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Nuclear Waste Transport and Residential Property Values: Estimating the Effects of Perceived Risks

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Spent nuclear fuel shipments have raised concerns that property values along the shipment route will be reduced due to the real or perceived risks from the shipments. While prior research has identified property value losses associated with proximity to certain environmental disamenities, findings on the effects of nuclear facilities is ambiguous and virtually no research has focused on the effects of transitory nuclear waste shipments. The initiation of radioactive waste shipments to New Mexico, and the prospect of shipments of high-level nuclear waste from across the U.S. to Nevada, make consideration of possible property value impacts of substantial concern for federal policymakers. This study employs data on 9432 real estate transactions in South Carolina to model the effects of a series of highly publicized shipments of spent nuclear fuel to a storage facility at the Department of Energy's Savannah River Site. Using a model that corrects for spatial autocorrelation, we obtain 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, we find that the shipments did not affect property values. In more populous urban areas, property values appear to have been lowered in a substantive manner. Limitations in the data leave uncertainties, however, which must be addressed in future research. © 2001 Academic Press

1. INTRODUCTION

Proposals to transport nuclear waste have generated concerns about potential harm to the health and economic well-being of those who live near the route. Particular worries are expressed about potential losses in residential property values, which often represent a substantial fraction of household investment. For example, in a recent debate on the floor of the U.S. Congress, Congressman Gibbons (Republican, NV) argued that the creation of a proposed temporary nuclear waste repository for spent nuclear fuel in Nevada would devalue the properties of those who lived in communities along the transport route to the repository. He added:

> "If H.R. 1270 passes, almost 80,000 tons of nuclear waste will be transported across the country, devaluing property along the way. And who will pay for this devaluation in private

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> property? Of course, the American taxpayer. They will foot the bill to support a radical and extremely costly policy mandated upon them by Congress."[1]

If the claims of large property value losses due to nuclear waste transport shipments are valid, the implications are of considerable importance. Shipments of radioactive materials criss-cross every state, numbering millions of radioactive "packages" per year [45, 46]. After decades of controversy, shipments of transuranic radioactive waste from nuclear weapons facilities to a deep geologic repository in southern New Mexico began in 1999, and low-level wastes continue to be transported to a number of regional disposal sites. Perhaps most notably, as indicated by Gibbons' argument, federal plans to transport spent fuel from domestic nuclear power plants to a centralized waste repository in Nevada will result in the shipment of thousands of tons of highly radioactive materials across the U.S. over many years. If public awareness of the transport of radioactive materials does indeed reduce property values along the route, the potential economic impact across the U.S. may be large and widespread.

This paper uses the case of a current and highly publicized spent nuclear fuel shipment program to test the claim that transport of radioactive materials will affect nearby residential property values. The program involves the return to the U.S. of spent fuel rods from foreign research reactors that had originally been leased to other nations as part of the Atoms for Peace program. Beginning in 1994, and following a protracted and highly visible political and legal dispute between the state of South Carolina and the federal government, shipments of spent fuel have been transported by ship and rail from foreign reactors to the U.S. Department of Energy's Savannah River facility in South Carolina. All of the shipments have passed through Charleston, SC, by rail en route to the Savannah River Site.

We begin with a review of the literature on the effects of potential environmental and health "disamenities" (including nuclear facilities) on residential property values, then turn to the specific case of the transport of foreign spent nuclear fuel. We assess the perceived risk of nuclear waste transport among members of the public and realtors in the area, and summarize local news media reporting on the issue. Next, using residential property value data from three counties along the rail route for the period 1993 through 1996, we test the hypothesis that property values have declined in response to the onset of a series of spent fuel shipments. Our analysis indicates that property values have reacted in different ways to the shipments in the three counties. No declines were evident in predominantly rural Berkeley and Aiken Counties, while an economically and statistically significant decline was evident in more populous Charleston County. Implications of these findings are discussed in the concluding section.

[1] H.R. 1270, the Interim Nuclear Waste Storage Bill, was amended to require compensation for land owners if the transport of the waste could be shown to have devalued their properties by at least 20%. Loss of value of 20% or more would require compensation, while losses of 50% or more would require the U.S. Department of Energy to purchase the affected property. (*Congressional Record*, September 30, 1997.)

2. PROPERTY VALUES AND DISAMENITIES

2.1. *Housing Prices and Disamenities*

The contention that property values will be affected by the presence of hazardous materials is not a new one. Studies of the effects of potential environmental and health hazards on residential properties—including incinerators, electricity transmission lines, landfills, and nuclear power plants—have tested for the effects of proximity to the hazard on localized values (Keil and McClain [26]; McClelland *et al*. [31]; Kohlhase [27]; Michaels and Smith [33]; Gamble *et al*. [15]). Because property values are influenced by the characteristics of the property and neighborhood, measuring the effects of environmental quality on property values has proved to be a rich area for the application of hedonic pricing models.

Some of the earliest efforts to link property values with disamenities concerned air quality (Harrison and Rubinfeld [19]), in which the marginal value of clean air was inferred from housing prices. More recently, using panel data on repeated sales in the New Bedford, MA, area, Mendelsohn *et al*. [32] found that proximity to polluted waters reduced property values in the New Bedford area, by $7000 to $10,000 (in 1989 prices), amounting to an aggregate damage estimate of around $36 million. From a sample of Boston area housing prices between 1975 and 1992, Kiel [25] found that distance to Superfund sites significantly impacted residential prices, with premiums of between $3000 and $6000 per mile. As these studies make clear, a wide range of kinds of environmental disamenities have been shown to reduce residential property values.

In a well-functioning market, even the probable future imposition of a disamenity should be reflected in downward pressure on current property values, and property values should rebound when it is clear that the disamenity will be removed. Put differently, if the disamenity is transitory, it should not have permanent effects on housing prices. In support of this proposition, Kohlhase [27] found that premiums on locating away from hazardous waste (Superfund) sites are greatly reduced once a cleanup is announced or started. From a sample of New Jersey homes, Ketkar [24] estimated that once hazardous waste sites were cleaned up, the median house value recovered by between $1300 and $2000 (in 1980 prices). Using nonparametric methods Stock [42] found that housing prices in 1978−1981 near 10 Boston area hazardous waste sites support Ketkar's results. Striking evidence for the responsiveness of housing prices over time to disamenities is presented in two studies, one by Carroll *et al*. [5], who studied the effect of an explosion of a chemical plant in Henderson, Nevada, and another by Dale *et al*. [9], who studied the effect of a lead smelter in Dallas county. Carroll *et al*. found that although residential prices neighboring the explosion declined, they became less sensitive to distance from the explosion site when the plant was relocated elsewhere. Dale *et al*. similarly found that closure of the smelter and a series of cleanup measures led property prices to rebound. Cumulatively, these studies demonstrate that housing markets respond to the introduction and elimination of disamenities, possibly due to changing risk perceptions about the environmental hazards. Once the hazards are not seen as being permanent, prices rebound.

Nevertheless, some studies have suggested that there are limits on housing market responsiveness to changes in disamenities. Kiel and McClain [26] used housing prices in Andover, MA, over a 19-year period to test for the effects of the location of an incinerator on nearby property values. Interestingly, Kiel and McClain found no change in prices in the "rumor stage" in which the prospective incinerator was initially disclosed in the local papers, the largest decrease in property values was during the "construction stage," and there was a slight recovery in prices in the "on-going operations stage." In another study, Kiel [25] found that property values of homes near Superfund sites in the Boston area did not fully rebound when EPA announced cleanup plans. In sum, as expected, residential housing prices appear to decline in response to disamenities and recover when disamenities are eliminated, but the response to information about the onset or elimination of the disamenity is not as rapid or complete as might be expected.

What might explain "sticky" housing prices in the face of information about impending onset or elimination of disamenities? A study of the effects of risk perceptions on the housing market near a California landfill provides a possible answer (McClelland *et al.* [31]). Expert and lay perceptions of the risks posed by the landfill differed greatly, with experts perceiving little risk and the public perceiving greater risk. Empirically, however, greater perceived risk by the residents was associated with lower housing prices, after controlling for property characteristics. While expert information may matter, it is the translation of such information into the public expectations associated with the disamenity that appears to affect housing prices.

2.2. *Housing Prices and Nuclear Materials*

A growing body of research (Slovic *et al.* [39]; Kunreuther and Easterling [28]; Jenkins-Smith [21]) has examined the extent to which nuclear images of a place shape preferences for vacationing or relocating there. It has demonstrated that (a) nuclear images are quite negative, and (b) nuclear images of a place (e.g., the state of Nevada) reduce the preference for vacationing there. This literature would suggest that properties near nuclear power plants, nuclear waste storage facilities, or nuclear materials transport routes would become "stigmatized" and therefore lose value.

Some of the earliest such claims, produced in the wake of the Three Mile Island (TMI) nuclear power plant accident, suggested that housing prices in the vicinity of TMI dropped after the accident (Commonwealth of Pennsylvania [7]). More systematic analyses have failed to find such effects. Nelson [35] analyzed housing prices in two nearby communities, and found no statistically significant effect of proximity to the plant on housing prices. Gamble and Downing [14] using a larger data set and longer time span than Gamble *et al.* [15], similarly found no decrease in housing prices (or rates of change in housing prices) due to proximity to the TMI plant. More broadly, studies of changes in property values in 64 municipalities in the northeastern U.S. found that communities hosting nuclear power plants grew faster than non-host communities, presumably due to the effect of the nuclear plants on local tax bases (Gamble *et al.* [15]). Thus, evidence of a link between proximity to nuclear power plants and property values is mixed, and generally does not support the contention that such plants stigmatize nearby properties.

The effects of nuclear waste *storage and transport* on nearby property values may be quite different from those of operating nuclear power plants, since nuclear power plants produce electricity, jobs and tax revenues, which may offset the effects of associated disamenities. Nuclear waste storage and disposal are likely to produce fewer jobs and tax revenues, and nuclear waste transport will produce no jobs or tax revenues in many affected communities. Studies of sites that are contaminated with nuclear wastes, such as the Frenald plant in Ohio (Feiertag [10]) and Rocky Flats in Colorado (Hunsperger [20]), suggest that the effects on property values are similar to those of Superfund sites.

We are aware of no systematic studies of the effects of nuclear waste transportation routes on residential property values, though a recent court case in New Mexico awarded compensation for lost property value when the City of Santa Fe used eminent domain to create a bypass to move radioactive materials around the city ([6], Whitmore [47]). That case, coupled with the concern over ongoing and prospective nuclear waste shipments (as voiced by Rep. Gibbons), makes this study relevant and important.

3. NUCLEAR WASTE TRANSPORTATION AND PROPERTY VALUES

In this study we focus on the possible effects of highly publicized shipments of spent nuclear fuel on residential property values in three counties in South Carolina; Aiken, Berkeley, and Charleston. The shipments are part of the foreign spent nuclear fuel (FSNF) return program, which involves the return to the U.S. of fuel rods used in nuclear reactors that were provided by the U.S. to foreign countries for medical research, training and the production of isotopes beginning in the 1950s. The fuel rods are made of highly enriched uranium (HEU) which, in addition to producing energy, can be used as material for nuclear warheads. In order to prevent the spread of nuclear weapons, and to avoid having nuclear materials fall into the hands of potential terrorists, the fuel rod lease agreements with foreign countries stipulated that the U.S. would reclaim the fuel rods once they were "spent."[2] Thus began the "urgent return" of foreign spent nuclear fuel to the federal government's Savannah River Site (SRS) in Aiken County, South Carolina.

Four shipments occurred over 1994–1996, the period we analyze. The first two shipments arrived at Sunny Point, a military port in North Carolina, in September 1994 and October 1995, and were shipped south by rail through Berkeley and Charleston Counties en route to the SRS. Subsequent shipments (September and December 1996) arrived at the naval port in Charleston, from which they were shipped by rail through Charleston and Aiken Counties to the SRS. Over the lifetime of the FSNF return program, the spent fuel shipments are expected to return to the U.S. through Charleston. They continue to this day.

The FSNF return program was the subject of strident and sustained objections by South Carolina officials. The shipments were preceded by local hearings, a court injunction to temporarily block the shipments, and outspoken objections to a program that would (in the words of Senator Strom Thurmond) make South

[2] Spent fuel consists of fuel rods that, through the normal fission process in reactors, have accumulated quantities of radioactive byproducts (such as cesium, strontium, and plutonium) that impede the efficient and controlled generation of heat in the reactor. Some of these byproducts are highly radioactive. Spent rods are removed from the reactor and temporarily stored in pools or other shielded containers near the reactor.

Carolina "the world's nuclear dumping ground." Once the shipments were imminent, the leading newspaper published a front-page story with a map detailing the route that the shipments would take. Systematic analysis of the print news reporting in the Charleston Post and Courier found that reporting on the FSNF program peaked in the months preceding the first shipment, then dropped off over the subsequent years. The stories carried a distinctly negative tone, suggesting that the FSNF shipments posed health and environmental risks and would harm the image of the state.

Survey research findings suggest that many citizens of South Carolina were convinced that the FSNF program would pose significant health, environmental, and economic risks for those living near the shipment route (Jenkins-Smith *et al.* [22]). Results of a random household telephone survey taken in September/October 1994 before any shipments had occurred, and again in March/April 1995 after two shipments had taken place, illustrate the views of residents of Aiken, Berkeley, and Charleston Counties, about the risks of the shipments.[3] Table I summarizes the main conclusions of the survey. Respondents from randomly selected households were asked to indicate:

- Perceived Likelihood of a Spent Fuel Train Accident (0 = not likely, 10 = certain)
- Perceived Likelihood of Rupture of Spent Fuel Train Containers (0 = not likely, 10 = certain)
- Perceived Harm to Those Living Near Spent Fuel Accident Site (1 = yes, 2 = no)

Perceptions of the risks posed by the spent fuel shipments were substantial, though that perception varied by County. Aiken County respondents perceived less risk on all three measures than did respondents from either of the other counties (the difference of means was statistically significant, at the 10% level, in all three questions). Berkeley and Charleston respondents did not differ significantly. Thus it appears that respondents in Aiken County perceive the FSNF shipments to pose less of a threat, perhaps due to the cumulative experience of residents with the Savannah River facility. If perceived risks do influence property values then one would expect a smaller property loss in Aiken County than in Charleston and Berkeley Counties. The changes in perceived risks and harms after the first shipment were not statistically significant. The only noteworthy change is the 10% decline in Aiken County respondents who believed that a transport accident would harm local residents. Otherwise, the mean perceived likelihood of an accident or container break tended to fall near the mid-point of the 0 to 10 scale, and sizeable majorities expected an accident to bring harm to local residents.

If the FSNF return program has had an effect on property values, one would expect that real estate agents would be the first to know. Whether it is in their best interest to tell the truth is an issue that deserves inquiry, but we take their response at face value. In a 1997 telephone survey of 173 realtors in Aiken, Berkeley, and Charleston Counties, respondents were asked a series of questions about trends in residential property values and causes of those trends. When asked

[3] The survey was conducted in September and October of 1994 by the University of New Mexico's Survey Research Center, and had a response rate of 57%. Overall, 1202 interviews were conducted in North and South Carolina.

TABLE I

Survey Results

Perceived Likelihood of a Spent Fuel Train Accident

(0 = "Accident will not happen" and 10 = "accident is certain to happen")

County		Sept/Oct 1994	May/July 1995	Difference	*P*-value of Diff
Charleston	Mean	4.68	4.77	0.10	0.645
	Std. error	0.17	0.13		
	Sample size	292	328		
Berkeley	Mean	4.72	5.16	0.45	0.111
	Std. error	0.21	0.19		
	Sample size	158	165		
Aiken	Mean	4.00	4.32	0.32	0.3108
	Std. error	0.24	0.21		
	Sample size	140	144		

Question wording: "The foreign spent nuclear fuel program will use trains to carry the material to the Savannah River Site. How likely do you think it is that one or more of these trains will have an accident? Using the scale where zero means an accident will not happen and 10 means an accident is certain to happen, where do you place your views regarding the Jpossibility that a train accident will occur while transporting the material?"

Perceived Likelihood of Rupture of Spent Fuel Train Containers

(0 = "Containers will not break open" and 10 = "Containers are certain to break open")

County		Sept/Oct 1994	May/July 1995	Difference	*P*-value of Diff
Charleston	Mean	5.07	4.66	−0.41	0.076
	Std. error	0.18	0.15		
	Sample size	284	317		
Berkeley	Mean	4.97	5.04	0.07	0.830
	Std. error	0.24	0.021		
	Sample size	157	162		
Aiken	Mean	4.00	3.65	−0.35	0.303
	Std. error	0.24	0.23		
	Sample size	138	143		

Question wording: "If there were an accident involving the trains that would carry the material to the Savannah River Site, how likely do you think it is that the nuclear fuel containers would break open and allow radiation to escape? Using the scale where zero means the containers will not break open and "10" means the containers are certain to break open, where do you place your views regarding the possibility that the containers will open and allow radiation to escape?"

Perceived Harm to Those Living Near Spent Fuel Accident Site

(0 = "No" and 1 = "Yes")

County		Sept/Oct 1994	May/July 1995	Difference	*P*-value of Diff
Charleston	Percent "Yes"	84%	80%	−0.04	0.182
	Std. error	0.03	0.02		
	Sample size	269	269		
Berkeley	Percent "Yes"	83%	87%	0.04	0.329
	Std. error	0.03	0.03		
	Sample size	151	151		
Aiken	Percent "Yes"	77%	67%	−0.10	0.063
	Std. error	0.04	0.04		
	Sample size	124	130		

Question wording: "Do you think a transportation accident would bring harm to the people who live near the location of the accident?"

in an open-ended format to explain the trends in property values (with follow-up probes by the interviewers), none of the realtors mentioned the FSNF shipments. In subsequent questions the realtors were asked if they had heard about the FSNF shipments (82% said yes). They were then asked: "Have the shipments of foreign spent nuclear fuel influenced the outcome of any real estate transactions that you have worked on?" Ninety-four percent said "no." Thus realtors generally did not support the argument that the FSNF shipments affected property values.

Overall, the literature on property values and survey data give mixed signals. The existing research generally supports the argument that disamenities affect residential property values. Survey data indicate that radioactive waste in general, and spent fuel in particular, are seen as quite risky by the public, and—at least in the survey context—most people believe that such shipments would lower property values of nearby residences (Flynn *et al.* [12]). On the other hand, our survey of realtors in South Carolina did not indicate that the FSNF shipments had affected property values. Given these mixed signals, empirical evidence of actual value changes due to nearby transport of radioactive materials would have a direct bearing on both public policy and legal decisions.

4. DATA

Our sample includes the population of residential properties that were sold at least once during the period 1991–1996 in the three South Carolina counties of Aiken, Berkeley, and Charleston. Data on sale price and date of sale were obtained from REIS, a firm that specializes in the collection and reporting on property values and transactions in South Carolina. Figure 1 shows the routes taken by the first four spent fuel transportation shipments. The first two shipments (in September 1994 and October 1995) were offloaded at the Naval port in Sunny Point, near Wilmington in North Carolina. The spent fuel rods were loaded on rail cars and shipped through Lumberton, then south to Charleston and west to the Savannah River Site. Subsequent shipments (September and December 1996) reached port at the U.S. Navy facility in Charleston, and were taken by rail directly to the SRS. Thus only the first two shipments passed through Berkeley County, while all four passed through Charleston and Aiken Counties. The shipments were expected to continue several decades.

Of the 9432 observations in our sample, 471 are from Aiken County, 1834 from Berkeley County, and 7228 from Charleston County. Aiken, Berkeley, and Charleston Counties differ markedly in their demographic and economic characteristics. Aiken is primarily rural (40% of residents were identified as rural in the 1990 Census) but contains the SRS where the waste is temporarily stored, and is one of the major employers in the county. Berkeley is a rural county (35% of residents were identified as rural). Charleston County, where the port of Charleston is located, is a populous urban county (12% identified as rural). Consequently, the sample is largely drawn from Charleston County and the city of Charleston. The sample means (standard deviations) for housing prices in the three counties in thousands of dollars are, respectively, 89.57 (34.4), 78.69 (30.5), and 67.27 (42.5). The full sample mean is 71.87 (40.59).

In order to remove underlying inflationary pressures on real estate prices that affect all properties generally, we constructed real estate deflators separately for

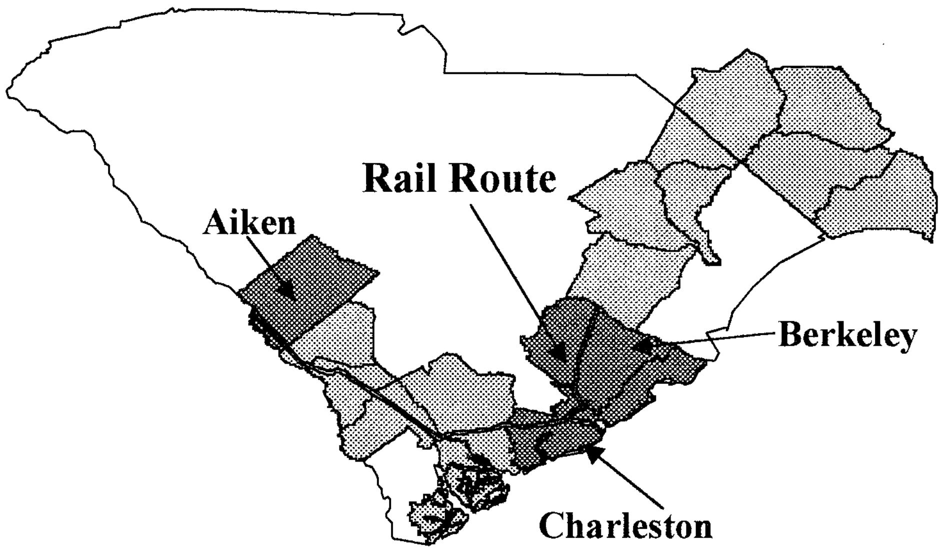

FIG. 1. Route of the foreign spent nuclear fuel shipments.

each county, with base year 1990. Taxable value of properties, taken from issues of the South Carolina Annual Report, permits deflators to be constructed at the county level since taxable values reflect the general county-level rise in real estate prices reasonably well. We checked the integrity of the deflators with a 1996 survey of the percentage change in home values between the fourth quarters of 1994 and 1995 from State Policy Reports (1996). The South Carolina value of 5% agreed with a weighted average of our figures for Aiken, Berkeley, and Charleston Counties (respectively, 20, 7, and 2%).[4] Only homes with sale prices above $25000 were considered for his study. Further, housing prices that were "unrepresentative," in the sense described below, were dropped leading to a sample of 9432 sales.

Data on housing characteristics include built-up square foot area (SQFOOT) and age defined as the year of sale of the house minus the year it was built (AGE). The distance of each house in the sample from the fuel shipment route (DISTANCE) is calculated as the nearest distance from the center of the property to the route using coordinates obtained from the Geographical Information System

[4] The following raw and imputed data were used to compute the deflators.

Total taxable property value, $ Mn. (South Carolina Annual Reports, 1991–1996)

County	1990	1991	1992	1993	1994	1995	1996
Aiken	137	146	153	161	151	180	189
Berkeley	126	105	116	127	129	138	145
Charleston	449	458	568	678	667	681	715

The 1992 figures are the average of the 1991 and 1993 values, since 1992 data were not available. The 1996 data, which were unavailable, are imputed at 5% over the 1995 values.

(GIS) based on the residence address. Data on neighborhood characteristics are at the census block level, obtained from the 1990 U.S. Census. They include percentage of the population in the census block who are White (PCWHITE), percentage Black (PCBLACK), percentage with high school degree (PCHS), percentage with college degree (PCCOLL), and median household income in the census block (MHHINC).

5. METHODOLOGY

We consider a hedonic house price model with individual structural characteristics (S), neighborhood characteristics (N), and distance from FSNF rail route (DISTANCE):

$$P_i = \alpha + S_i \beta + N_i \gamma + \delta \,\text{DISTANCE}_i + \varepsilon_i, \qquad i = 1, \ldots, n, \tag{1}$$

where P_i is the transaction price for house i, and S_i and N_i are, respectively, vectors of measures of its structural and neighborhood characteristics. Each element of β: $k \times 1$ measures the marginal valuation of the corresponding structural characteristic in S, each element of γ: $g \times 1$ measures the marginal effect of the corresponding neighborhood characteristic, and δ is the marginal effect of distance from the transportation route on the valuation of house i.

In the literature the error vector ε: $n \times 1$ is assumed to be independently, usually normally, distributed. There are compelling reasons to believe that samples of residential sales prices from a locality will not be independent, but spatially correlated. In fact this is probably as central a feature of our data as are the hedonic characterisitics. We believe spatial correlation afflicts other studies as well, but has remained an underexamined issue. This is unfortunate, since the market prices similar properties similarly, especially if they are in the same neighborhood. Not accounting for spatial correlation has the same effects as not accounting for serial correlation in time series data. It leads to inefficient, and probably inconsistent, estimates of the model parameters.[5] This is quite untenable, given the public policy and legal implications of this study. A contribution of this paper to the literature is to demonstrate the relevance of spatial correlation, and its correction via a straightforward technique.

We begin by examining Moran's I, an exploratory spatial diagnostic, for our data of $n = 9432$ homes. It is computed as follows. Denote the price data by the $n \times 1$ vector y. Let W denote the $n \times n$ spatial weights matrix such that Wy is a vector of "spatially lagged" values of y. If the rows of W are standardized to sum to 1, then the ith element of the vector Wy is a weighted average of those elements of y for which the ith row of W is nonzero, with these nonzero elements as the weights. The exploratory analysis is based on an especially simple system of weights: for any sale price y_i, all sales in a neighborhood of within 0.025 degrees (approximately an

[5] A reason for the spatial correlations is that realtors use comparable values or "comps" to set the asking price and guide the buyer's bidding price. These "comps" are based on neighboring values, causing prices at which residences sell to be intimately related to prices of neighboring residential sales. While markets, not realtors, set prices, realtors facilitate market clearing by providing information which would be expensive for buyers and sellers to acquire. "Comps" constitute important elements of the information set.

TABLE II
Testing for Spatial Autocorrelation

Normal approximation	
Moran's I	z-value
0.390	56.3

arc distance of 25 miles) are coded as 1 in the ith row of W. The remaining elements of W are coded as zero. W is then row-standardized by dividing each element in a row by the row sum. Hence, each row in W sums to 1. Then, Moran's I is computed as $I = (y - \mu)'W(y - \mu)/(y - \mu)'(y - \mu)$, where μ is the mean of y. Moran's I is thus the regression coefficient of $W(y - \mu)$ on $(y - \mu)$. A positive value of I indicates that similar values (either high or low) are more spatially clustered than would be expected due to pure chance. Table II presents Moran's I for the sample, computed using Spacestat 1.86 (Anselin [2]).[6]

The Moran I test indicates a strong spatial correlation in the data. The value of $I = 0.39$ is large in magnitude and highly statistically significant. Since the spatial weights matrix W is a key determinant of I, we searched over different constructions of W where small and large neighborhoods were chosen, as well as non-uniform weights (equal to inverse of distance from neighboring properties sold). All yielded large and statistically significant values of I. Further, since Moran's I is one of many diagnostic statistics, and valid under specific distributional assumptions, we also estimated Geary's C statistic, the Kelejian–Robinson statistic, and the Gettis–Ord statistic (see, e.g., Anselin [2]). They all indicated significant spatial correlation in the data.

In order to correct for spatial autocorrelation, maximum likelihood methods are preferred in settings with small samples. But since they require inverting or calculating eigenvalues of $n \times n$ matrices with large data sets it is practical to use instrumental variables methods. We use the spatial autoregression model (Anselin [1]) given by $y = \rho Wy + Xb + u$, where b is the vector of coefficients to be estimated and W is an appropriately defined spatial contiguity matrix. ρ is the spatial autoregressive coefficient on the spatially lagged dependent variable Wy. In this model the assumption of independence of the error term u is tenable.

Can and Megbolugbe's [4] method of constructing Wy is simple and attractive for our purpose. In their method, the $\{i, j\}$th element of W, w_{ij}, is defined to be inversely proportional to distance d_{ij} between house i and house j, and normalized to sum to 1. Then the spatially lagged vector Wy, denoted NPRICE, is given as:

$$\text{NPRICE}_i = \sum_{j=1}^{n} w_{ij} P_j = \sum_{j=1}^{n} \left[\frac{\frac{1}{d_{ij}}}{\sum_{j=1}^{n} \frac{1}{d_{ij}}} \right] P_j, \tag{2}$$

where P_j's are housing prices in the neighborhood of house i. An appropriate W should be constructed so that only chronologically previous y values appear on the right-hand side in Wy, otherwise an endogeneity problem occurs. The P_j's are taken

[6] We used the sparse matrix option in Spacestat since W is a large matrix.

from within a year prior to the sale price date of P_i, but not from the month immediately preceding the sale. In order to limit the number of previously sold houses j to be within close proximity to the house i, NPRICE is defined to includes the closest three houses sold, that is, $n = 3$. Hence, the variable is named NPRICE3. In the data section above we indicated dropping "unrepresentative" observations. PRICE_i is considered unrepresentative if the difference $|\text{NPRICE}_i - \text{PRICE}_i|$ is greater than \$100,000. That is, the price is an aberration because of data entry error, or it is simply unrepresentative of neighboring houses.

Our spatial hedonic regression model is thus:

$$P_i = \alpha + \rho\,\text{NPRICE3}_i + S_i\beta + N_i\gamma + \delta\,\text{DISTANCE}_i + \varepsilon_i, \qquad i = 1,\ldots,n. \quad (3)$$

The primary focus of analytical interest is on DISTANCE and its interactions with timings of FSNF shipments. If perceptions of risk from the transportation of spent fuel indeed lead to lower property values, we hypothesize that such effects will dissipate with distance from the source of the risk.

6. EMPIRICAL ANALYSIS

6.1. *Model Selection from Baseline Models*

The primary purpose of the baseline models discussed in this section is to select the best models for use in the later investigation of the effects of the FSNF program on housing values. In this preliminary set of models we therefore abstract from the timing of the shipments. Importantly, the baseline models provide checks for model adequacy in terms of (a) whether the coefficients on the control variables make intuitive sense, (b) whether spatial correlation remains an issue, and (c) whether the models fit the data well.

Table III describes and provides descriptive statistics for the variables used in the empirical analysis. The baseline models include the property characteristics (SQFOOT, AGE), neighborhood characteristics (PCWHITE, PCBLACK, PCHS, PCCOLL, MHHINC), county dummies (DA, DB), time dummies (D92–D96), and a constant term. The time dummies capture any trend remaining in housing sales after deflating to 1990 prices. Admittedly, the hedonics are not comprehensive. Other studies have focused on property characteristics such as quality of school districts, distance to amenities such as parks and recreation areas, traffic, noise, and area disamenities such as air pollution. We do not have access to data on property characteristics other than SQFOOT and AGE. On the other hand, NPRICE3 also serves as a good proxy for the hedonic variables. Area amenities and disamenities that do not vary with distance from those amenities, such as school district, are captured in sale prices of neighboring houses, and hence the presence of NPRICE3 controls for those effects. Further, the characteristics are not the main issue of interest here per se, as in other hedonic pricing studies. Their main role, a crucial one nonetheless, is as control variables.

In the baseline models reported in Table IV, distance from the shipment route is interacted by the county dummies (the interacted variables are DISTA, DISTB,

TABLE IIIA
Variable Definitions

Name	Definition	Units	Mean	Std. dev.
DISTANCE	Distance of residence from spent fuel shipment route	Miles	4.851	5.23
DA	Dummy variable for Aiken County	NA	0.050	0.22
DB	Dummy variable for Berkeley County	NA	0.192	0.39
DC	Dummy variable for Charleston County	NA	0.758	0.43
DISTA	Distance from spent fuel shipment route in Aiken County: DISTANCE × DA	Miles	0.998	4.40
DISTB	Distance from spent fuel shipment route in Berekely County: DISTANCE × DB	Miles	0.768	1.957
DISTC	Distance from spent fuel shipment route in Charleston County: DISTANCE × DC	Miles	3.085	4.069
PRICE	Sale price of residential property	$1000s	70.58	40.59
NPRICE3	Average of sale price of the three nearest residences sold in the most recent year prior to the month of sale (see (3))	$1000s	66.71	40.71
SQFOOT	Square footage of residence	Sq. feet	1621	627
AGE	Age of residence	Years	20.5	15.7
PCWHITE	Percentage of population in Census Block who are White (from U.S. 1990 Census)	% pop	74.15	19.87
PCBLACK	Percentage of population in Census Block who are Black (from U.S. 1990 Census)	% pop	23.14	19.93
PCHS	Percentage of population in Census Block who are high school graduates (from U.S. 1990 Census)	% pop	41.80	6.481
PCCOLL	Percentage of population in Census Block with college degrees (from U.S. 1990 Census)	% pop	17.72	10.84
MHHINC	Median household income in Census Block (from U.S. 1990 Census)	$1000s	33.03	8.182
D92–96	Dummy variables for the years 1992 through 1996	—	—	—

Note. Data are from 1991–1996, unless otherwise noted.

TABLE IIIB
Sample Means for Shipment Date Dummies

Name	Definition	Dates1	Dates2	Dates3
DT0	Preshipment effect dummy	0.518	0.326	0.325
DT1	First shipment effect dummy	0.243	0.242	0.288
DT2	Second shipment effect dummy	0.189	0.221	0.184
DT3	Third shipment effect dummy	0.050	0.211	0.173

Note. See Tables V and VI. Dates1–Dates3 are defined in Section 6.

DISTC).[7] A Davidson–MacKinnon nonnested test (e.g., Greene [18]) showed the interacted variables to be preferable to DISTANCE alone. Consider, first, estimates from the linear models in the first three columns of Table IV, specifically the values of the Akaike information criterion (AIC) and the Schwarz information criterion (SIC) at the bottom of the table. Since Model 3 nests Model 2, which nests Model 1, these are appropriate model comparison criteria (Judge *et al.* [23], pp. 870–873). They are computed as $\text{AIC} = -2(\ln L - k)/n$, and $\text{SIC} = -[\ln L/n - 0.5k(\ln n/n)]$, where n is the sample size, k is the number of regressors, and $\ln L$ is the log of the maximum likelihood. Hence, lower values of AIC and SIC are preferred. While the AIC penalizes for additional regressors somewhat more than the adjusted R^2 criterion does, the SIC penalizes additional regressors even more severely. Of the three linear models in Table IV both criteria favor the largest model, Model 3, which includes property and neighborhood characteristics.

Freeman [13] indicates that the linear functional form is probably inappropriate for hedonic pricing models. Cropper *et al.* [8] have explored the important issue of what should be the appropriate functional form of hedonic pricing models, specifically in the presence of specification error caused by poorly measured hedonic variables. Since a linear Box–Cox model performs well in their simulations in the presence of specification error, and also provides accurate marginal price estimates under perfect measurement, they suggest it as their functional form of choice. It has been generally argued that the Box–Cox transformation can make the dependent variables approximately normal, justifying the normality of errors. It can also correct for unspecified heteroskedasticity, as we will see it do here by essentially log-transforming the dependent variable.

The second set of models (Models 4–6) in Table IV are the Box–Cox-transformed versions of the linear models. The Box–Cox models reported here are of the form: $y(\lambda) = \beta' x(\lambda) + \alpha' z + \varepsilon$, where the transformation $q(\lambda) = (q^{\lambda} - 1)/\lambda$. Of note is the fact that in the limit as $\lambda \to 0$, $q(\lambda) = \ln(q)$. We transform the dependent variable, residential property sales price, as well as the right-hand-side variables NPRICE3, since they are measured in the same units. All other variables are untransformed, because their transformation makes little theoretical sense. Among the Box–Cox transformed variables, again the AIC and SIC values are lowest for the full model that includes property and neighborhood characteristics. In the examination of whether the FSNF shipments had deleterious effects on property values, we therefore use extensions of the full model.

A closer examination of the chosen baseline models (Models 3 and 6) brings out several other favorable features. First, the adjusted R^2 on (linear) Model 3 demonstrates an adequate absolute fit.[8] Second, the coefficients on property characteristics (SQFOOT, AGE) are significant in magnitude and they are highly statistically significant. The neighborhood characteristics are collectively significant, as a likelihood ratio test between Models 2 and 3 (resp. Models 5 and 6) demonstrate for the linear (resp. Box–Cox) model. The coefficients make economic

[7] Michaels and Smith [33] argue for valuing disamenities differentially across housing submarkets. They find different effects of distance from a hazardous waste site on housing prices across premier, average, and below average locales. Our distinction is between urban (Charleston) versus rural (Aiken, Berkeley) properties.

[8] Adjusted R^2 is not appropriate for the Box–Cox models. Log-likelihoods are reported.

TABLE IV

Baseline Models of Residential Property Values
(Dependent Variable: Deflated Residential Selling Price ($1000s))

	Linear models			Box–Cox models		
Indep. Var.	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	−0.288	−11.12**	−57.05**	2.674**	1.754**	0.850**
	(1.809)	(1.360)	(10.30)	(0.064)	(0.041)	(0.136)
DISTA	−0.108	0.368	0.251	0.002	0.006	0.007
	(0.444)	(0.333)	(0.333)	(0.0003)	(0.005)	(0.004)
DISTB	−0.817**	0.275	0.284	−0.0004	0.006*	0.005
	(0.251)	(0.188)	(0.193)	(0.0016)	(0.003)	(0.003)
DISTC	3.168**	0.646**	0.739**	0.020**	0.016**	0.014**
	(0.084)	(0.069)	(0.077)	(0.0014)	(0.001)	(0.001)
NPRICE3	—	0.635**	0.624**	—	0.473**	0.425**
		(0.007)	(0.008)		(0.007)	(0.008)
SQFOOT	0.042**	0.026**	0.026**	0.0027**	0.0004**	0.0003**
	(< 0.001)	(< 0.001)	(< 0.001)	(< 0.0001)	(< 0.0001)	(< 0.0001)
AGE	−0.020	−0.021	−0.058**	−0.0009**	−0.0007**	−0.001**
	(0.022)	(0.017)	(0.017)	(0.0002)	(0.0002)	(0.0002)
PCWHITE	—	—	0.544**	—	—	0.011**
			(0.102)			(0.001)
PCBLACK	—	—	0.537**	—	—	0.011**
			(0.102)			(0.001)
PCHS	—	—	−0.023	—	—	−0.0001
			(0.058)			(0.0007)
PCCOLL	—	—	0.159**	—	—	0.005**
			(0.043)			(0.0006)
MHHINC	—	—	−0.244**	—	—	−0.002**
($1000s)			(0.047)			(0.0006)
DA	−10.04	−22.28**	−19.13**	0.084	−0.272**	−0.262**
	(9.035)	(6.763)	(6.790)	(0.059)	(0.100)	(0.089)
DB	28.95**	8.077**	11.25**	0.209**	0.193**	0.257**
	(1.472)	(1.128)	(1.222)	(0.017)	(0.020)	(0.021)
D92	−2.841	−0.725	−0.624	−0.008	−0.0003	0.0008
	(1.662)	(1.244)	(1.240)	(0.011)	(0.018)	(0.016)
D93	−13.635**	−5.971**	−6.078**	−0.086**	−0.099**	−0.096**
	(1.536)	(1.153)	(1.150)	(0.011)	(0.018)	(0.016)
D94	−13.102**	−4.937**	−5.057**	−0.084**	−0.088**	−0.086**
	(1.510)	(1.134)	(1.130)	(0.011)	(0.017)	(0.015)
D95	−12.03**	−5.544**	−5.663**	−0.075**	−0.091**	−0.087**
	(1.557)	(1.168)	(1.165)	(0.011)	(0.018)	(0.016)
D96	−10.89**	−6.049**	−6.165**	−0.074**	−0.099**	−0.097**
	(1.575)	(1.180)	(1.177)	(0.011)	(0.018)	(0.016)
N	9432	9432	9432	9432	9432	9432
K	13	14	19	13	14	19
Adj. R^2	0.512	0.727	0.729	—	—	—
ln L	−44926	−42191	−42157	−2632	−2294	−1103
AIC	9.529	8.949	8.943	8.862	8.459	8.437
SIC	4.769	4.480	4.479	4.436	4.235	4.226
λ	—	—	—	−0.140**	0.035*	0.007
				(0.016)	(0.015)	(0.015)

Notes. Standard errors are in parentheses. Akaike info. criterion: AIC $= -2(\ln L - k)/n$; Schwarz info. criterion: SIC $= -[\ln L/n - 0.5k(\ln n/n)]$, where n is the sample size, k is number of regressors, and ln L is the log of the maximum likelihood. Box–Cox transformation of the form: $y(\lambda) = \beta' x(\lambda) + \alpha' z + \varepsilon$, where $q(\lambda) = (q^{\lambda} - 1)/\lambda$. Only NPRICE3 is transformed among the right-hand-side variables.

**Denotes statistical significance at 1%, * at 5%.

sense as well.[9] The county dummies and the time dummies are useful control variables, judging from their statistical significance. If any trend remained in the deflated housing prices, the time dummies should capture it. Their coefficients are neither high nor systematic, reinforcing our belief that the deflated housing prices are a reasonable measure to use in the models.

Third, importantly from a modeling perspective, the spatial correlation correction is effective. Not only is NPRICE3 highly statistically and economically significant, but a computation of Moran's I on the residuals from the Model 3 showed that the spatial correlation was reduced by a factor of nearly 10. However, it was not completely eliminated. Finally, the estimated value of λ from the preferred Box–Cox model (Model 6) was not statistically significantly different from zero, implying a log-linear model, with logged dependent variable and linear explanatory variables (other than NPRICE3 which is also logged). This is due, in large part, to the reduction in influence of the remaining outlying observations, after our careful effort to remove unrepresentative values.

6.2 *Models with Spent Nuclear Fuel Shipments*

We now estimate the effect of the Foreign Spent Nuclear Fuel Shipment program on housing prices from information about the timing of the shipments. Four shipments occurred over the period of our analysis, on 9/30/94, 10/20/95, 9/22/96, and on 12/15/96, for which four dummies {DT0–DT3} are defined as follows. DT0 takes the value 1 before any shipment occurred (pre-September 1994) and is 0 otherwise, DT1 takes the value 1 for the period *between* the first and second shipment (from September 1994 until before October 1995) and is 0 otherwise, DT2 takes the value 1 for the period *between* the second and third shipments (from October 1995 until before September 1996) and is 0 otherwise, and DT3 takes the value 1 for the remainder of the sample (from October 1995 until the end of 1996) and is 0 otherwise. Hence, the dummies sum to the constant term, that is, their means sum to 1.

The issues of focus are the coefficients on the interactions of DISTANCE with county dummies and the timing of shipment dummies. For the set of timing dummies above, there are 12 possible interactions denoted by DISTA0–DISTA3, DISTB0–DISTB3, and DISTC0–DISTC3. From their coefficients we can infer the effect of the FSNF shipments on residential prices, disaggregated by county. Our *first* working hypothesis is that homes distant from the FSNF shipment route

[9] The individual significances of the census block characteristics deserve further discussion, even though their main role is as control variables. The estimates indicate that while property values increase with the percentage of whites in the block, they also increase with the percentage of blacks in the block. This increase in housing prices in neighborhoods with greater proportion of blacks may reflect transactions by upwardly mobile blacks, which is not a surprising result. Other results on neighborhood characteristics indicate that housing prices increase with percentage of residents with high school and college degrees (PCHS, PCCOLL). Surprisingly, housing sales prices are seen to decline with median household income (MHHINC). One reason for the contradictory sign on MHHINC is that it is also highly correlated with PCWHITE (correlation $= 0.64$) and PCBLACK (correlation $= -0.62$). That may cause collinearity in the variables, making it difficult to interpret the individual coefficients even though there is information collectively about the three variables. If two variables A and B are highly collinear then the regression model $y = A + B$ will yield little or confusing information about the individual effects, but it will yield clear inference about $+$. Collinearity, however, does not diminish their primary collective role as control variables, which they perform well.

commanded a *greater* premium once the shipments commenced. That is, the coefficients on DISTA0, DISTB0, and DISTC0 are each lower than, respectively, the coefficients on DISTA1, DISTB1, and DISTC1. Our *second* working hypothesis is that in Aiken and Charleston Counties the premium did not decrease as the shipments proceeded, since over this time period there was no news about terminating the shipments. That is, the permanence of the shipments determines the permanence of the stigma from locating closer to the rail route. We therefore expect the coefficients on DISTA1 and DISTC1 to equal those on their counterparts in the last two periods. In contrast, only the first two shipments passed through Berkeley County. Therefore, effects in that county as reflected by DISTB1 should not be permanent.

While the first hypothesis has been tested in many studies involving other "disamenities," as cited earlier, many of these studies have concluded that the effects were transitory once there was learning about the low probability as well as small absolute damage from the disamenity. We have a case with large perceived levels of absolute (minimax) damage. The subjective probability assessments of damage indicated in Table I are large enough that expected utility models of housing prices would indicate a decline in housing prices in areas susceptible to such damage.

Of course, even if the shipments did have some effect it is not clear that property values would have reacted precisely on the date of commencement of the shipments as presumed in the construction of the set of date dummies above. They may have reacted when news about the impending shipments first became public, or when the public began to believe that the shipments would occur with near certainty. Hence, we report results based on different sets of date dummies to account for these various possibilities. In order to do so sensibly, we undertook a systematic analysis of the Charleston-area newspaper coverage for the period spanning the shipments, scanning for news about the FSNF shipments. Newspaper story summaries that may be influential are contained in the appendix table. Based on these, we created a second and third set of "shipment timing" dummies.

The first set of timing dummies, which we denote "Dates1," were based on the presumption that the exact dates of shipments constitute watershed points. A second possible set of watersheds is indicated by the series of reports beginning around November 1993 describing the possibility of Charleston as a candidate entry port. We therefore define the "pre-shipment-effect" dummy DT0 here to take the value 1 in the pre-1994 years, so that the effects of the shipments on property prices are presumed to begin in January 1994. The next three dummies are arbitrarily defined to take the value 1 for home sales during the years 1994 (DT1), 1995 (DT2), and 1996 (DT3). The dummies sum to the constant term. This set of timing dummies is denoted "Dates 2."

A third possible watershed is indicated by the February 1994 news report that a hearing had been set for October 1994, which meant that conditional on that hearing, the shipments were a virtual certainty. We define the "pre-shipment-effect" dummy DT0 in this case to take the value 1 before March 1994. The next three dummies are arbitrarily defined for the (disjoint) periods March 1994 through May 1995 (DT1), June 1995 through March 1996 (DT2), and the post-March 1996 period (DT3). This set of dummies is denoted "Dates3." The idea behind the arbitrariness in the last three dummies is to see whether inference about our second working hypothesis, namely permanent stigma effects, is robust to different dates at which expectations may have begun to change, thereby affecting home sale prices.

Table V presents estimates of the effects of the FSNF shipments from a set of linear models. According to SIC, the models with *no* timing interactions with DISTANCE for Aiken or Berkeley County home sales was preferred over the model with all 12 interactions (and also over the models with the eight interactions for Charleston and Berkeley Counties). These models are labeled "Model 1." According to AIC, however, the models with all 12 interactions were preferred over other (nested) permutations. These models are labeled "Model 2." Why would the SIC and AIC criteria favor different models? In general, the SIC criterion penalizes for additional regressors, if they do not commensurately add to the fit. All of the Aiken County, and some of the Berkeley County, interactions fail to reach statistical significance, and are therefore penalized by the SIC. The AIC criterion, on the other hand, does not penalize as much for the extra regressors.

Consider Model 1 (preferred by the SIC criterion) which brings focus on Charleston County residential prices. Even before any shipments occurred, the rail route was considered a disamenity in Charleston County. If we consider the set of timing dummies given by "Dates 1," then the coefficient of 0.500 on DISTC0 indicates that in the preshipment period, for every mile a property was located away from the rail route, its value increased (on average) by about \$500. This "disamenity" value *increased* after the shipments commenced. DISTC1 indicates that the disamenity value jumped to \$911 per mile, on average, after shipments commenced. Since this estimate is conditional on property and neighborhood characteristics, it is plausible that the deleterious effect on home sale prices resulted from the FSNF shipments. The estimates are both statistically and economically significant. The average difference of \$411 per mile translates into a value of 0.6% for an average Charleston County property. By this estimate, a home adjacent to the rail route would be valued 3% less than a similar home 5 miles from the rail route *after the onset of the FSNF shipments*. This is a sizable difference. Runs of this model with quadratic terms of the interactions did not find that the quadratic terms were statistically significant. That is, there was no evidence that the damaging effect of the shipments decreased as distance increased. Our Charleston County sample had a mean distance of 4.07 miles from the rail route with a standard deviation of 4.22 and a skewness coefficient of 1.7, indicating a fairly symmetric distribution. Based on our sample, one could infer that the linearity holds for approximately 12 miles, if we are willing to assume it to hold two standard deviations from the rail route. More reasonable estimates of the geographical distribution of the property value effects will require data extending farther from the rail route than were available in our sample.

Whether the detrimental effects of the FSNF shipments on housing prices decreased as shipments continued is investigated via a Wald test. While the Wald test rejects the hypotheses that the coefficients on DISTC1 and DISTC2 are equal to that on DISTC0, it fails to reject the hypothesis that the effects of DISTC3 (Table V, shaded cells) and DISTC0 are also equal. At first, this seems to imply that the effect of the FSNF shipments was transitory. However, the same models estimated with the two other sets of timing dummies (columns labeled "Dates2" and "Dates3") show that the effect of the shipments persists over time. The Wald tests reject the hypothesis that individually (and collectively) the effects of DISTC1, DISTC2, and DISTC3 are equal to the effect of DISTC0. For "Dates3," the Wald

TABLE V

Linear Models of the Effects of FSNF Shipments on Property Values
(Dependent Variable: Deflated Residential Selling Price ($1000s))

	Model 1			Model 2		
	Dates1	Dates2	Dates3	Dates1	Dates2	Dates3
DISTA	0.231	0.226	0.225	—	—	—
	(0.333)	(0.333)	(0.333)			
DISTA0	—	—	—	0.192	0.238	0.288
				(0.333)	(0.333)	(0.333)
DISTA1	—	—	—	−0.579	0.053	0.452
				(0.366)	(0.403)	(0.365)
DISTA2	—	—	—	0.018	−0.451	−0.024
				(0.406)	(0.364)	(0.381)
DISTA3	—	—	—	−0.066	−0.028	−0.227
				(0.577)	(0.413)	(0.418)
DISTB	0.289	0.289	0.283	—	—	—
	(0.193)	(0.193)	(0.192)			
DISTB0	—	—	—	0.471*	0.509*	0.436*
				(0.199)	(0.220)	(0.213)
DISTB1	—	—	—	−0.549	0.415	0.180
				(0.353)	(0.294)	(0.284)
DISTB2	—	—	—	−0.953*	−1.183**	−0.948
				(0.483)	(0.426)	(0.497)
DISTB3	—	—	—	0.799	−0.585	−0.192
				(0.859)	(0.464)	(0.495)
DISTC0	0.500**	0.379**	0.315**	0.566**	0.491**	0.377**
	(0.097)	(0.132)	(0.119)	(0.098)	(0.136)	(0.120)
DISTC1	0.911**	0.664**	0.824**	0.850**	0.735**	0.811**
	(0.114)	(0.116)	(0.104)	(0.115)	(0.119)	(0.104)
DISTC2	0.994**	0.930**	0.696**	0.959**	0.793**	0.648**
	(0.120)	(0.126)	(0.120)	(0.121)	(0.129)	(0.120)
DISTC3	0.748**	0.927**	1.148**	0.720**	0.898**	1.125**
	(0.193)	(0.123)	(0.127)	(0.194)	(0.125)	(0.128)
Controls	NPRICE3, SQFOOT, AGE, PCWHITE, PCBLACK, PCHS, PCCOLL, MHHINC, DA, DB, D92, D93, D94, D95, D96					
N		9432			9432	
K		22			28	
Adj. R^2	0.729	0.729	0.729	0.730	0.730	0.730
ln *L*	−42148	−42149	−42141	−42127	−42131	−42127
AIC	8.942	8.942	8.940	8.939	8.940	8.939
SIC	4.479	4.479	4.479	4.480	4.480	4.480

Notes. Standard errors are in parentheses. DISTxn = DISTANCE × Dx × DT_n, where Dx = dummy for county x, and DT_n, $n = 0, 1, 2, 3$, are four date dummies. There are three sets of date dummies (Dates1, Dates2, Dates3) per model, with each set containing four date dummies as explained in Section 6.2. Akaike info. criterion: AIC = $-2(\ln L - k)/n$; Schwarz info. criterion: SIC = $-[\ln L/n - 0.5k(\ln n/n)]$, where n is the sample size, k is number of regressors, and ln L is the log of the maximum likelihood. Shaded cells indicate no statistical difference from preshipment effect. Complete output, including estimates for control variables, is available from authors.

**Denotes statistical significance at 1%, * at 5%.

test even rejects the hypothesis that DISTC3 is equal to DISTC2 or DISTC1, indicating that the negative effect of proximity to the rail route increased over the period considered.

The last three columns of Table V report estimates from the model favored by AIC. There are three main features to these models. First, the results from the Charleston county sample are qualitatively and quantitatively similar to those from the more parsimonious model chosen by the SIC criterion. Inferences about whether the effects were permanent or transient are similar to the SIC-chosen models—two of the three models indicate permanent effects, while one does not (shaded). Hence, regardless of whether the AIC or SIC preferred model is chosen, we obtain the same inferences for the Charleston County sample.

Second, the Aiken county interactions are nowhere statistically significant, indicating that neither was proximity to the rail route considered a disamenity before the shipment, nor did the onset of the shipments make it so. The survey results reported in Table I suggest a reason for such a finding: Aiken County residents perceived the FSNF shipments to be less risky than did respondents from the other counties, perhaps due to greater familiarity with the management of nuclear materials.

Third, the Berkeley county sample yields somewhat confounding results. The shaded cells indicate estimates that are statistically *not* significantly different from the preshipment effect as measured by the coefficient on DISTB0. The estimates on DISTB2 indicates however, that over this period (different for different "dates," but all having in common the last quarter of 1996) proximity to the rail route was actually increasingly considered an amenity by the DISTB2 time period. These results are contrary to our working hypotheses, particularly in light of the relatively high perceived risks evident in Table I. What explains these findings? One explanation is that the transport of the spent fuel through Berkeley County was temporary, including only the first two shipments. While our analysis of the local news service did not provide data on when the change in the shipping routes became public knowledge, it is quite possible that early information on the change rapidly offset any increase in disamenity due to proximity to the (old) route. Our estimates show no effect on prices between the first and second shipments (i.e., DISTB1 is nonsignificant). *After* the second *and last* shipment, living near the transport route became an amenity (i.e., DISTB2 is negative and significant). A second explanation for the Berkeley findings is that the county is largely rural, wherein any (temporary) disamenity associated with the shipments would be potentially offset by the amenity associated with access to one of the major highways linking the county with Greater Charleston (U.S. Highway 52). If the value of living near the transport corridor changed over the period of our analysis, such changes would confound our hypothesis tests. Disentangling such effects will require a larger and richer dataset of Berkeley County housing sales than we had to work with. Regardless, our results clearly *do not* show the predicted decrease in the value of residential homes near the transport route coincident with the onset of the spent fuel shipments.

In sum, the results from Table V are suggestive of persistent deleterious effects on housing prices of the FSNF shipments in urban Charleston County, but not in the other two more rural counties. The findings for Charleston County are not unequivocal: two out of three models indicate permanence, while one indicates transience.

Cropper *et al.* [8] argue that the Box–Cox model is the preferred specification for hedonic pricing models. Whether the Box–Cox model yields results similar to the linear models, and whether the Box–Cox model is indeed the "correct" specification, are the questions investigated next. Table VI presents results about timing of shipments and their effects on housing sales prices from the Box–Cox models. The estimates from the Box–Cox models have been transformed into original units, so the slope coefficients reported are comparable in magnitude to the estimates from the linear models. The first three columns in Table VI are estimates from the model chosen according to the Schwarz information criterion (from among various permutations of county–shipment timing–distance interactions). The SIC-preferred models include no interactions of shipment timings with DISTA, but do include interactions with DISTB and DISTC. For Charleston County, the Box–Cox models indicate that housing prices near the route were adversely affected at the time of the onset of the spent fuel shipments, and that the adverse effects did not diminish over time. This finding is robust across the three date schemes, Dates1–Dates3. Note that with Dates2 housing prices did not respond immediately, though they did drop eventually. Recall that the dates for Dates2 correspond with the early announcement that Charleston was a candidate

TABLE VI
Slopes from Box–Cox Models of the Effects of FSNF Shipments
(Dependent Variable: Deflated Residential Selling Price ($1000s))

	Model 1			Model 2		
	Dates1	Dates2	Dates3	Dates1	Dates2	Dates3
DISTA	0.431	0.428	0.424	—	—	—
DISTA0	—	—	—	0.380	0.417	0.446
DISTA1	—	—	—	−0.220	0.300	−0.095
DISTA2	—	—	—	0.092	−0.157	0.099
DISTA3	—	—	—	−0.042	0.050	0.220
DISTB0	0.469**	0.489**	0.435*	0.499**	0.589**	0.504**
DISTB1	−0.410	0.474*	0.276	−0.574*	0.332	0.132
DISTB2	−0.915*	−1.005**	−0.959*	−1.076**	−1.254**	−1.136**
DISTB3	0.429**	−0.661	−0.318	0.287	−0.847*	−0.465
DISTC0	0.715**	0.680**	0.597**	0.746**	0.747**	0.64**
DISTC1	1.011**	0.763**	0.906**	0.973**	0.777**	0.891**
DISTC2	1.139**	1.075**	0.949**	1.124**	1.009**	0.920**
DISTC3	1.010**	1.106**	1.244**	1.000**	1.098**	1.235**
Controls	Intercept, NPRICE3, SQFOOT, AGE, PCWHITE, PCBLACK, PCHS, PCCOLL, MHHINC, DA, DB, D92, D93, D94, D95, D96					
N		9432			9432	
K		25			28	
λ	0.008	0.006	0.008	0.009	0.008	0.009
ln *L*	−39747	−39742	−39746	−39733	−39731	−39736
AIC	8.433	8.432	8.433	8.431	8.431	8.432
SIC	4.226	4.226	4.226	4.226	4.226	4.227

Notes. Slope coefficients are expressed in original (untransformed) units of the dependent variable. They are comparable in magnitude to the estimates in Table V. Ln *L* (and AIC and SIC) were computed in original (untransformed) units of dependent variable. See Notes to Table V.

**Denotes statistical significance at 1%, * at 5%.

port-of-entry for the FSNF. Apparently prices began to react more sharply with the actual shipments, which is consistent with the findings of Kiel and McClain [26] regarding the effects of construction of an incinerator on housing prices.

The set of Box–Cox models labeled “Model 1” therefore reinforce the suggestion that property values in Charleston County were adversely affected by proximity to the route coincident with the onset of the FSNF shipments. They reverse the one result from the linear models (with Dates1) that the effects of the FSNF shipment may have been temporary. Whether the Box–Cox models are preferable to their linear counterparts is addressed subsequently. The second set of Box–Cox models labeled “Model 2” are preferred by the AIC criterion. They also show that enduring adverse effects on property prices were evident from the period of the first spent fuel shipments onward. Hence, inferences about Charleston County properties are robust across the two sets of models, and across the three shipment–timing schemes. Inference about the effect of the FSNF shipments on Berkeley County properties is consistent across the two sets of models. In neither case did the results support the working hypothesis, as discussed above with respect to the linear models.

Since the linear model and the Box–Cox models yield different inferences (the Box–Cox models collectively are more unequivocal about the effect of shipments on Charleston County properties than are the linear models), we performed a nonnested comparison of the two models. Since the estimates of the Box–Cox parameter λ are near-zero and statistically insignificant, the Box–Cox models are essentially log-linear models. It is easy to test a linear versus a log-linear specification using a Davidson-MacKinnon procedure (see, e.g., Greene [18]). However, it is frequently the case that neither model, when considered as the alternative data generating process (alternative hypothesis), rejects the maintained model (null hypothesis). That is precisely the case here. Hence, the nonnested tests cannot guide the choice of whether the linear or the Box–Cox methods are to be preferred in this context. As we let the readers make their choices by reporting both the AIC- and SIC-chosen models, so we do for the linear and log-linear models. Proponents of the Cropper *et al.* [8] view will prefer to infer from the log-linear models.

In closing, we ask whether there may have been other events responsible for the change in the FSNF route distance premium. In order to have had such an effect, the events would need to (1) coincide with the onset of the shipments, (2) have an effect on property values that is a function of distance from the route, and (3) be sufficiently broadly publicized to systematically influence residential property transactions. We used the results of our survey of area realtors and content analysis of local news to search for candidate events that met these criteria. According to the realtor survey respondents, the median property value change was an increase of 4% over the period.[10] Among the list of explanations for these changes, *none* could directly be linked to either the FSNF rail route or the major transport arteries. Indeed, when asked directly about the FSNF shipments, only 6% said the shipments had any effect on property transactions (and a majority of these said they were uncertain of the direction of that effect). A systematic review of

[10] When asked what factors could explain the changes in property values, the realtors identified the following. The overall increase in the population in the area due to climate and other factors; the aftereffects of hurricane Hugo, growth in business in the area, a widespread desire to locate near the beach; an influx of retirees, the closure of the Navy Base in Charleston, and a host of other reasons.

reporting in the *Charleston Courier* over the 1993–1995 period involved a search for any news items related (even remotely) to property values. These included all articles related to the FSNF shipments (as described earlier in this paper), as well as any other topic that could be linked to property values, including regional variations in crime, controversies concerning property value assessments for tax purposes, reports on new home construction, highway construction, and many others. As with the explanations given by the realtors, *none* of the stories from the *Charleston Courier* met the criteria for identifying a plausible confounding explanation for the increase in the distance premium.

Our failure after systematic search to find alternative explanations for the change in property values does not, of course, mean that there *was* no other cause. Nevertheless, it does increase our confidence that the change in the distance premium in Charleston County was induced by the onset of the FSNF shipments. Extension, refinement, or reversal of this finding will require additional data, preferably consisting of a sample of property transactions covering a more extensive geographic region, additional years, and including a richer array of property attribute variables. Since shipments continue to this day, a new sample would provide pertinent new information. Other cases, such as the ongoing shipments of FSNF through Contra Costa County in California, provide further opportunities for testing hypotheses regarding the effects of highly publicized and controversial spent fuel shipments on residential property values.

7. CONCLUSION

Do shipments of transient and highly publicized hazardous materials like spent nuclear fuel reduce residential property values? We supply an answer based on foreign spent nuclear fuel shipments in South Carolina, using pre- and postshipment housing price data. Our first working hypothesis of an increase in the distance premium from the FSNF (spent nuclear fuel) rail route, once the shipments commenced, is suggested in the data in the most populous of the three counties studied. Importantly, our second working hypothesis that the distance premiums have persisted over time is also suggested in the data. That is, our model results for Charleston County are consistent with the proposition that the FSNF shipments stigmatized properties close to the route, and the ongoing nature of the shipments induced persistence in the stigma. An earlier survey of area residents showed that the public's subjective assessment of the probability of a container breaking open with health effects for the nearby population was neither minuscule nor did it change significantly over time. Hence, the decline in prices, and its permanence over the period considered, are consistent with a model of housing prices under uncertainty based on simple expected utility.[11] Even under nonexpected utility (see, e.g., Machina [30]), simple prospect-theoretic models can also generate the results that we obtain.

In populous and urban Charleston County, from which three-quarters of our sample is drawn, we find that the size of the distance premium is not trivial. After the shipments began, the net gain in value associated with being 5 miles away from the route relative to a property on the route was nearly 3% of the average home

[11] There is a duality here: If we do find evidence of persistent deleterious effects on housing prices, then we should also find that a newly conducted survey, say, in 2000, should reveal the same subjective beliefs as reported in Table I. If not, the results with newer housing price data would show evidence that the effects found here were transitory.

value. The suggestion of permanence of the distance premium is generally robust across a variety of linear and Box–Cox models, chosen from among a competing set according to formal information criteria.

However, these results are not equally applicable to the whole sample. For example, in more rural Berkeley County the inference about the effect of FSNF shipments is ambiguous. We believe the results reflect the fact that the shipments through Berkeley County ceased after the second shipment, and the possible confounding influence of a major transport artery along the rail route. The value of being near the route increased upon the termination of the second FSNF shipments, the last one to go through Berkeley County, after which proximity to the rail route was viewed with indifference.

If risk perception is responsible for market effects, we should expect smaller effects in Aiken County due to the long experience of its residents with nuclear materials management and the smaller perceived risks as indicated in Table I. Indeed our results show no correlation between the FSNF shipments and Aiken County property prices. The differences across counties in our findings should lead to caution when making generalizations about the effect of hazardous materials shipments. Indeed, Li and Brown [29] suggest that such effects may come about as a result of the netting out of negative and positive externalities due to proximity to the shipment route.

Our analysis of the data from Charleston County suggests that real price effects can occur when highly publicized and controversial shipments of radioactive waste materials take place. Despite a systematic and extensive search for alternative explanations, the onset of the shipments remains a plausible explanation for the estimated drop in housing values close to the route. Further, these results are consistent with research regarding the effects of other disamenities (e.g., polluted water and air and Superfund sites), with the self-reports of perceived risk of spent nuclear fuel shipments obtained in public opinion surveys, and with surveys of expected effects of nuclear waste shipments on housing values (Flynn *et al.* [12]).

This study has important implications for policymakers. If shipments of radioactive waste are shown to lower property values due to public perceptions of risk, it may not matter whether public perceptions of the risk are accurate. Legal precedent in "takings" disputes, based on a substantial number of cases across many legal jurisdictions, indicates that negative impacts on property values due to risk perceptions may be grounds for legal damages *even if the public perceptions of risk are not deemed "reasonable"* (Schutt [38]; Gibson [16]). Unlike cases of contamination from hazardous waste which were decided upon ex post, more recent cases are decided even before any deleterious event actually occurs. A directly relevant recent example is the case of *City of Santa Fe v. Komis* (Whitmore [47]; Thrower [44]) in which the prospect of public fears of radioactive waste shipments was found to be sufficient to warrant damages in a takings case.

At the same time, our findings do not speak directly to the question of whether shipments of hazardous nuclear materials are in the public interest. Clearly, issues of public health, nuclear security and energy policy are likely to remain the appropriate overriding considerations. Our results, if confirmed in further studies, indicate that there may be important distributional consequences of such shipments that should be considered in policy making. These potential consequences include suppressed property values when the shipments are highly publicized and controversial and the focus of claims is about extreme risk, as occurred in South Carolina.

APPENDIX: TABLE

Date	Title	Story Summary	Type of Story
10/22/93	"DOE Considers Charleston to Unload Spent Nuclear Fuel"	Front page article reports Charleston being considered as entry port. Lists a schedule of hearings. Local figures voice opposition against. Lists other areas being considered. Storage would be at SRS.	News report
11/4/93	"Hearing Set on Wando Nuclear Shipment"	DOE public hearing on shipment of spent fuel rods.	News report
11/6/93	"Fuel Rod Import Deal Is Rejected"	A Belgian research reactor won't transfer spent rods to SRS.	News report
11/22/93	"Slap in the Face"	Send jobs for displaced workers, not "nuclear garbage."	Letter to the editor
11/26/93	"Uranium Waste Plan a Hard Sell"	This story is front page above the fold and leads in "We don't want it . . ."	News report
11/29/93	"Let Spent Fuel Through"	Spent fuel shipments would provide work for all the navy and SRS technicians.	Letter to the editor
11/29/93	"Keep Spent Fuel Out"	Bad idea to transport through the heavily populated Wando terminal.	Letter to the editor
12/9/93	"Decision Postponed on Nuclear Waste Port"	DOE postpones decision on whether to ship waste through the Wando terminal. Pleasant, SC til mid-January.	News report
2/9/94	"Hearing Is Set on SRS Spent Fuel Proposal"	Article states that hearing is set for 2/10/94.	News report
5/5/94	"Terminal May Receive Nuclear Rods"	The first shipment of nuclear rods was not going to be sent to Charleston. However, Charleston was scheduled for later shipments.	News report
8/31/94	Radioactive Fuel Will Travel State	The program makes front page complete with a map of its route statewide.	News report
9/3/94	Two Nuclear Rod Ships on Way		News report
9/14/94	Nuclear Shipment Stopped	U.S. District Judge issued injunction forbidding ships from docking.	News report
9/14/94	South Carolina not the World's Nuclear Dump		Editorial
9/15/94	DOE Appeals Waste Decision	Ships are still 2,000 miles away.	News report
9/24/94	Court Clears Way for Nuclear Waste	SC Attorney General says he will take it to the Supreme Court.	News report
9/27/94	SC Still Battling Fuel Shipment		News report
9/27/94	Spent Fuel Lawsuit Will Have Important Repercussions	What DOE needs is a comprehensive long-run plan for disposal.	Editorial
9/28/94	State Pushes Case Against Nuclear Waste		News report
9/29/94	The Nuclear Waste Fight	SC is complaining about the Fed's plan since it will become a long-run facility.	Editorial
10/7/94	Fuel Rod Case Will Go Back to Court	Further litigation to prevent additional rods from coming into the state.	News report
10/21/94	Nuclear Waste Shipments Targeted	North Carolina activists will join South Carolina's fight.	News report
11/2/94	South Carolina Urges Case Against Nuclear Waste	Women and environmental groups fighting fuel rods' entry.	News report
11/20/94	Dumping Ground	When you ship spent fuel rods to SC, everybody is a winner except SC.	Letter to the editor
4/13/95	Charleston port on DOE list	The spent fuel rod program may go through Charleston.	News report
5/9/95	Few turn out to protest nuclear fuel rod shipments	A public hearing on the issue had minimal attendance.	News report
6/5/95	Some worry about high-level waste in state	Discussion of public concerns about the spent fuel rod program.	News report
6/13/95	Nuclear waste here and abroad	The paper says we should solve our own nuclear problem.	Editorial
6/24/95	Court clears way for nuclear waste	European fuel rod program injunction lifted.	News report

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Attachment N
Exhibit 4015-000027-CWF
Columbia Waterfront LLC