such and property value investigations was sufficient to allow a market reequilibration which obviated any earlier price differentials associated with the plants. If this argument has validity, it would also serve to explain why neither G-D or Nelson (1981) observed any price adjustments following the TMI accident: the surrounding market had already equilibrated into a configuration of predominantly indifferent households.

Of course, the previous argument remains highly speculative, and offers only theoretical reasons why the (unobserved) short-run impact of nuclear power plants is likely greater than the (observed) long-run impact. However, evidence supplied by G-D themselves suggests that the argument has some basis in fact. They showed [Gamble and Downing (1982, Figure 2, p. 471)] that from 1966–1970 the annual

[2]This is clearly the focus of G-D; see Gamble and Downing (1982, p. 469).

mean sales values of homes within 5 miles of TMI rose slower than those of homes in the 5–25 mile range, which in turn rose slower than those in a comparable control area well beyond the influence of any announced or operational nuclear power plant. During the 1970s, growth rates in all three areas were virtually identical. This evidence is consistent with the hypothesis that the 1967 announcement of TMI's forthcoming construction had some substantial, if temporary, deleterious impacts on proximate property values, although its subsequent start-up in 1974 did not.

In conclusion, this comment has argued that existing research can only be interpreted as having demonstrated that nuclear power plants do not have any significant long-run impacts on proximate property values. Theory suggests that the short-run impact may be considerably higher. Obviously, whether this is in fact the case must be left to future empirical investigations which collect data on property values soon after a plant location is announced. Just because a long-run impact is nil does not necessarily remove the issue from the agenda of public concern. Indeed, short-run adjustment costs borne by some located near nuclear power sites may be substantial.

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