Externalities of Nuclear Power Plants: Further Evidence

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Abstract: Nelson (1981), Gamble and Downing (1982) and Clark et al. (1997) found no detrimental external effects of nuclear power plants when studying the distance gradient for housing prices within a hedonic model. Other papers, Clark and Nieves (1994) and Folland and Hough (1991), found significant negative effects of nuclear power when studying real asset prices in cross-sections of broad market areas. The present research verifies that an installation effect occurs after controlling for the tendency of facility builders to seek out cheap land. The study assembles a large panel of all commercial market areas in the contiguous United States observed 11 times over roughly equal intervals covering the span from 1945 to 1992.

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1. INTRODUCTION.

The harm done to farmers by nearby nuclear facilities in the United States, whose history rarely involves a serious accident of relevance to the farmer, must be the perception of risk, real or imagined. It is an understandable perception, because a nuclear leakage would cause him damage in two ways. As a businessman, he perceives the added risk as a depreciation of the expected present value of the profit stream from the land. As spouse and parent, he worries about health consequences, a disamenity of living downwind from the facility. He may not be fully aware of agencies that insure him, or as Tyran and Zweifel (1993) conclude, the available insurance may not fully cover the anticipated loss. In any case, a decline in land prices begins upon an announcement of the installation (Galster, 1986). Under one scenario, the expected present value of the land depreciates, the small probabilities of the land's diminishment acting much like physical depreciation factors. Under a second scenario, exit of human beings from the area operates to cause supply to exceed demand at pre-nuclear land prices.

It is without question that some people perceive a substantial risk. They may be rational or irrational in these perceptions; the issue of just compensation becomes muddied. Compensation is sometimes provided through the courts in cases where scientists are close to unanimous in denying the scientific validity of the claim. Our focus is the question of whether farmers and other landowners express their risk perceptions in observable ways, beyond the subjective responses to hypothetical survey questions. Selling farmland at a reduced price or leaving the area are responses that can be measured with reliable econometric tools.

Previous empirical research is mixed on this issue, two designs being prevalent. Nelson (1981), Gamble and Downing (1982), and Clark et al. (1997) assembled data from selected market areas that contained a nuclear facility. These researchers built a hedonic model of housing prices, which for each study area estimated the distance gradient (distance from the property to the nuclear facility). A positive gradient would support the externality hypothesis. The distance coefficients (or gradients) were generally insignificant and sometimes took the “incorrect” sign. A negative gradient may suggest the alternative hypothesis; nuclear facilities may raise asset values through association with economic growth and broadening of the tax base. Viewed only from the perspective of the distance gradient studies, the hypothesis of a negative nuclear externality would appear baseless.

There are two reasons, however, why the design of these three studies is not a sufficient test of the externality hypothesis. First, these few studies are really each single cases (or involve very few cases) even when hundreds of residential homes are evaluated. The public perceptions regarding reactor safety may be general, affected by or dependent on the broadcast media, which conveys the views of experts, community leaders and news of energy company behavior. In one locality, the company’s reputation may purvey excellent safety, in another there may even have been an accident.

One of us lived for several years within view of Three Mile Island after the time of its well known accident, an area that was included in two of the above studies. Continued residence by tens of thousands of people in that vicinity would seem to anecdotally suggest there was no external effect. However, other anecdotes abounded. The threatened leakage had been terrifying to pregnant women, some of whom sought safety far from the area either in miles or to areas protected by natural mountain barriers. Further, the reactors were quickly shut down, and, ironically, some people perceived the area to be safer in the shut down period directly following the accident than it was before the accident.

Second, one may err by embedding hypotheses that prescribe how the local people perceive distance to relate to risk. Should someone living five miles from the reactor site feel more at risk than someone living 15 miles away? The embedded hypothesis that the nuclear externality would necessarily affect the distance gradient could prove false, the risk being experienced generally throughout the area. "Acceptance distances," the distances from a nuclear reactor that laymen state they would accept when choosing a residence location sometimes average as high as 60 miles (Krupnick, Markandya, and Nickell, 1993).

To complement the distant gradient research, Folland and Hough (1991) studied a cross-section of broad market areas across the United States drawn from 1978-1980. They found a significant negative coefficient for a nuclear dummy and other nuclear variables suggesting a negative nuclear externality. Clark et al. (1994) also studied broad areas in cross-section; they found reductions in land rents as well as higher wages in nuclear areas, both results support a negative external effect. Thus, the two approaches seem to reach opposite conclusions: within a nuclear area, real asset prices are unaffected by proximity to the plant; between markets in cross-section, those with nuclear plants tend to record significantly lower asset prices, ceteris paribus. These results are not logically inconsistent, but a resolution would be welcome.

2. THE BASIC THEORY AND ECONOMETRIC MODEL

Potential nuclear externalities can been approached two ways by theory: 1) amenities models would describe the psychological or health effects of the exposure to the risk of an accident or to distaste from the reactor's presence; and 2) asset depreciation models would describe the loss in value of a location specific property. We have chosen the asset depreciation approach in part because it has been the lesser developed in this literature and in part because the owner of a real asset may not reside in the area studied while nevertheless responding to nuclear announcements. A theoretical model defines the terms and their relationships in an assets approach; it is followed by a description of the data and the econometric approach.

Theory: Farmland as an Asset Depreciated by the Nuclear Risk

For a given market period, which is treated as a year and encompasses an agricultural season, the quantity of land within an agricultural market area available for farm use is assumed to be fixed, $L_{St} = L_{to}$. On the urban fringe, a small fraction of the land will be developed for residential use within each year, and this process implies that the supply of farming land will decline with time, *t*. The fraction of land that is already zoned and ready to be converted to urban use during the year, however, will generally not be large enough to affect the market price of agricultural land considerably during the same year. Nevertheless, the magnetic attraction of the encroaching city will draw land into urban use over time, and the future selling price will become capitalized into the price of farmland before conversion occurs.

The farming process is split conceptually into land title holding, the landlord function, and farm operating, the tenant function. The fixed supply of land is the same for both markets, land buying and land renting, and we assume that both markets clear during the year. The demand for rental land is determined by the tenant's attempt to maximize profit from the sale of Q_t of agricultural product at price, p_t; he incurs costs, C_t, that are increasing in output and are conditioned by parametric input rental prices for capital, *r*, and land, *l*. The farmer also must pay unit transport costs, γ, which increase with *D*, the distance to the major trade area market, and p_d, the freight transportation price per unit of distance. His profit function is then:

(1) $$\prod_t = p_t Q_t - C_t(Q_t; r_t, l_t) - \gamma\,(D, p_{dt})Q_t$$

The equilibrium farmland rental price, R_t, then becomes:

(2) $$R_t = \{l_t \ st \prod_t = \prod_t^* \ \forall \ tenants, \ and \ L_{Dt}(l_t) = L_{Sot}).$$

where the asterisk indicates the maximum profit, and L_{Dt} indicates the combined tenants demand function for farmland, treating all tenants as similar profit maximizers and assuming that nonnegative profits are attainable. Equation (2) states that the equilibrium land rental price for the period will be that rate that clears the rental land market given that all tenants have accepted the rental price as a given and have adjusted to it so as to maximize their profits.

Let this equilibrium rental price of farmland be the landlord's sole return on the property while he holds it. The landlord's demand for owning land is then dependent on the discounted present value of these returns as amended, truncated, or adjusted by the nuclear risk. This present value is then the landlord's reservation price for land, the highest price that he would be willing to pay under the conditions of *no speculation regarding possible urban encroachment.* To generate this reservation price, first define a truncated return:

(3) $$\hat{R}_{t,k} = \int_{t}^{t+k} e^{-bt} R_t \, dt$$

where discounted returns from land purchased in period t are truncated if a reactor accident should occur in exactly the *kth* year following the land purchase and if the accident reduces that land value to zero in perpetuity. The value *k* is thus the life of the reactor in this specific sense, it depicts each possible "worst case" scenario given that the interval from the purchase to the event of the worst case is variable.

The landlord's reservation price can then be derived given his probability density function, *f*, for the occurence of the worst case in exactly *k* years:

(4) $$P_{Dt} = \int_{k=0}^{H} \hat{R}_{t,k} \; f(t+k)dk$$

where *H* is the potential buyer's finite time horizon, which can well exceed his own life span; he can reasonably expect to find a buyer when he decides to sell. The function *f* properly integrates to unity given that we define period *H* as a time distant period to represent the case that a reactor event never occurs, such as when no reactor is present. Absence of a reactor implies that for ($k < H$), f=0, and for k=H, f=1. By picking a sufficiently time distant period and provided a discount factor approximating a discounting by the market rate of interest, *H* is in practicality "beyond" his horizon, that is, the discounted present value of income foregone because of truncation at *H* is negligible.

For farmland on the urban fringe, this agricultural reservation price may be outbid by developers or in some cases effectively outbid by conservancies wishing to dedicate the property to preservation. When this happens, the agricultural demanders are superceded and represent only the minimum of what the market will bear. We assume that the developer also maximizes profits, and without loss of generality, we further assume that he rents his acquired property for residential use. The additional demand by developers is thus similar in form to the demand by agricultural buyers, though the pattern of encroachment implies that farm purposes are gradually outbid. We emphasize that the developer is a speculator, and his optimism becomes capitalized in land prices perhaps well before conversion of the land takes place.

The equilibrium price for land is then determined as the maximum of each demander's reservation price such that market demand for ownership equates with the fixed supply:

(5) Equilibrium land price: $\checkmark_{Dt} = \{P_{Dt} \text{ st } L_{Dt}(P_{Dt}) = L_{Sot}\}$.

The introduction of a nuclear power facility into the area implies that earlier years come to be given positive probabilities. Information of the introduction may form complex patterns including pre-announcement rumors, official announcements, and ground-breaking, each prior to installation and operation (Kiel, 1995; Kiel and McClain, 1995). These would reduce the buyer's expected discounted value of ownership as the information became available to him. New information, such as news of serious accidents elsewhere, would in principle also cause a drop in his valuation of the land.

The other parameters of the model stem from the tenant's decision problem. Let the farmer-operator be a price taker; then by differentiating the profit function in (1), the necessary condition for profit maximiztion becomes:

(6) $$\Pi_{Qt} = p_t - C_{Q_t} - \gamma_t = 0$$

The comparative static effects of the cost-raising parameters are illustrated for the case of input price, r, while changes in other cost raising parameters, l, D, and p_d as well as the competitive product price, *p*, are for the moment held at zero. In this case, by totally differentiating the profit function, (1), and borrowing from (6), we can establish that the maximum profit to the tenant declines with an increased rental price of capital under conventional economic assumptions:

$$\text{(7)} \qquad d\prod_t = (p_t - C_{Q_t} - \gamma_t)Q_{r_t} dr_t - C_{r_t} < 0; \quad or \ \frac{d\prod_t}{d r_t} < 0.$$

This, in turn, implies a reduction in land price, and in similar fashion, a rise in *D* or p_d will also lower the equilibrium land price while an improvement in product prices will raise it:

$$\text{(8)} \qquad \frac{\partial \overline{P}_t}{\partial r_t} < 0; \quad \frac{\partial \overline{P}_t}{\partial D} < 0; \quad \frac{\partial \overline{P}_t}{\partial p_{dt}} < 0; \quad \frac{\partial \overline{P}_t}{\partial p_t} > 0.$$

Recall that new information on a reactor installation or news related to reactor safety will alter the perceived probability of an accident and recalibrate the density function, *f*. This unambiguously lowers the reservation price of landbuyers and will lower the equilibrium land price. Letting *N* represent these forms of information increasing nuclear risk, we have also $\partial R_t/\partial N < 0$ and hence $\partial \overline{P}_t / \partial N < 0$.

The Data and the Econometric Model

We generated a panel of 494 market areas based on the trading areas developed in Rand McNally's Commercial Atlas. These Basic Trading Areas (BTAs) were designed by Rand McNally to represent well-integrated market areas. Within an area, farming generally is focused on a single group of products such as grains, livestock, truck farming, or rangeland, while across BTAs the differences range widely. The center of each BTA is identified with the dominant city for local market activities, and these are also often, but not uniformly, near the geographic center of the area.

The BTAs are groups of counties, most often just three or four but occasionally as many as eight or more, averaging just over six. These collectively exhaust the contiguous 48 states and create areas roughly 40 miles in radius. In addition, Rand McNally identified just over 50 Major Trading Centers. These were chosen to represent the hub city to which various products from a BTA would go either for processing or for connection to the major transportation avenues including highway, railroad, air and waterway hubs. It is understood that the geographic and market patterns devised by Rand McNally are necessarily imperfect for our purpose, primarily because the individuality and idiosyncracies of the area, including its terrain, farmland, farmers and wholesalers, which can never be fully perfectly captured by such data as these. The data, however, have advantages for interarea studies of nuclear externalities affecting agricultural land. They have greater homogeneity as markets than larger areas selected with political boundaries, and these small areas collectively cover a very large area with a fairly consistent methodology, and they are defined with relatively few changes over the period for which nuclear power was at issue. Having a panel, we can also investigate whether the results are affected or distorted by failure to collect a sufficient number of variables to describe the individuality of the BTAs; this issue is tested by incorporating a group fixed effect for each BTA in some analyses.

Table 1 About Here

The 11 cross-sections in the panel survey the years 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, and 1992. Agricultural data are derived in each case from the Census of Agriculture made available from the National Archives; data on nuclear power plant location and date of installation are from the Nuclear Energy Commission, the remaining data are demographic and geographic. The demographic data were input from the City and County Data Books. All data were aggregated to the BTA level. The geographic data included locational coordinates, which were applied to calculate the *Distance* from the BTA center to the Major Trading Center. The panel data analyses were conducted with Limdep 7.0.

In addition to the *Distance* variable just described, the following variables in the panel data were used to repesent the parameters in the theoretical model. The *Landtotal*, variable measures the fixed land supply, $L_{Sot.}$ Over the time period, the supply of agricultural land was encroached on by development on the urban fringe, affecting land prices (Dunford et al., 1985; Chicoine, 1981). To account for this affect, we calculated the population density, *Popdensity,* from data provided by the City and County Data Books for each observation year. Transportation costs to bring produce to the Major Trading Center are represented by *Distance* and *Port*; *Port* is a dummy variable identifying the presence of a port suitable for shipping products.

No direct measure was available for the agricultural product price or for the fertility and productiveness of the local soil, climate and topography; however, we were able to approach these in two ways. First, the *Valueofproduct* per acre, which is measured in current dollars, become a proxy for the combined effect of product price and the soil fertility. Second, a panel analysis included BTA specific fixed effects as well as observation period effects, and these capture many of the idiosyncratic characteristics of each area such as climate and terrain and local price levels. Fixed effects for the 11 time periods adjust for time dependent factors including the general level of prices in the country.

Time trends are very important to the analysis. First, the time period indicator is set to t=1 for the first observation year, 1945, and counts by observation year so that t=2 for the second observation year, which is 1950, and so on. Second, the variable *Nuctime* is reactor specific, and it counts by calendar years beginning with the installation year as *Nuctime=1*.

Also related to the installation is a dummy variable, *Nuclear*, which equals one if a plant is present and operating. Thus, *Nuctime* and *Nuclear* together test the central hypotheses; *Nuclear* tests whether installation has a lump sum negative effect on land price, and *Nuctime* tests whether installation continues to alter the land prices over time.

We investigated both linear and loglinear versions of the model and applied the Box/Cox approach to adjudicate between the two. The linear version generates the same signs for the coefficients but performs much less well on goodness of fit criteria and the Box/Cox result is close to the loglinear. Thus, we will present the loglinear and Box/Cox results in Table 2 along with a variant to be described in what follows. The basic model presented in its loglinear form, with logrithms of the variables represented by lower case lettering, is as follows:

$$\begin{aligned} Eq.1:\quad & landprice = a_0 + a_1\, landtotal + a_2\, valueofproduct + a_3\, distance \\ & + a_4\, port + a_5\, nuclear + a_6\, nuctime + a_7\, popdensity + u \end{aligned}$$

The theoretical model predicts the following: $a_1 < 0$; $a_2 > 0$; $a_3 < 0$; $a_4 > 0$; $a_5 < 0$; $a_6 < 0$; $a_7 > 0$.

Estimating the model with panel data has advantages for testing external effects. First, if the externality hypothesis is correct, then the nuclear coefficient, a_5, must be negative; it is a stronger test than a single cross-section, because it summarizes the effect for eight reactor observation years (the first year to record an active site was 1959) and three observation years prior to any reactors. Second, the nuclear hypothesis suggests a second related hypothesis that of a distinct, declining time trend during the years following installation; a negative coefficient for *nuctime* ($a_6 < 0$) would give strong support to the externality hypothesis.

In contrast, the *cheap land hypothesis* states that the "depression" in land prices is spurious and occurs well before rumors of or announcements of a reactor; under this alternative hypothesis, the apparent nuclear externality occurs only because energy companies seek out cheap, less populated and less controversial sites. This can be tested in panel by defining dummy variables preliminary to the reactor's installation. To account for such effects, we define three additional variables: *Pre* equals one in each of the years preceding the reactor installation and zero post installation as well as for nonreactor areas; *Pre1* equals one for nuclear BTAs beginning with the date of the Contract Permit and is intended to capture an announcement effect; and *Pre2* equals one in nuclear BTAs for all observation years prior to the date of the Contract Permit and is intended to capture the *cheap land* effect. These *pre* reactor variables, or "ghost reactors," will support the *cheap land hypothesis* if *Pre and Pre2* take negative coefficients, in the latter case when controlling for the announcement effects, *Pre1*. Finally, a finding of a significant positive coefficient, a_6, would capture another alternative hypothesis under which an installation will be associated with a growth in land prices post installation, $a_6 > 0$. This might occur if the power facility stimulates economic growth or improves the tax base. It also occurs under scenarios where better or fuller information regarding the nature of nuclear power processes reassures residents on nuclear safety issues (Rhodes and Beller, 2000).

In summary, the hypotheses to be tested are:

H1: The installation of a nuclear power facility in the area causes a permanent decrease in the level of agricultural land prices, *ceteris paribus*, $a_5 < 0$.

H2: The installation of a nuclear power facility introduces a new negative trend in land prices, *ceteris paribus*, $a_6 < 0$.

H3: The statistical, inverse relation of land prices to nuclear facilities reported in studies is only an apparent one and is due to the energy firms' preference for choosing cheap, undeveloped land for installations, *ceteris paribus*, Pre, $Pre2 < 0$.

H4: The installation effect of a nuclear facility is countered over time by the introduction of a new positive time trend so that, *ceteris paribus*, $a_6 > 0$.

3. RESULTS OF THE BASIC MODEL

Table 2 reports the initial estimates of *Equation 1* in panel with fixed period effects applying the Box/Cox transformation and the loglinear form; the third version includes 494 fixed effects representing the BTA groups.[1] Please note three main features of these data. First, the nuclear externality is supported consistently by negative coefficients for the *nuclear* dummy, which are each significant given the appropriate one-tail test of confidence at the 95 percent level.

Table 2 About Here

Second, the added hypothesis, that the installations will slow the rate of land price growth is contradicted in this version of the model. However, the alternative hypothesis--that installation stimulates land price growth does not attain significance in the appropriate

[1] Between the fixed effects, FE, and random effects, RE, versions, the former was generally favored based on the Hausmann test, and only these fixed effects are presented.

two-tail test, though it is consistently positive. The models perform well overall, are easily significant, and they explain a large portion of the variation in land prices. The other variables take the predicted and plausible signs without exception.

The Rand McNally BTAs, which are formed as groups of counties, are often irregular in shape and often are smaller in diameter than the 60 diameter of the "nuclear acceptance areas" reported by some studies. The BTAs average about 40 miles in diameter, posing the possibility that nonnuclear BTAs may be near enough to nuclear areas for the public to perceive an increased risk.

To investigate this issue, we coded the nonnuclear BTAs for each of the 11 observation years as to their distance from the nearest operating reactor, provided that it was within 60 miles of the BTA's central city, and reanalyzed the data. Table 3 reproduces the loglinear version of the basic model and compares this with variations treating the nearby BTAs as also affected areas; the second column separates nonnuclear and nearby-nuclear areas and the third column combines them.

The nuclear external effect hypothesis embedded with the hypothesis of a 60 miles acceptance distance is stongly supported. All signs remain "correct" and the t values on nuclear dummies improve sharply. The post-installation time trend changes sign and its t statistic becomes larger in absolute value.

Table 3 About Here:

4.. LAND PRICES IN FUTURE NUCLEAR AREAS—THE “GHOST REACTORS”

As mentioned, a plausible alternative hypothesis to the nuclear externality states that energy companies seek out “cheap land.” The panel data offer a special test, because they contain land values for each nuclear site dating numerous years before the installation. We created false dummy variables to indicate preliminary land prices, hence "ghost reactors."

The dummy variable *Pre* equals one for a nuclear BTA in years prior to installation, zero else. To test for announcement effects, we also split *Pre* into component parts: *Pre1* equals one for all years from and including the year the Construction Permit was issued, zero else; and *Pre2* equals one in the years prior to the Construction Permit issuance. A negative *Pre* indicates support for the *cheap land hypothesis*, though it may or may not be contaminated by a negative announcement effect. A negative *Pre1* would indicate an external effect via the announcement of the installation; and, by removing this, we are able to test for a relatively pure *cheap land effect*, which would be indicated by a negative *Pre2* coefficient. Further, if these ghost reactors eliminate the previously measured effect of installation, then we would conclude that the previously measured nuclear externality had been spurious.

Table 4 About Here:

In Table 4, the *Pre* variables usually do not attain the usual significance level, but more importantly the *Pre2* estimates are both negative with large absolute values of the t statistics. Notably, the variables added to the basic equation seem plausible on theoretical grounds and they "improve" the performance of the hypothesis tests. Rather than declaring the external effects to be spurious, the nuclear effect becomes statistically stronger. By comparing nuclear and nonnuclear BTAs and incorporating the "ghost reactor" effect, the negative nuclear is revealed more strongly as both a lump sum decline in land values as well as a continuing, significant negative time trend.

5. NUCLEAR EXTERNALITIES AND VINTAGE OF REACTOR

A significant and negative post-installation trend in land prices suggests, at first consideration, that the older installations generate the greatest accumulated effect. Large changes in time, however, are accompanied by larger changes in technology, information and public knowledge. We call these possibly omitted factors "vintage effects." By separating reactors by vintage, we hope to get vintage-dependent information not captured by the panel results.

For this purpose, *oldnuclear* reactors are defined by installation prior to 1970; *midnuclear* reactors were installed from 1970 through 1979; and *newnuclear* reactors were installed after 1979. Previous research by Folland and Hough (1991) reported differential effects by vintage; older reactors showed a somewhat greater negative effect than the newer, presumably safer, reactors. Theirs was a single cross-section centered at 1978-1980. The data for our 1978 cross-section are consistent with that earlier study. The present panel, however, reveals little difference between oldnuclear and midnuclear vintages as a general rule; and, the newer installations generally show positive effects.

Table 5 About Here

6. DISCUSSION AND CONCLUSIONS

The preponderance of significant, negative estimated effects across all varieties of models, strongly suggests a negative nuclear externality and one that appears throughout the major portion of the nuclear era. Part of the observed negative effect on land prices is only apparent, most likely contributed by the actions of energy companies and governments who seek out cheap land for installations. Removing spurious effects nevertheless leaves a significant negative installation effect.

It is a one-time adjustment in land asset values consistent with the theoretical account, which describes profit maximizes adjusting to the introduction of the perceived nuclear risk much like equity, markets adjusting to negative news regarding the future profit streams of a corporation. In the best performing models we examined, those incorporating both preliminary land price controls and nearby nuclear areas, the installation also alters the trend of land prices downward. In the best performing and most complete models, land prices continue downward after installation.

Finally, the positive effects of recent vintage reactors are significant in the panel models. This result is consistent with several alternative hypotheses, including the idea that the public is more informed about reactor safety as well as the idea that the newer, modern reactors are safer and more safely managed.

Though these data do not resolve each of the questions raised, they reinforce the proposition that the discrepant findings in the literature derive less from error than from the alternative study designs. Comparisons across areas, which reported a significant negative effect of nuclear power plant installation, are compatible with studies of variations within areas, which show little or no effect on housing prices due to the distance from the plant. If our conjecture is correct, a meta study reexamining the distance gradient studies should show different asset price levels when compared to matched nonnuclear areas.

Further, research that seeks to confirm these and related results might investigate population movements throughout the nuclear era. Although the absence of such movements would not be sufficient to prove the absence of a public response to perceived risk, the finding of such movements would be a strong confirmation of the externality hypothesis. Case studies of nuclear areas could also be helpful. Selected assets could afford a richer sample for study if they are especially vulnerable to fears of radioactive contamination, for example: food processing; bottling of beer, water and soft drinks; fisheries; or industries sensitive to elevated water temperatures.

Our data support the proposition that a public perception of nuclear risk causes a change in land prices, and that the reduction continues after installation and is associated largely with the middle and older vintage reactors. The data show an installation effect centering around 10 percent of land value. Inasmuch as the amount of land affected by a given installation could be large (the effect is significant applying a 60 mile radius) the loss in value could exceed tens of millions of dollars, a significant additional consideration for installation/removal decision making. In the present climate of public opinion, the public logic more plausibly runs toward removal, and the harm or perceived harm of removing and storing nuclear waste may not be easily reversed. In any case, these findings add to the knowledge needed in cost/benefit determinations on the replacement of a perceived risky plant with a perceived safer one. All of these issues concern information as understood by the public, and they are pertinent to assessing the value of improved public information.

Finally, the results add to the importance of welfare economic theory regarding harmful external costs in cases where information is imperfect. Should a misperceived threat of an externality warrant compensation? Is it sufficient to show that the individual consumer has become fully informed and is acting voluntarily? Is it a sufficient defense for an energy company to show that the consumer's perceived fear is unscientific? Nevertheless, negative external effects exceeding 10 percent of asset value are real one-time costs to some members of society relevant not only nuclear installation but also to decommissioning (Eyre, 1997; Ballard et al., 1991; Hall, 1990). The economic approach to efficiency requires the recognition of these external costs as well as their internalization into the calculus of nuclear energy decisions.

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APPENDIX

Derivations in detail for all the predicted effects:

(A1) Define the tenants profit as: $\Pi = p_g Q - C(Q; r, p_l) - \gamma(D, p_d)$

where p_g is the price of the farm produce, for example, grain; this is assumed to be fixed throughout the analysis; Q is the quantity of farm product produced; costs, C, are a function of quantity produced, and costs are also affected by the input prices, r *and* p_l, which are respectively the rental price of capital used in farming and the rental price of farmland; transportation costs, γ, represent the cost of shipping one unit farm output, and this cost depends on the distance, *D*, and the per mile of distance price charged by farm produce carriers, p_d.

The change in profits that occurs when at least some of the parameters change is depicted by

TABLE 1: Descriptive Statistics on the Panel Data

Variables and definitions	Mean	Standard deviation	Minimum	Maximum
landprice,* Value of agricultural land per acre; the dependent variable.	5734.9	8643.8	18.4	195875.8
landtotal, Total land in agriculture	2154.3	3274.2	2	23415
valueproduct, Value of agricultural product per acre	145929	256484	40	4559723
distance, Distance to Major Trading Center from coordinates	137.1	132.7	1	826
port, Presence of a commerical port in the BTA	0.11	0.31	0.0	1.0
nuclear, Presence of an operating nuclear power facility	0.061	0.239	0.0	1.0
nuctime, Counts years from installation	0.774	3.56	0.0	33.0
popdensity, Population density	115.9	216.7	1	2558
nearnuclear, BTA center is <=60 miles from a nuclear BTA's center	0.159	0.366	0.0	1.0
nukcombined, BTA is either *nuclear* or *nearnuclear*	0.220	0.414	0.0	1.0
timenukcombined, Counts years from installation for *nukcombined.*	1.416	4.539	0.0	33.0
Pre, Nuclear BTA in the years prior to the nuclear installation	0.084	0.278	0.0	1.0
Pre1, Nuclear BTA in years between Contract Permit and Installation	0.061	0.239	0.0	1.0
Pre2, Nuclear BTA in years prior to the *Pre1* period.	0.060	0.237	0.0	1.0
period indicator	5.99	3.16	1	11
group indicator	248.6	142.9	1	494

Note: *These data from the Census of Agriculture combine the value of land and buildings. All variables except *port* and *distance* are specific to the time period. The 11 observation years by 494 BTAs generated 5434 observations, however, invalid data and missing values required the rejection of 73 of these observations resulting in a sample size of 5361.

TABLE 2: Basic Model Estimated on Panel Data in BoxCox, and Loglinear Forms, The Dependent Variable is the Land Price in Logs.

Variable	Fixed period effects BoxCox Model	Fixed period effects Loglinear Model	Fixed period & group effects Loglinear Model
landtotal, a_1	-0.540 (-63.2)	-0.560 (-73.9)	-0.477 (-29.8)
valueproduct, a_2	0.297 (65.7)	0.517 (79.3)	0.297 (22.8)
distance, a_3	-0.032 (-4.2)	-0.029 (-7.4)	-----*
port, a_4	0.678 (15.1)	0.146 (9.6)	-----*
nuclear, a_5	-0.31 (-2.7)	-0.061 (-1.6)	-0.524 (-2.0)
nuktime, a_6	0.014 (1.9)	0.0007 (0.3)	0.221 (1.3)
popdensity, a_7	0.312 (30.3)	0.152 (25.5)	0.163 (10.7)
Adjusted Rsquare	0.926	0.938	0.976
F-Value-for-Model	3142.6	4820.8	435.4
Prob. for Model	0.000	0.000	0.0000

Notes: Data include 11 observation periods and 494 BTA Groups Spanning the Era from 1945 to 1992. *t* values in parentheses. *the *distance* and *port* variables do not change within the BTA over the 11 periods, thus their presence along with group effects for the 494 BTAs would create perfect collinearity in the fixed-group&period-effects model. After creating indicators for group and period, observations with invalid or missing data were rejected from the original sample of 5434, resulting in a final sample of 5361.

TABLE 3: Nearby BTA Effects, and Effects on Combined Nuclear and Nearby BTAs

Variable	*landprice, dependent variable*	*landprice, dependent variable*	*landprice, dependent variable*
landtotal, a_1	-0.560 (-73.9)	-0.563 (-74.0)	-0.563 (-74.2)
valueproduct, a_2	0.517 (79.3)	0.518 (79.4)	0.518 (79.4)
distance, a_3	-0.029 (-7.4)	-0.029 (7.5)	-0.029 (-7.4)
port, a_4	0.146 (9.6)	0.143 (9.4)	0.143 (9.5)
nuclear, a_5	-0.061 (-1.6)	-0.069 (-1.9)	NA
nuktime, a_6	0.0007 (0.3)	0.0006 (0.3)	NA
popdensity, a_7	0.152 (25.5)	0.154 (25.7)	0.153 (25.8)
nearnuclear	NA	-0.047 (-3.6)	NA
nukcombined	NA	NA	-0.036 (-2.6)
timenukcombined	NA	NA	-0.0024 (-1.8)
Adjusted Rsquare	0.938	0.938	0.939
F-Value-for-Model	4820.8	4564.1	4836.1
Prob. for Model	0.000	0.0000	0.0000

Note: Total observations were 5361 after rejected 73 observations with invalid or missing data from the original sample of 5434.

TABLE 4: Land Prices in Areas with Future Reactors, the "Ghost Reactors" Test, Loglinear Form

Variable	*landprice, dependent*	*landprice, dependent*	*landprice, dependent*	*landprice, dependent*
landtotal, a_1	-0.561 (-74.1)	-0.560 (-73.9)	-0.564 (-74.4)	-0.563 (74.2)
valueproduct, a_2	0.517 (79.1)	0.518 (79.4)	0.518 (79.2)	0.520 (79.6)
distance, a_3	-0.029 (-7.5)	-0.030 (-7.6)	-0.029 (-7.5)	-0.030 (-7.7)
port, a_4	0.144 (9.6)	0.147 (9.7)	0.141 (9.4)	0.146) (9.6)
nuclear, a_5	-0.088 (-2.4)	-0.100 (-2.5)	NA	NA
nuctime, a_6	-0.0006 (-0.2)	-0.0007 (-0.2)	NA	NA
popdensity,a_7	0.152 (25.4)	0.153 (25.6)	0.153 (25.6)	0.156 (25.9)
nukcombined	NA	NA	-0.035 (-2.6)	-0.040 (-2.9)
timenukcombined	NA	NA	-0.004 (-2.8)	-0.004 (-2.4)
Pre	0.021 (1.2)	NA	0.014 (0.8)	NA
Pre1	NA	0.021 (0.7)	NA	-0.017 (-0.8)
Pre2	NA	-0.026 (-1.3)	NA	-0.036 (-1.8)
Adjusted Rsquare	0.939	0.939	0.939	0.939
F-Value-for-Model	4565.9	4325.6	4575.9	4336.9
Prob. for Model	0.0000	0.0000	0.0000	0.0000

Notes: *t* values in parentheses. *Pre* is a dummy variable defined equal to one in all years prior to the reactor installation, zero else, and zero for all nonnuclear areas. *Pre* is then separated into *Pre1*, which is coded one during the years beginning with the year of the Contract Permit. *Pre2* is set to one for the years prior to the Contract Permit for a nuclear BTA.

TABLE 5: Vintage Effects of Nuclear Power Facilities, Loglinear Form

Models: *nuclear* includes *near* BTAs	***Oldnuclear***	***Midnuclear***	***Newnuclear***	***Nuclear***
Panel, Period Effects, Pre	-0.108 (-3.9) [231]	-0.118 (-6.2) [557]	0.066 (2.4) [262]	-0.037 (-2.7) [1050]
Panel, Period Effects, Pre1,Pre2	-0.070 (-2.7) [231]	-0.085 (-4.8) [557]	0.121 (4.9) [262]	-0.039 (-2.8) [1050]
1959, Cross-section	-0.111 (-1.4) [16]	---	---	NA
1964, Cross-section	-0.110 (-1.3) [16]	---	---	NA
1969, Cross-section	-0.094 (-1.4) [22]	---	---	NA
1974, Cross-section	-0.115 (-2.1) [26]	-0.105 (-2.8) [69]	---	-0.066 (-2.2) [95]
1978, Cross-section	-0.177 (-2.6) [26]	-0.088 (-2.1) [81]	---	-0.087 (-2.4) [107]
1982, Cross-section	-0.152 (-2.3) [26]	-0.065 (-1.6) [81]	0.104 (1.5) [23]	-0.084 (-2.4) [130]
1987, Cross-section	-0.037 (-0.6) [26]	-0.053 (-1.4) [80]	0.068 (1.3) [36]	-0.012 (-0.4) [142]
1992, Cross-section	-0.011 (-0.2) [26]	-0.064 (-1.5) [80]	0.048 (0.8) [38]	-0.017 (-0.5) [144]

Notes: *t* values in parentheses; number of unique occurrences of a year and a BTA at or near a nuclear power facility are in brackets. *Oldnuclear, midnuclear,* and *newnuclear* are dummy variables defining a reactor's presence for reactors of vintage pre-1970, 1970-1978, and post-1978, respectively. *Nuclear* defines the presence of a reactor regardless of vintage. Regressions for *nuclear* thus are done separately and are omitted (NA=not applicable) for years during which only the "old" vintage reactors were present.