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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 Humboldt 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: $\ln\mathrm{RPRICE}_k = f$ (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

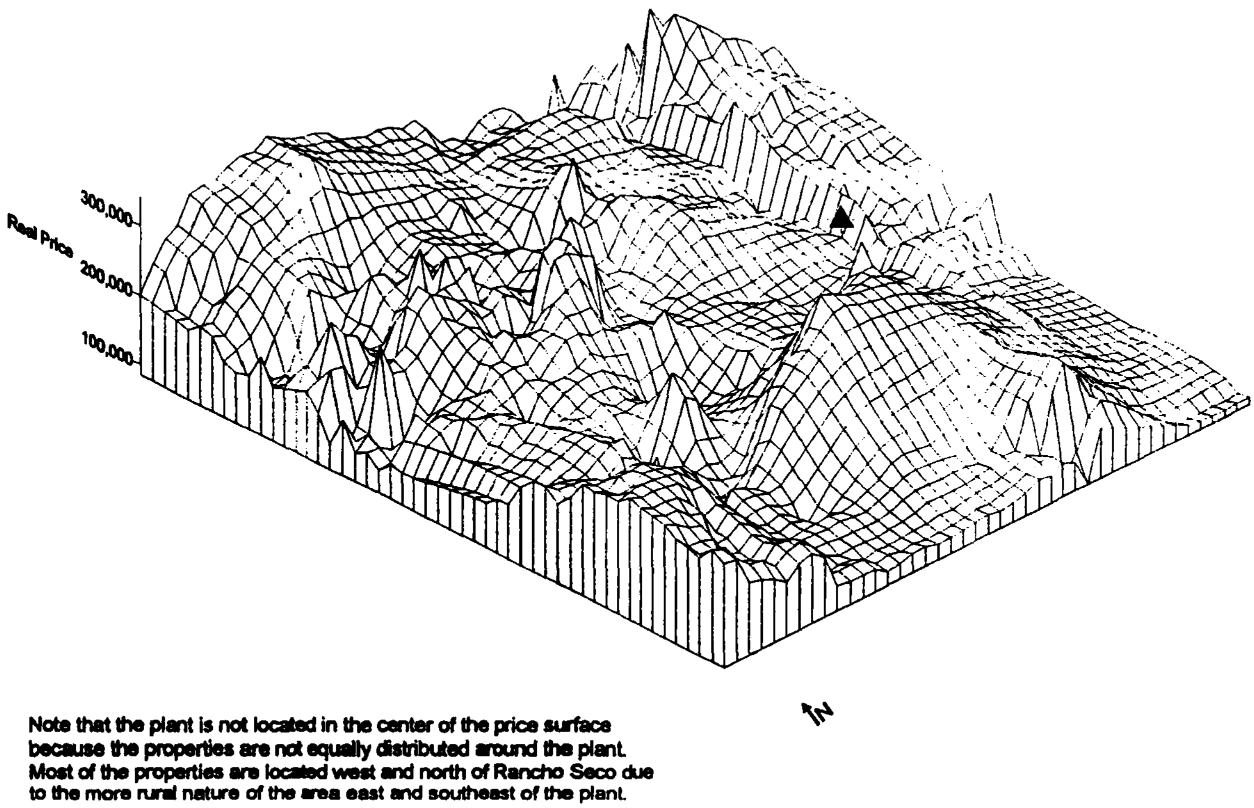

Fig. 1. Real estate price surface for all properties in sales sample (1990–1994) around Rancho Seco (15-mile radius).

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.

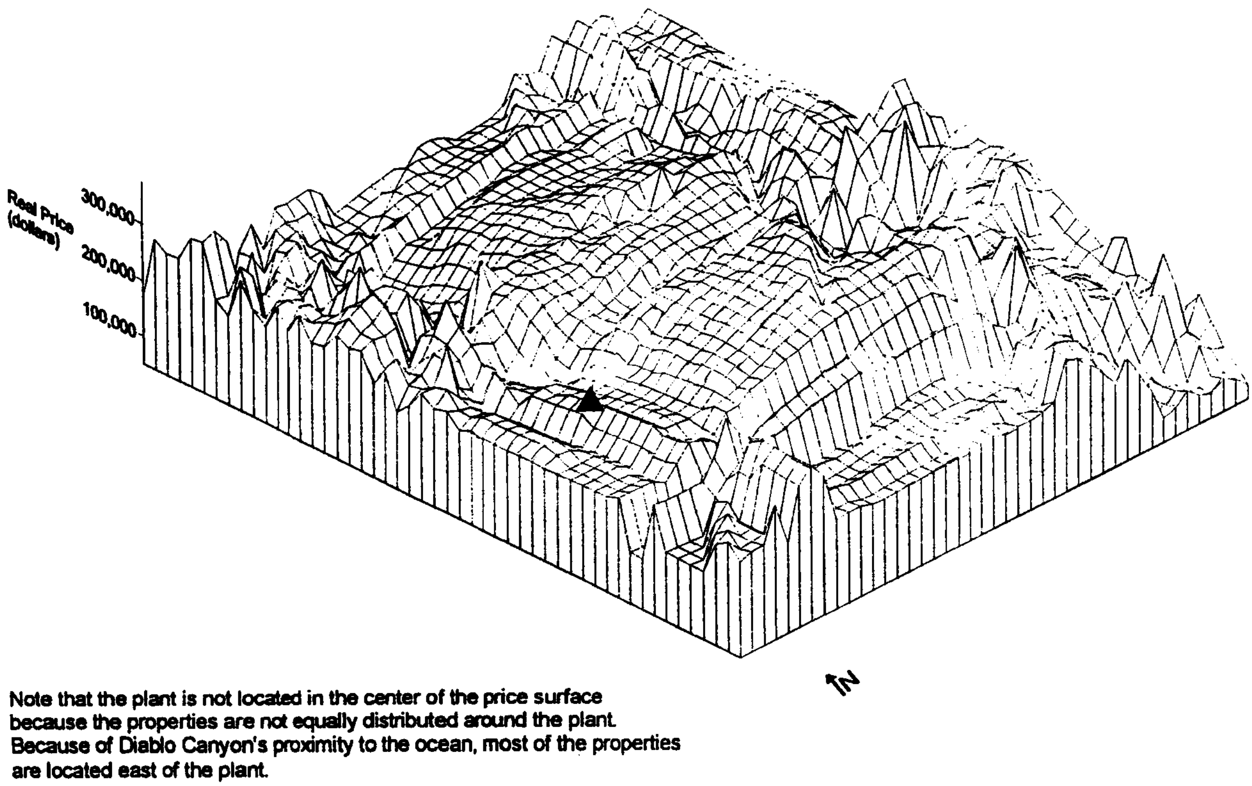

Fig. 2. Real estate price surface for all properties in sales sample (1990–1994) around Diablo Canyon plant (15-mile radius).

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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