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Measuring the Externalities of Nuclear Power: A Hedonic Study

by

Brian Prest

Professor Stephen Sheppard, Advisor

A thesis submitted in partial fulfillment
of the requirements for the
Degree of Bachelor of Arts with Honors
in Economics

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Abstract

In this paper, I use house price data to measure the extent to which the negative externalities posed by the Pilgrim Nuclear Generation Station in Plymouth, Massachusetts are capitalized into house prices. I find that homebuyers are willing to pay a significant premium to live farther away from the nuclear plant, finding a statistically significant price-distance elasticity estimate of 0.09. This effect is estimated to extend to about 8 km. This elasticity is found to fall over time and with the median age of the community. Under reasonable parameters, the aggregate damages attributable to the nuclear plant, and hence the estimated external benefits of its closure, are estimated at $7,940 per affected house on average, aggregating to about $53 million (in year 2000 dollars), or $1,024 per Plymouth resident. To conduct a full cost-benefit analysis the plant's continued operation, these external benefits must be weighed with the costs of replacing the energy produced by Pilgrim Station. Entergy Corporation, which owns and operates Pilgrim Station, also owns a large wooded green space that surrounds it, creating a buffer between the plant and the community as well as generating pleasing views and public recreational benefits. The price-distance elasticity of the green space is estimated to be a statistically significant -0.05, extending to about 5 km. This estimate implies external benefits of about $11,758 per affected house on average, or $79 million in aggregate. The effect of media coverage of the risks of nuclear power on house prices is also examined, finding the anomalous and counter-intuitive result that more media coverage is associated with higher house prices, especially near the nuclear plant.

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I. Introduction

In the face of the threat of fossil-fuel-induced global climate change, the expansion of environmentally cleaner means of producing energy has been a subject of much public discussion. One solution that has been proposed is the expanded use of nuclear power. When working properly, it produces little air pollution and consumes little fuel, making it an appealing alternative to dirty fossil fuels such as coal. However, there are clearly problems with nuclear power as well. The catastrophe at Chernobyl and the accident at Three Mile Island are clear examples of the dangers of nuclear power when essential precautionary systems fail. The issues of constant exposure to radiation and the safe storage of nuclear waste are costs of nuclear power as well. Further, the risk of accidents is not the only safety issue; the revelation that nuclear power plants were considered as potential targets for the September 11, 2001 terrorist attacks makes the threat of disaster all the more real.

In this paper, I use house sale data to examine the magnitude of the negative externality associated with Pilgrim Nuclear Generating Station in Plymouth, Massachusetts. By observing the extent to which a house's proximity to the nuclear plant is associated with its sale price, I estimate the price that individuals are willing to pay to avoid the risks of nuclear power, turning this price into an estimate of the aggregate damages associated with the plant. Pilgrim Station is currently under consideration for a renewal of its operating license, which is set to expire in 2012. The impact of the Pilgrim plant on the local community is certainly in the public eye, as evidenced by the numerous newspaper articles that are frequently published on the subject, and the issue of the plant's relicensing has sparked several activist groups and protests. When deciding whether to relicense the nuclear plant, the magnitude of the negative externality it generates is an important cost that must be estimated and considered.

Over the years, Pilgrim has been fraught with problems. There have been several instances of missing radioactive waste, breaking valves, and fires, and workers have been repeatedly found asleep or intoxicated on the job (see *Boston Globe*, 5/24/06, 1/29/89, 10/31/08, 10/14/04, 2/22/07, and 12/11/91). While its record today is much better than it has been in the past, it has historically received low safety ratings from the Nuclear Regulatory Commission (NRC), once even being included on the list of the ten worst run nuclear plants in the nation (*The Boston Globe,* 5/24/96).

The series of problems at the plant have contributed to public awareness, along with a highly publicized 1990 study of the health impact of living near the plant, in which the author studied leukemia rates near Pilgrim Station before and after the release of radioactive material. They found that individuals living downwind of the plant were four times as likely to suffer from leukemia after radioactive releases compared with the same local population before the release (Clapp et. al 1990). Another study found similarly detrimental effects of accidental leaks of radioactive material from Pilgrim Station on infant mortality (Sternglass 1986). While there has been controversy in the medical community about the validity of these studies, they are commonly referred to in newspaper articles on Pilgrim Station, suggesting that this information is easily accessible to the public. These facts suggest that the risks of living near Pilgrim Station have invaded the public consciousness. Media coverage of these studies and more generally coverage of the dangers associated with the plant (such as newspaper articles that discuss accidents at Pilgrim) could increase public awareness of the risks associated with living near the nuclear plant. This could feasibly result in lower property values, especially with regard to properties near the plant, as homebuyers gain information (or fear) regarding the dangers of living near a nuclear plant.

The above discussion leads to the following two hypotheses, which I test. First, that house sale prices will be positively associated with distance from the plant, holding other factors constant. Second, media coverage of the risks posed by the nuclear plant reduces house prices, especially near the plant. I test these hypotheses and quantify the value placed on these nuclear risks by using a hedonic model.

The hedonic method involves modeling property values as a function of various housing amenities, including proximity to Pilgrim Station. By considering a house as a bundle of many different goods and services (like size, style, location, etc.) which consumers can value independently, one can see the price of the entire "bundle" (the house) as made up of the prices of its component goods and services. One can model house prices as a function of these amenities to isolate the price paid for each particular factor, such as the price of distance from a nuclear power plant. Measuring this price of distance by using data on home sales then allows the estimation of the dollar-value that individuals place on the risks of nuclear power. Once the impact of proximity to the nuclear plant on prices is estimated, I use this to estimate the value that individuals place on the risks of nuclear power by comparing the predicted price of each house as a function of its distance from the plant to the predicted price of a hypothetical identical house at a "safe" distance from the plant. To test the second hypothesis, I by testing for a statistically significant relationship between the sale price of the house and the number of *Boston Globe* articles in the year of the house's sale.

Ultimately, I find strong evidence that house prices are adversely affected by proximity to the nuclear plant, with a one percent increase in distance from the plant increasing house prices by between 0.026 to 0.104 percent, depending on the model specification. With an average real sale price of $198,077.90 for Plymouth houses in my sample, this implies that doubling the distance of a house from the nuclear plant would be associated with an increase in house price of roughly $5,150 to $20,600 (in year 2000 dollars), a substantial sum. Most specifications produce estimated price-distance elasticities that are significant at the 99% level. These elasticities are used to generate estimates of the damages attributable to the nuclear plant. A range of estimates is presented in the results section, with a choice estimate of $52.9 million.

Entergy Corporation, the company that owns and operates Pilgrim Station, owns a large undeveloped green space that surrounds the plant. I find substantial benefits to living near the green space capitalized into house prices. In fact, on aggregate these benefits are of roughly the same size as or somewhat larger than the damages attributable to the plant itself, with a choice estimate of $78.8 million in benefits. This suggests that the undeveloped green space acts as a buffer to shield the community from the worst of the damages associated with the nuclear plant and generating some benefits of its own.

While the bundle of the nuclear plant and green space together seem to generate net benefits to the community, I still conclude that closing the plant and preserving the green space can generate significant external benefits,[1] on the order of $52.9 million. This is because the policy decisions regarding the status of the nuclear plant and green space can be made independently, so there is no necessary link between them. For example, the plant could be closed and the green space could be zoned to protect it from development. In order to make a policy decision regarding the plant's operation, the $52.9 million in damages would have to be compared with the value of the energy generated by Pilgrim Station. Similarly, development of the green space would require comparing the $78.8 million in benefits with the net benefits of an alternative scenario.

In the following sections I describe the methodology, data, and results from my study of the impact of Pilgrim Station on local property values and hence

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[1] Throughout this paper, I use the terms external benefits and external damages to refer to the effect of the nuclear plant and/or green space on the local community. These measures should not be confused with *net economic* damages benefits, which would account for all relevant costs and benefits.

the value placed on the risks of nuclear power. In section II, I briefly review the economic theory behind externalities. In section III, I discuss the relevant literature. In section IV I outline my methodology. In section V, I describe the data, including some descriptive statistics and maps. In section VI, I describe my regression results and damage estimates. I discuss my results in section VII, focusing on interpretation and possible biases. Finally, I conclude by summarizing my findings.

II. The Economic Theory of Externalities

In economics, an externality arises whenever "the actions of one party make another party worse or better off, yet the first party neither bears the costs nor receives the benefits of doing so" (Gruber 2007). In the case of an unregulated negative production externality, the private costs of production diverge from true social costs, leading to inappropriate production choices which cause inefficient deadweight loss. A simple model includes polluting firms in a competitive market. In this model, each firm's production of a good (Q) is associated with the production of a negative externality (e.g. air pollution) that harms other members of the community. The firm is not legally liable for this harm, so it does not take pollution levels into account when making production decisions. Instead, the firm makes production decisions based on its own private costs, maximizing profits at the point where the price of its production good equals private marginal cost (PMC). This produces the upward sloping supply curve seen in Figure 1.

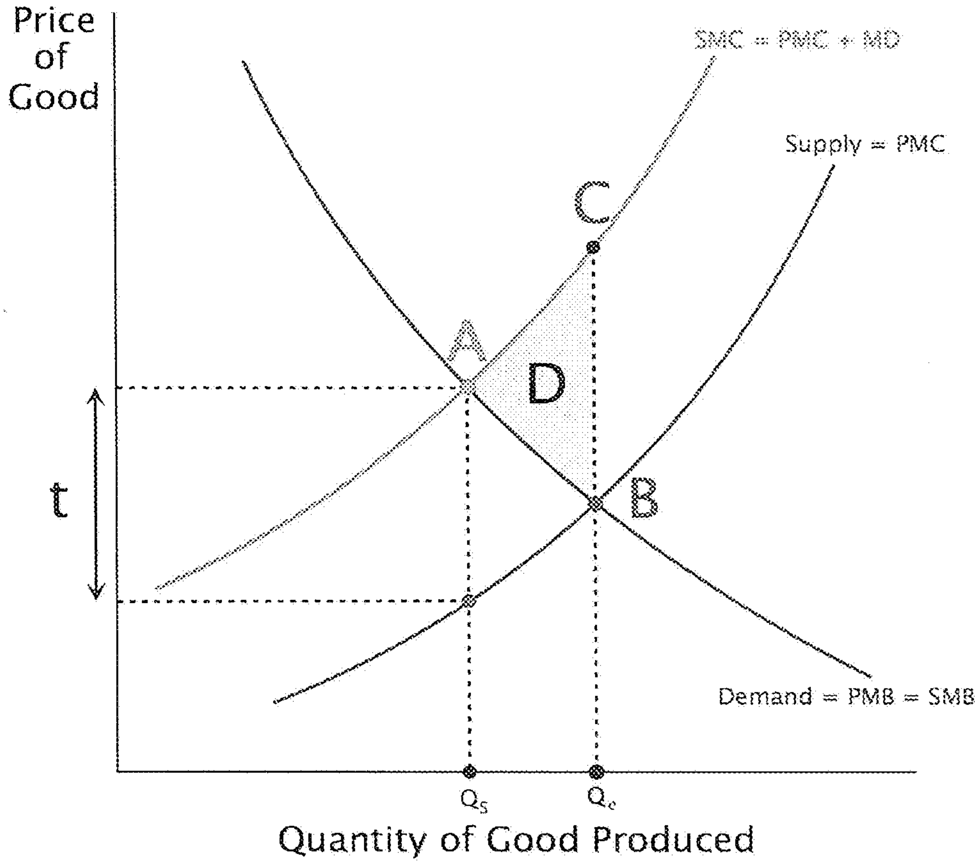
However, the true *social* costs of production are larger than this, since social costs must include the damages from pollution as well as production costs. Thus, the social cost is equal to the sum of private costs and the damages. Social marginal costs (SMC) then are equal to private marginal costs plus the marginal damages (MD) of pollution (SMC = PMC + MD), so that SMC is an upward sloping curve located above the firm's supply curve.

Finally, since the example under consideration is a negative *production* externality, the demand curve is normal, meaning that the social marginal benefits of consumption equals the private marginal benefits.

Social welfare is maximized at the point where SMC = SMB (point A, where $Q = Q_s$), but market equilibrium is at the point where PMC = PMB (point B, where $Q = Q_e$). This means that in a competitive market there is overproduction of the good and hence too much pollution, leading to deadweight loss D, represented by the shaded triangle in Figure 1.

Imposing a tax equal to t, the vertical distance between the SMC and PMC curves at Q_s imposes larger marginal costs on the firm, shifting the PMC curve upward. With the tax, the new market equilibrium will be at Q_s the socially optimal level. The tax shifted the burden of the externality onto the firms, “internalizing” it. This leads the firm to produce and pollute at the socially optimal level, eliminating the deadweight loss.

Figure 1. Supply and Demand with a Negative Production Externality



Turning to the subject of this paper, nuclear power arguably imposes a negative externality on the residents of the local community. The negative externality takes the form of the risk of accidents that would put residents in danger, the most obvious example being a nuclear meltdown. Other negative externalities could exist too, such as displeasure from pure unsightliness of the nuclear plant.

With regard to regulation, the primary methods of internalizing this externality in practice are legal liability and safety inspections. Placing legal liability on the nuclear plant for damages in the case of an accident. This liability does exist in practice, but it is not clear that it is sufficient. If the plant were liable for all damages in the event of an accident (and the only negative externality is due to the risk of these damages), then the risks would be internalized. Of course, there is the possibility that compensation gained in the event of an accident would be inadequate, in which case the externality would not be internalized. Indeed, in practice various factors limit the legal liability of the nuclear plant. In addition to corporate limited liability and bankruptcy, the Price-Anderson Nuclear Industries Indemnity Act is a federal law that limits the liability of nuclear plant operators, while requiring them to purchase insurance against the chance of an accident.

Another method of controlling the externalities associated with nuclear power is the use of safety regulations which directly impose requirements regarding the safety of a nuclear plant. These regulations are intended to reduce the risk of accidents occurring, and hence reduce the expected damages. However, only to the extent that there exist un-internalized risks due to the limitations of regulation and liability should I observe a people willing to pay a premium to live far away from the plant. If risks were fully internalized, there would be no reason to pay to avoid living near the plant because anyone harmed in the event of a nuclear accident would be fully compensated for their damages, so there would exist no net risk to the community.

In general, the goal of regulation is to price the externalities so that the emitter adjusts its operations to reach the socially optimal level of production and the externality. The efficient amount of regulation then should reflect the magnitude of harm caused by the negative externality. In order to find that magnitude, one must determine how much the affected individuals value the negative externality. As I have discussed, this value is exactly what is being reflected in differential house prices that are found using hedonic models. By estimating the price-distance relationship using a hedonic model, one can determine how strictly to regulate Pilgrim Station, or whether it should be allowed to operate at all.

III. Literature Review

Hedonic models have been used in the past to measure the impact of nuclear power plants, but the results have been mixed. Some studies have shown plants negatively affecting property values, some have found no statistically significant effect, and some have even found positive effects.

The first major study of nuclear power's effect on house prices was presented by Jon Nelson, in which he examined the impact of the accident at Three Mile Island in March of 1979 (Nelson 1981). Using home sale data, he investigated the impact of two independent variables on prices for houses within four miles of the plant: a dummy variable representing whether the sale was before or after the accident and a variable that interacted this dummy with the date of sale (effectively allowing the accident's impact to vary over time). After controlling for characteristics of the house, he found that the accident did not cause house prices to fall or even slow their rate of appreciation. Nelson hypothesized two possible reasons for this: (1) the damage was perceived a temporary, short-term shock, and so was not reflected in a market of farsighted buyers and sellers and/or (2) expected state and federal aid acted as insurance policies that offset any potential losses.

Gamble and Downing looked at the Three Mile Island incident as well, but they also analyzed other plants that did not have accidents (1982). In their study of the other plants, they used home sale data to examine the impacts of two variables: the nuclear plant being visible from the house and the house's distance from the plant. Under several different specifications, the coefficients on each variable were statistically insignificant after controlling for characteristics of the house. They applied this same model to the Three Mile Island plant, with the addition of a dummy variable indicating if the sale occurred after the accident, as well as a variable that interacted this dummy with the house's distance from the plant. Their results indicated that the coefficient on distance from the plant was significant and positive before the accident, but insignificant afterwards. Gamble and Downing attributed this change to the fact that the Three Mile Island incident was followed by the large-scale hiring of clean-up workers and nuclear technicians, potentially increasing the housing demand near the plant as the new hires moved in.

In 1986, Galster critiqued this study for its implicit long-run focus. Pointing out that the housing market collapsed for a brief period following the incident, he argued that the finding that there were little to no long-run effects of the Three Mile Island incident on house prices ignores the important short-run impacts (Galster 1986).

In 1997, Rephann used a quasi-experimental method to analyze the impact of various "LULUs" (locally unwanted land uses), including nuclear power (Rephann 1997), finding that nuclear plants significantly increase local tax revenue. He argued that the common finding that nuclear plants do not significantly affect house prices is due to the negative effects being swamped by the positive effects on the community of massive local property tax revenues.

Large amounts of tax revenues from nuclear plants can increase the amount of public services offered by the local government or by decreasing the tax rate needed to achieve a given level of public services. Both of these effects increase the value of living in that community. As a result, tax revenue from nuclear plants can increase house prices. This positive impact could hide the negative effect on property values of the risks posed by nuclear plants.

In reference to the employment effect, Rephann finds evidence that nuclear power plants do not significantly stimulate local employment because they generally perform national searches for a few highly trained specialists and because they are generally a high-capital, low-labor business. This finding is helpful for the interpretation of observed price-distance relationships in this paper, since it implies that estimates for the house-price impact of the risks of nuclear power are not strongly biased by employment effects.

A 2006 study by Bezdek and Wendling examined the areas around seven nuclear plants across the United States. They investigated the effect of the plant on house prices and employment, but they also considered the effect of increased tax revenue from the plant on local incomes, community development, and schools. They found that in each case the creation of the plant was associated with large net benefits for the community. Property values in regions with nuclear plants tended to appreciate on par with the state average, and economic growth in these areas following the construction of the plant exceeded the state-level average. Bezdek and Wendling attributed much of this growth to the nuclear power plant: for example, the tax revenue from each plant in their sample funded 50% or more of the budget for its county and school district. However, they made some caveats to this claim, such as the fact that the areas where the plants were built were initially in poor economic shape, so their disproportionately high growth could simply be the region catching up to the mean.

The issues emphasized in Bezdek and Wendling's study should not threaten to bias this paper's results. First, Plymouth is not an economically depressed area: its median household income of $50,838 in 2007 was remarkably similar to this figure for the United States as a whole: $50,740, and a smaller proportion of the Plymouth population falls under the poverty line, 7.4%, compared to the Massachusetts state average of 9.3% (2000 Census, City-Data). Second, the potential positive effect on property values due to tax revenues should not bias this paper's results, since the positive effect should increase house prices evenly across the entire town. This implies that the observed price-distance relationship should not be biased, since the tax revenue from the nuclear plant should affect all houses equally.

In contrast to the above findings of insignificant or even positive impacts of nuclear power plants on house prices, Folland and Hough's 1991 cross-region study found that regions with nuclear power plants had significantly lower house prices than those without. This finding was reinforced by another cross-region study by Clark and Nieves in 1994 that looked at a variety of noxious facilities including nuclear power plants. They found that significant negative impacts on house prices for each nuclear plant within a set distance of the property. An objection to these findings is that when searching for a location to build a nuclear power plant, facility builders tend to seek out cheap land for construction. As a result, this negative interregional association between house prices and the existence of a power plant could simply reflect the tendency of plants to be built in areas with initially cheap land. In response to this criticism, Folland and Hough (2000) followed up their initial study by controlling for this tendency of builders to seek out cheap land by comparing house prices before and after the announcement and installation of each power plant, and the negative impact of nuclear plants on house prices persisted. They estimated a nuclear plant "installation effect" of about -10% on house value. Further, the authors criticized the studies of Three Mile Island by pointing out that the area was actually safer after the accident, since the reactor went offline, so the findings of no effect on house prices is not necessarily inconsistent with the existence of a nuclear-based negative externality in this instance.

In another application of the hedonic model to nuclear power plants, a study by Clark, Michelbrink, Allison, and Metz (1997) examined two California nuclear power plants: one in Diablo Canyon and one in Rancho Seco. In each case, Clark *et al.* found that house prices actually increased with proximity to the plant, suggesting that any detrimental impact of the plants could not have been large, if it existed at all. In a related study, Metz and Clark (1997) also examined the impact of media coverage of these two plants on house prices. They analyzed the level of newspaper coverage regarding plans to construct a new dry storage nuclear waste facility at these plants, finding that this coverage had only minor impacts on prices. Interestingly, the new dry storage facility was not housing more waste; it only changed the type of storage of pre-existing nuclear waste. Although small, these price impacts could simply reflect changes in the salience of this nuclear waste storage among the public, not actual changes in risk. In this study, I similarly test the relevance of this kind of "salience effect" by testing for a relationship between media coverage and sale price.

Clark and Allison continued to analyze the impact of newspaper coverage of local nuclear power plant issues on housing prices in their 1999 paper. This study focused on the Rancho Seco plant examined in their previous papers. After including a large number of controls, they found that reminders of the plant in the forms of visual cues, proximity, and media attention had statistically significant negative impacts on house prices, although these impacts were generally small (Clark and Allison 1999).

Gawande and Jenkins-Smith performed a study in 2001 that examined the impact of a series of highly publicized shipments of nuclear waste in South Carolina on house prices. This study differentially considered the price impacts in different kinds of areas: those with low risk perception and those with high risk perception. Areas that had more experience dealing with nuclear waste tended to have a lower perception of the risk of the shipment, and correspondingly the house-price impact of these shipments was not statistically significant. However, urban areas considered these shipments more risky, and there was a significant negative impact on house prices there. They argue that "it may not matter whether public perceptions of the risk [on which price impacts are based] are accurate" since the impacts on house prices are nevertheless real. In terms of legal cases, they also point out that negative price impacts based on public risk perceptions are still legally considered grounds for a lawsuit, "even if the public perceptions of risk are not deemed 'reasonable'" (Gawande and Jenkins-Smith 2001, p. 230).

In sum, the evidence on the impact of nuclear power plants on local property values is mixed, and the issue remains contentious. Many studies find no effect of nuclear power plants on local house prices, while others argue that there does exist a significant negative effect. Still others argue that nuclear power plants benefit the local community through various channels: one channel being the large amounts of tax revenue they generate, and a more controversial one being the claim that physical proximity to nuclear plants actually directly *increases* property values. Further research is needed to settle this contentious issue, and in this paper I hope to aid in the progress toward that goal by examining Pilgrim Station, keeping in mind the problems and biases discussed in past studies on the issue.

IV. Methodology

In order to estimate the impact of the Pilgrim nuclear plant on house values, I use a hedonic model following Rosen (1974). These models generally assume that houses contain a bundle of services. Since homebuyers take into account the array of different services that homes provide, their willingness to pay for a house can then be broken down into a different willingness to pay for each individual service. By estimating the magnitude of the effects of each housing amenity on the price of a home, I can estimate consumer willingness to pay for certain environmental goods. For example, when comparing two otherwise identical houses, save for the fact that one is located near a nuclear power plant, one would expect this house to fetch a lower price than its twin. The difference between the prices of these houses can then be considered a rough measure of the value that individuals place on avoiding the risks of living near a nuclear power plant. In this paper, I use this type of method to examine the value that individuals place on the risks and unsightly imagery of nuclear power in Plymouth, MA.

The idea laid out above explains the core intuition behind the hedonic price method, but further elaboration is required. In this section, I formally lay out the methodology that I use to estimate the value placed on avoiding living near Pilgrim Station.

IV. 1. Hedonic Model Estimation

In my analysis, I assume that house prices can be modeled as a function of various housing amenities of the following form:

$$Log(\text{Real House Price})_i = \beta_0 + \beta_1 Log(\text{Pilgrim Distance})_i + \sum_{j=2}^{n} \beta_j x_{ji} + \varepsilon \qquad (1)$$

where each x_{ji} variable represents an amenity of property i such as number of acres, house style, and local demographic statistics, with j indexing the n different housing amenities included in the model. These variables act as controls, so that I can isolate the effect of the primary variable of interest: the distance of the property from Pilgrim Station ("*Log*(Pilgrim Distance)" in equation (1)). In the absence of bias, estimating β_1 will then provide a measure of the "price" of reducing the risks of nuclear power.

Note that the functional form assumed above is a log-log model; this model has many advantages over a basic linear model. The log-log model has been used extensively in the hedonic studies, in which it has performed reasonably well at fitting the data and measuring marginal prices (Sheppard 1999). One advantage is that the coefficients on the log variables represent elasticities. Thus, β_1 represents the percentage change in house price from a one percent increase in the distance from the nuclear plant. This makes interpreting the results from the log-log functional form intuitive and easy.

Second, the logarithmic functional form is one that allows the magnitude of the dollar-denominated effect of distance on price to diminish with distance, as intuition would imply. Clearly a one-kilometer increase in distance from the nuclear plant should matter more near the plant than it does further away because the damages of a nuclear accident would dissipate with distance, and the logarithmic model incorporates this idea. Third, the logarithmic form also "pulls in" outliers, so that properties with extreme prices or distances do not single-handedly drive the results.

I also include a variable representing the extent of media coverage of the dangers of nuclear power: the logarithm of the number of *Boston Globe* articles in the year of the house's sale[2] that prominently feature Pilgrim Station and the risks to the community associated with the plant. The inclusion of this variable allows me to test for the existence of an effect of media coverage on the public perception of nuclear risks and hence on house prices. The coefficient of this variable represents the relationship between the extent of media coverage and house prices.

In this paper, I estimate equation (1) with several variations. I estimate the basic model outlined above, using two different sets of house style indicator variables to find the most appropriate model. I then estimate the two models including year fixed effects to control for year-to-year shocks (such as the burst of the housing bubble) and to gain a better sense of the effect of the media variable, which could produce anomalous results if it is associated with year-based shocks. I use the results of these models to find the damages associated with the plant.

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[2] The main body of this paper uses the number of *Boston Globe* articles in the year of sale, but other time periods and specifications are explored in the appendix.

IV. 2. Damage Estimation

To measure the economic efficiency of policy decisions regarding the operation of the negative externality-producing power plant, I must estimate costs and benefits. In the case of a nuclear power plant, the benefits of closing it are simply equal to the negative of the damages. These damages can be estimated as the marginal willingness to pay to avoid pollution (MWTP) that is reflected in house prices. However, as Figure 2 demonstrates, the price of avoidance and the marginal willingness to pay *functions* are not the same. MWTP1 represents the marginal willingness to pay curve derived from the utility function of a hypothetical consumer 1, which should feasibly decline with distance. The price of increasing a house's distance from the plant represents the house price premium placed on increasing distance by one unit from the equilibrium hedonic price function. This is assumed to decline with distance in Figure 2, reflecting the declining value placed on distance father away from the plant, where exposure to radiation would be less sensitive to marginal changes in distance.

Given this price function, consumer 1 will "purchase" distance until its price is equal to the marginal willingness to pay for an additional unit. The same applies to consumer 2, who is more averse to living near the nuclear plant and hence buys a house farther away than consumer 1. Ideally, one would like to directly observe the marginal willingness to pay functions. Unfortunately, one only observes the prices paid for houses, although the hedonic method allows one to separate out the price paid for individual characteristics such as distance from the nuclear plant. Still, the observed prices provide a clue about each consumer's underlying willingness to pay. For both consumers, the value placed on the initial units of distance exceed the price paid for them,[3] so the true willingness to pay to reduce the risks of nuclear power (and hence the damages of these risks) are larger than the price indicates. Thus, the price of distance (or, equivalently, the measured damages to a house) understates the true willingness to pay to reduce the risks of nuclear power. This result is analogous to the market for any good, in which the price of the good is less than or equal to consumers' willingness to pay. If this were not the case, consumers would not purchase it.

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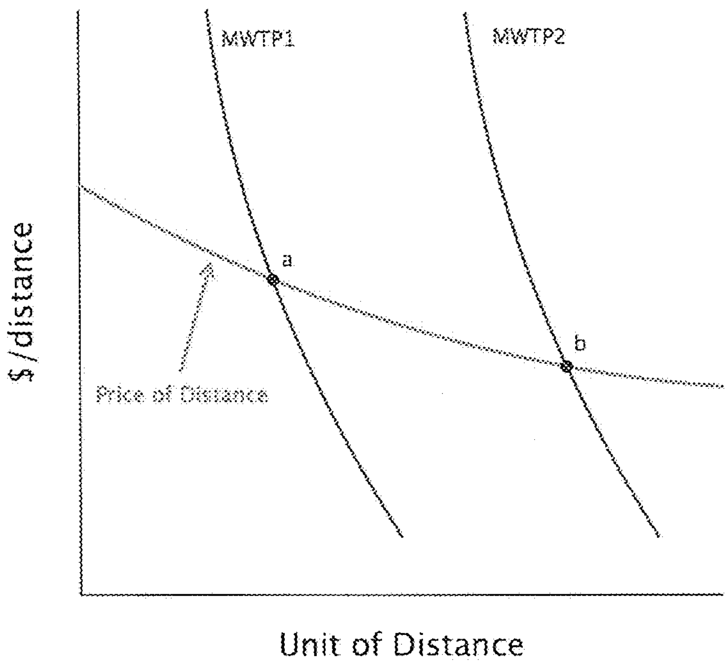
[3] This assumes that the marginal willingness to pay curve is steeper than the price curve. This is a reasonable assumption when one considers the alternative, in which the consumer would want to purchase a house infinitely far from the nuclear plant.

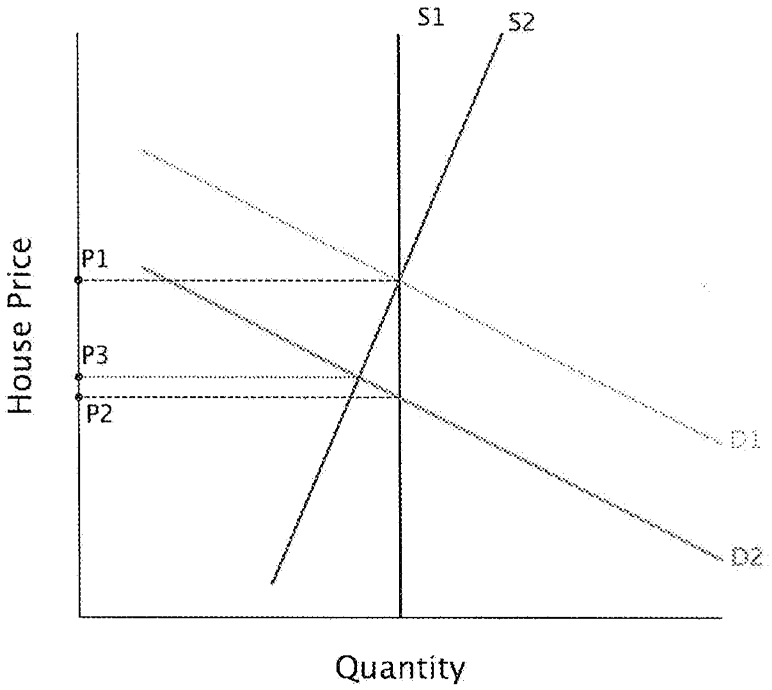
Figure 2. The Price of Distance and MWTP



While the "price of distance" from the nuclear plant understates the willingness to pay for a house farther away from the nuclear plant, the observed price-distance relationship can still be used to estimate damages attributable to the plant. Consider Figure 3, which shows the hypothetical supply and demand for housing in a region. D2 and D1 represent the demand functions for properties that are identical in every way except for their exposure to the negative externality, with "D2 houses" being adversely affected and "D1 houses" being "safe," or unaffected. If housing supply is fixed and invariant to distance from the plant (a case represented by S1), then the difference in marginal willingness to pay from increased exposure (D2–D1) will be fully reflected in difference in price (P1–P2).

Since an individual buys a house at this price, the observed difference in price corresponds to an individual's intersection point between his or her marginal willingness to pay curve and the price line in Figure 2. In this case, the price differential between the houses is an accurate measure of the damages from the negative externality.

Figure 3. Supply and Demand for Houses



Housing supply can reasonably be considered to be fixed in the short-run, when houses cannot be built quickly in response to changes in prices, but what if housing supply is upward sloping? This case is represented by S2 in Figure 3, showing that the difference in price (P1–P3) will not reflect the full difference in marginal willingness to pay. Thus, directly measuring the difference in average house prices gives a lower bound for the difference in marginal willingness to pay due to the increased exposure to the negative externality. While recognizing the fact that the observed difference in house prices based on distance to the plant will likely understate the true willingness to pay to avoid pollution and hence understate economic damages, estimating such price differences can still provide a useful lower bound measure of the magnitude of these damages. Once an estimate of the damage for each house is calculated, I can sum this estimate over all houses to give an estimate of the total damages of the negative externality.

The process described above works well when one has a natural experiment, but unfortunately I do not have one. For example, if I had data on house prices in Plymouth before and after the plant was announced and built in 1972, then I could compare house prices before and after this time to accurately estimate the effect of the nuclear plant. It becomes more difficult when one has data for only non-experimental situations such as this. In such a situation, one must assume that the houses that are sufficiently far away from the plant are "safe," meaning that the price is unaffected by the negative externality associated with the nuclear plant. Then, I can assume that the price level of these houses would prevail (*ceteris paribus*) for properties near the plant as well. In other words, I choose properties that are significantly far away from the source of the negative externality as "safe" houses to which properties near the plant can be compared. The difference in prices between these safe houses and houses near the nuclear plant (holding other differences constant) can then be used as a measure of the damages of the negative externality. To elucidate the damage calculation mathematically, recall equation (1):

$$Log(\text{Real House Price})_i \;=\; \beta_0 + \beta_1 Log(\text{Pilgrim Distance})_i + \sum_{j=2}^{n} \beta_j x_{ji} + \varepsilon$$

Raising e to each side of the equation gives the real house prices as a function of log-distance and the other independent variables:

$$e^{Log(\text{Real House Price})_i} \;=\; e^{\beta_0 + \beta_1 Log(\text{Pilgrim Distance})_i + \sum_{j=2}^{n} \beta_j x_{ji} + \varepsilon}$$

Note that the left side of this equation simplifies to the real house price. Once equation (1) is estimated, I use the estimated $\hat{\beta}$ coefficients to predict real house prices for each house:

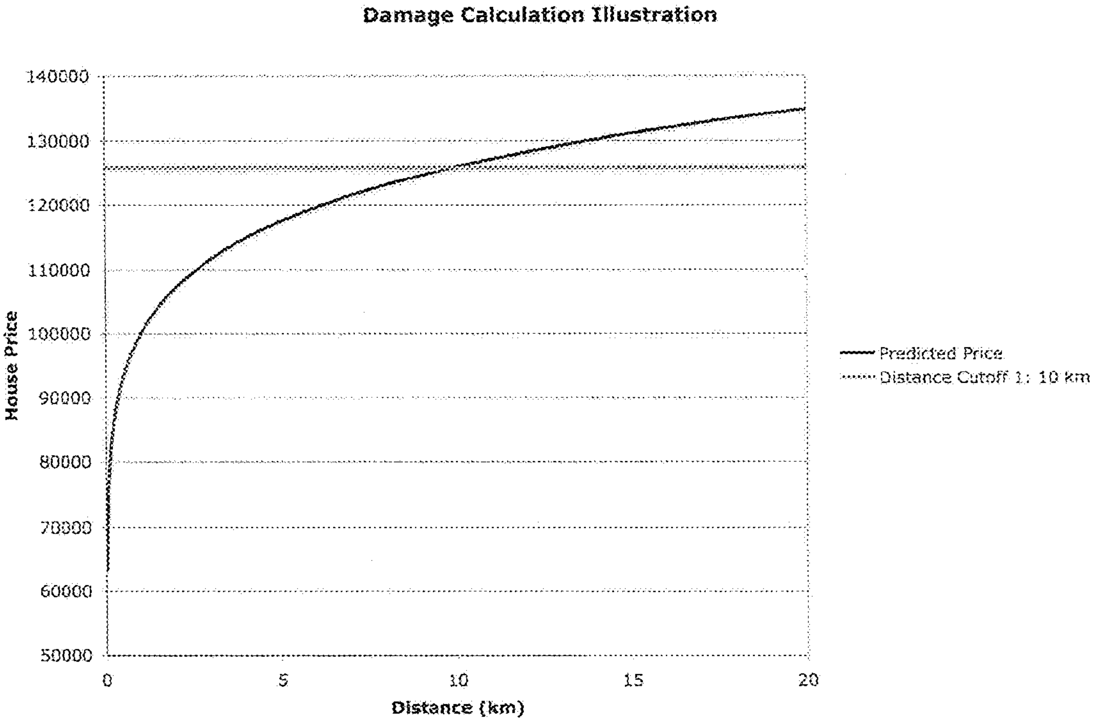
$$\text{Predicted Real House Price}_i \;=\; e^{\hat{\beta}_0 + \hat{\beta}_1 Log(\text{Pilgrim Distance})_i + \sum_{j=2}^{n} \hat{\beta}_j x_{ji}}$$

Denote the distance that I assume to be the point beyond which houses are considered in the "safe" group as D_C. Comparing the real house price of house i that is distance D_i from the power plant to the predicted real house price of a house that is D_C away results in equation (2), which represents estimated damages:

$$\text{Estimated Damages}_i(D_i) = e^{\hat{\beta}_0 + \hat{\beta}_1 Log(D_i) + \sum_{j=2}^{8} \hat{\beta}_j x_{ji}} - e^{\hat{\beta}_0 + \hat{\beta}_1 Log(D_C) + \sum_{j=2}^{8} \hat{\beta}_j x_{ji}} \quad (2)$$

Estimating the damages using equation (2) for each house in effect compares each house's predicted price to a hypothetical identical house that is D_C kilometers away, attributing the price difference to the damage from proximity to the plant. Graphically, this estimation technique is similar to computing the difference above the "predicted price" line and below the "distance cutoff line" in Figure 4 at a given distance.[4]

Figure 4.



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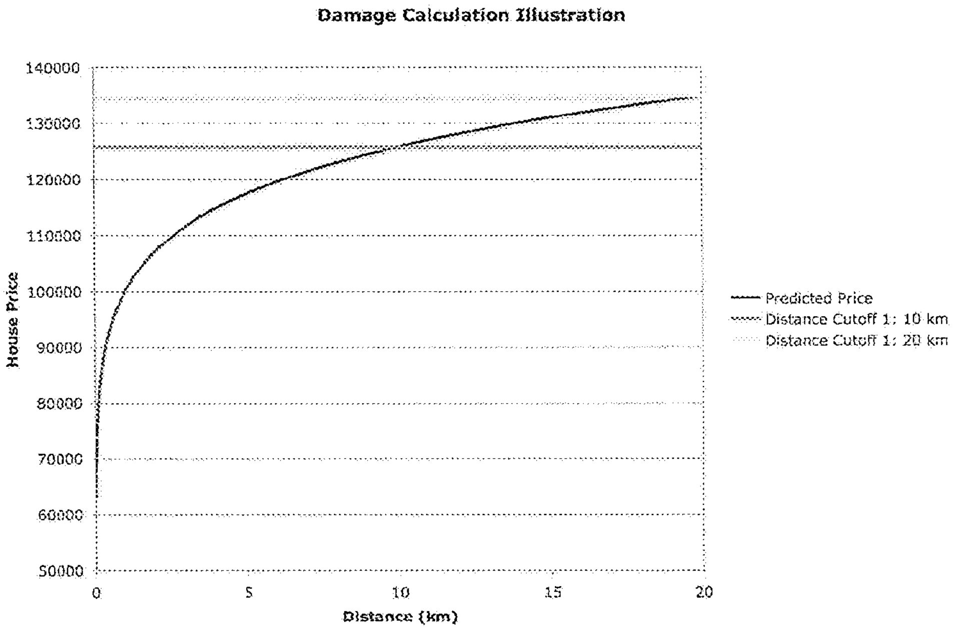
[4] I say "similar" because it is not quite identical to this procedure. The difference is that the predicted price curve in Figure 4 is based on the control variables taken at their sample means, whereas the damage calculation used uses the actual values of sample variables for each observation.

Since the price-distance relationship should be zero at distances beyond D_C, direct damages should theoretically be zero for houses where $D_i \geq D_C$. However, as Figure 4 illustrates, the logarithmic functional form is strictly increasing in D_C, so damages for these houses are measured as negative.

These "negative damages" are excluded from my analysis for several reasons. First, the distance cutoff should theoretically be chosen to be a point beyond which houses are no longer affected by the nuclear plant. Otherwise, this is not a proper choice of comparison group. Second, if prices are believed to continue to rise beyond D_C, then these estimated "negative damages" would be unbounded with distance. For example, houses 1000 kilometers away would be predicted to have exceedingly high value because of the assumed logarithmic functional form, which is strictly increasing. Of course, this relationship is not likely true at extreme distances. In my calculations, "negative damages" are only finite because the sample is finite and limited to the town of Plymouth, with the sample's maximum value of the distance from the nuclear plant of 20.49 km. Finally, the higher prices for houses further away may be appreciated by their residents, but they still represent a willingness to pay to avoid a negative externality, so they actually reflect diminishing damages.

For houses within D_C of the plant, damages will be positive, decreasing in D_i, and increasing in D_C. The first two of these three effects are clearly illustrated in Figure 4. Figure 5 demonstrates the fact that damages are increasing in D_C. Clearly, the choice of a 20 km cutoff rather than a 10 km cutoff results in larger damages for every house, as the difference between the cutoff line and the predicted price line becomes larger with the higher cutoff choice.

Figure 5.[5]



The intuition for this relationship is simple: increasing the distance cut-off places more houses into the "damaged" group, as well as increasing the estimated hypothetical "unaffected" price. As a result, D_C must be chosen carefully. In the results section, I estimate damages for several values of D_C to illustrate the level of sensitivity of the results to this choice and to provide a sense of the range of the damage estimates.

Once damages are estimated for each house, the total damages due to the nuclear plant can be calculated as the sum across all houses in Plymouth. Since

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[5] For the graphs illustrating the damage calculation technique, I have used a hypothetical relationship where the predicted value of a house is $100,000 at 1 kilometer away from the plant, with an elasticity of price to distance of 0.1 (i.e. +1% distance implies +0.1% house price).

my sample does not contain every house in Plymouth, summing damages across the sample will understate damages. To correct for this, these damages are summed for each Census Block j and scaled by a factor α_j according to the sample's misrepresentation of the actual number of houses in that block. For example, if there are 1000 houses in a block as measured by the year 2000 Census, but the sample only has 500 houses in that block, then the damages are summed across all 500 observations and multiplied by $\alpha_j = \frac{1000}{500} = 2$ in order to replicate the damages for the unobserved houses in that block. Then, estimated total damages are given by:

$$\text{Total Damages} = \sum_j \alpha_j \sum_{i \in j} \text{Damages}(D_i)$$

On average, each block contains about 1.88 as many households as observed in my sample according to the Census, so in effect this correction roughly scales damage estimates by 1.88. A house's distance from Pilgrim Station is negatively associated with α_j, with a 1 km increase in distance being associated with a 0.023 decrease in α_j (significant at the 99% level). This means that the sample was drawn more heavily from areas near the plant, but the magnitude of this relationship seems small. This could suggest some sample selection bias, but it is not immediately clear which direction this would bias the estimates.

As I have argued, the damage estimate would then be biased downward to the extent that prices understate true willingness to pay. However, there is also the possibility that prices for houses in the "safe" group are artificially high. This could be so if the presence of the negative externality shifts housing demand further away from the plant, pushing up house prices in the "safe" group. This would bias estimates of damages upward, so the true net direction of these biases is unclear. Unfortunately, this is a potential bias that cannot be controlled for in the absence of an experimental situation.

V. Data Description

The bulk of the data was obtained from the Plymouth Tax Assessor's office. After discarding obviously problematic observations (e.g. houses with a real sale price under $5,000 in year 2000 dollars), there exist well over 13,000 observations, with the bulk of them dating back to 1992, as well as a few observations from the 1970s and 1980s. The data include many variables describing the house, including most importantly sales price, sales date, street address, and number of acres.

I focused the analysis on residential house sales that were sold at arms length as a single lot (i.e. not tied to the purchase of another lot). I focus on residential houses because commercial property prices are unlikely to reflect the negative externalities of living near the nuclear plant, biasing estimates of the true impact on Plymouth residents. I do not include properties that were sold as part of a bundle package of many lots because the only price that was recorded for these sales was the aggregate price for the entire bundle. As a result, the sale price of such houses is unlikely to reflect the true value of the single lot of land. Finally, I excluded houses that were not sold at "arms length." A sale that was *not* done at "arms length" is defined as a sale within a family or corporation, or a sale due to bankruptcy or foreclosure. In these cases, the sale was likely done at a price well below the true market value. Indeed, including these observations in the model along with indicators for each of these characteristic results in large, significant, and negative coefficients on each indicator.[6] Even after excluding houses that are not residential, single lot, and sold at arms length, the sample still has over 10,000 observed sales.

In order to examine the hypothesis that media coverage has an effect on the damages of the nuclear plant to property values, I searched the Lexis-Nexis database of *The Boston Globe*, tallying the number of articles from each year between 1992 and 2008 that significantly discuss the risks of nuclear power. Articles that only tangentially referred to the plant (e.g. as a frame of reference when describing the energy output of another plant) are not included in this tally. There were only a few articles that reported positive aspects about the plant, and these articles were not included in the tally. The mean number of articles over the 17-year period is 18.7 articles per year, with 8 years having fewer than 18 articles, and 9 years having more. Figure 6 shows the distribution of these articles over time.

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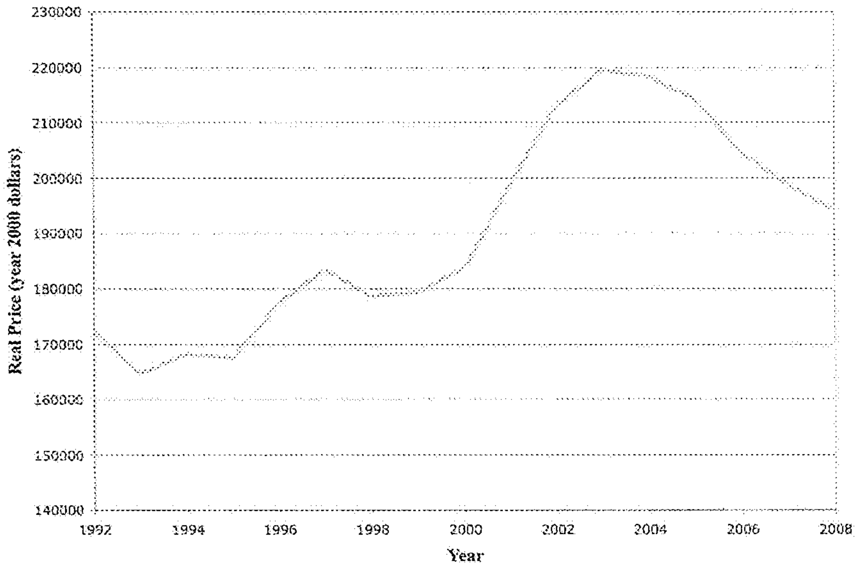
[6] Including these indicators in the model does not significantly affect the estimated impact of proximity to the nuclear plant, but it reduces the R-squared value.

Figure 6. ***Boston Globe*** **articles over time**

I also collected the monthly Housing Price Index (HPI) for the Boston metro area from the Office of Federal Housing Enterprise Oversight (OFHEO). I use the Boston HPI to deflate the observed nominal sales prices in the raw data. This deflation serves two purposes: first, it controls for general inflation in the economy, and second, it controls for regional trends in house prices. The latter adjustment is especially important when considering the recent boom and bust in house prices in the United States, Boston included. However, even with this deflation of nominal prices, the real price data for Plymouth appears still to show a pattern of boom and bust in recent years, as can be seen in Figure 7. The persistence of this pattern indicates the fact that Plymouth was hit harder than the general Boston area by both the rise and fall of house prices.

Figure 7. Annual Average House Prices
Deflated by Boston HPI, Year 2000 dollars



I used the program ArcMap (a Geographic Information System program) to measure the distance of each house to the nuclear plant, as well as the distance to several other relevant locations, by using the house's recorded street address. For each house, I calculated a distance to each of the following locations: the Pilgrim nuclear plant, the state park, the shore, the highway, and the Pilgrim green space (the wooded area surrounding the nuclear plant). The means and standard deviations of the independent variables included in my models are reported in Tables 1 and 2.

Table 1. Summary Statistics

n = 10,428

Variable	Mean	Std. Dev.
Real Sale Price (HPI deflated, year 2000 dollars)	$198,077.90	$94,734.44
Adjusted Total Acres	0.589 acres	0.970 acres
Distance from Pilgrim Nuclear Plant	9.615 kilometers (km)	4.136 km
Distance from State Park	5.282 km	1.977 km
Distance from Shore	2.528 km	2.111 km
Distance from Pilgrim Green Space	5.258 km	3.205 km
Distance from Highway	2.259 km	1.631 km
House Age	29.88 years	36.64 years
Finished Area	1860.843 sq. ft.	2029.85 sq. ft.
No. of Stories	1.69	0.55
No. of Rooms	6.57	2.19
No. of Bedrooms	2.96	1.08
No. of Full Baths	1.66	0.76
No. of Half Baths	0.49	0.54
Percent of House Air Conditioned	27.72%	44.66%
Boston Globe articles in year of sale	20.06	13.08

Sample Description

Category	Characteristic	Proportion of Properties
Owner Occupied?	Yes	84.26%
	No	15.74%
Condition	Average	73.02%
	Good	26.22%
Building Type	Ranch/Raised Ranch	19.65%
	Colonial	19.35%
	Cape	15.53%
	Condo	11.72%
	Contemporary	6.86%
	Garrison	6.74%
	Gambrel	5.29%
	Townhouse	3.51%
	Cottage	1.64%
Roof Type	Regular	88.60%
	Metal	6.15%
	Membrane	4.47%
Zone	Residential – Medium Lot	37.57%
	Residential – Rural	25.58%
	Residential – Small Lot	19.49%
	Residential – Mixed Density	11.86%
Sale Information	None	82.05%
	Changed Assessment	5.00%
	Bank Sale	2.84%
	Court/Probate	2.25%
	Other	1.93%
	Changed Sale	1.84%
	Partial Ints.	1.21%
	Convenience	1.08%

Table 2. Census Block Demographics*

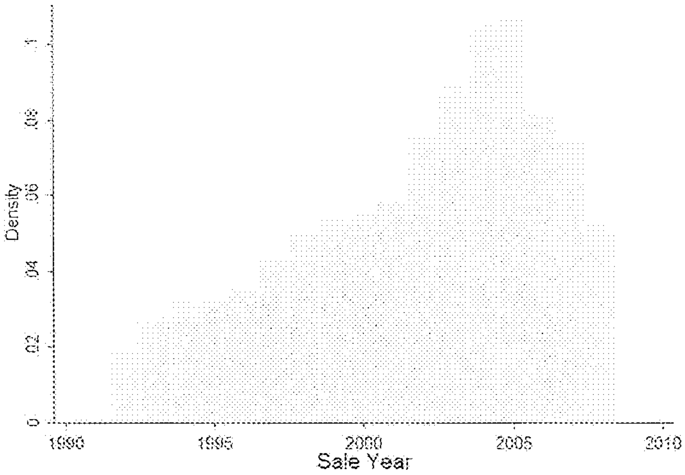
Variable	Mean	Std. Dev.
Average Household Size	2.74	0.36
Percent Caucasian	95.69%	3.77%
Percent of Properties Vacant	6.34%	7.94%
Percent of Properties Owner Occupied	28.84%	5.45%

*The demographic statistics presented here do not accurately represent the demographic makeup of Plymouth as a whole. Rather, the statistics here are averaged across the sample, meaning that they represent the average demographics of the community among all houses. In other words, the denominator when averaging is the number of house observations.

A few notes must be made on the control variables listed in Table 1. The reader may notice that many of the continuous "logged" variables are labeled as "Adjusted," such as "Log(Adjusted House Age)." For each of these, the underlying variable was equal to zero in the original data for some homes. For some of these variables, this is logical (for example, it is possible and common for a house to have an age of zero at the time of sale), but the logarithm of zero is undefined. For all of these variables except "Log(Adjusted Total Acres)," I have added one to the underlying variable, and then taken the logarithm, so that these variables can be included in the model while preserving the underlying relationship between the variables and house price. For the total acreage, some entries were recorded as having zero total acres. To help correct for these missing values, I adjusted the total acres for the observations to equal the total finished area of the house in order to approximate the minimum size of the plot of land that the house must be built upon.

The reader may notice that several other location-based independent variables are included in the model. One may worry that this would pose problems of collinearity, which would manifest itself in the form of large standard errors. Fortunately, there appears to be sufficient independent variation in the data to provide reasonably precise estimates, as most estimates of the elasticity of house price to the distance from the nuclear plant are significant at the 99% level.

Figure 8. Sale Date



The span of years for which I have sales data is fairly broad. Most sales fall between 1992 and 2008, with only five sales occurring before 1992.[7] Figure 8 illustrates the distribution of sales over time, showing that I have a broad distribution of observations over time. There is a trend of an increasing volume of house sales leading up to 2005, and falling thereafter, but this is unsurprising given the national housing boom and bust corresponding to this time frame.

Further, the level of media coverage is unrelated to the number of sales in each year. The correlation between the number of *Boston Globe* articles and the number of house sales in a year is -0.002. There does seem to be a significant relationship between the location of sales and the amount of media coverage. A univariate regression of the annual average distance from the nuclear plant among all sales on the number of *Globe* articles found a negative relationship that was significant at the 95% level. However, the magnitude of this relationship is small, with an additional article being associated with a reduction of 8 meters in average distance from the nuclear plant. This seems small in comparison, when considering that the average distance from the nuclear plant among all houses is 9.6 km.

Figure 9 presents a map of Plymouth, Massachusetts, created using ArcMap. This map includes a large red dot indicating the location of the Pilgrim nuclear plant, and smaller blue dots representing house sale observations that are included in the model. This map provides a sense of the layout of the area of

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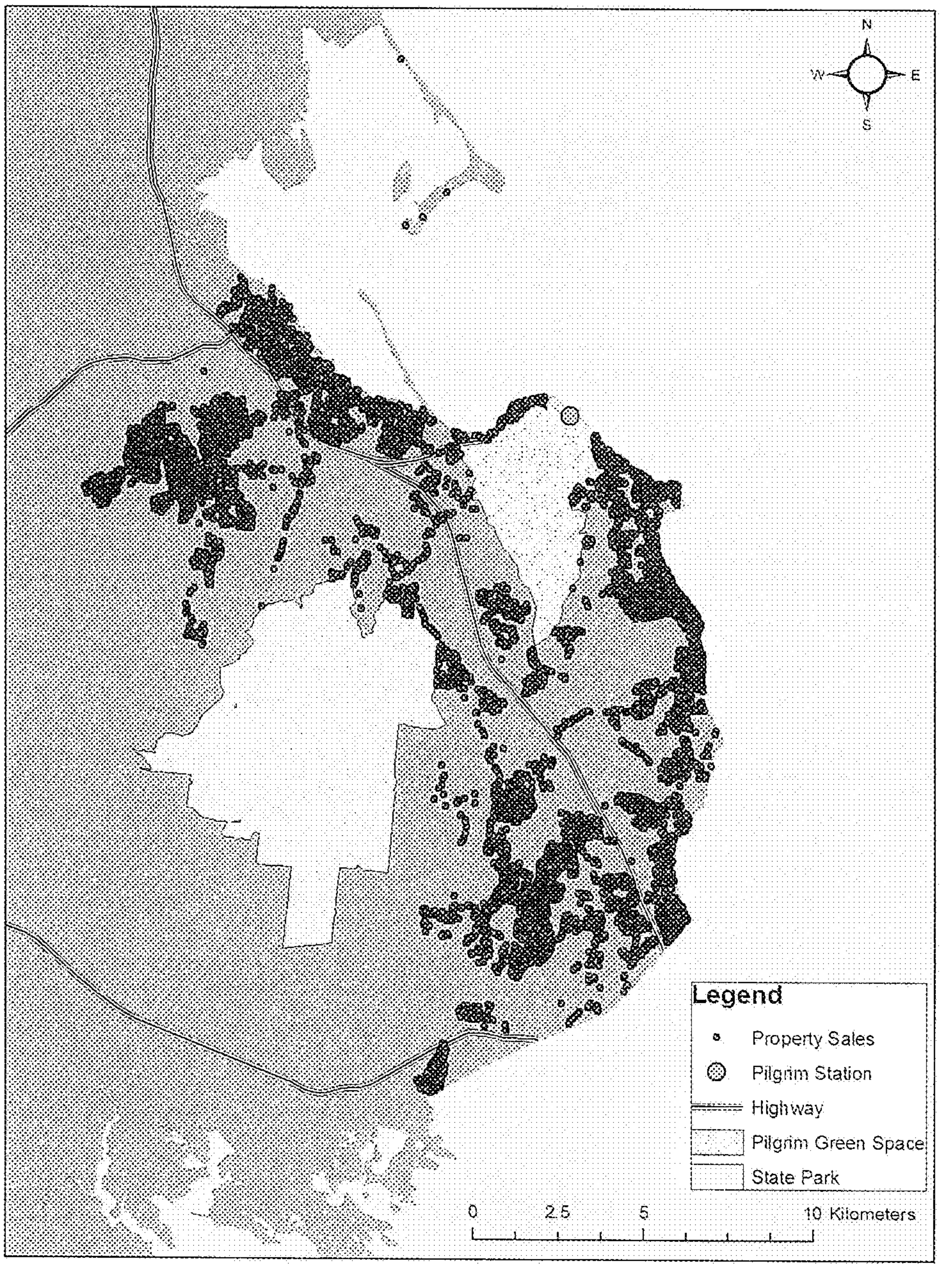
[7] Because there is no indication of why these five old sales were included in the data set, whereas other old sales were not, I have excluded them from the analysis.

study.

Figure 9. Plymouth Map



VI. Results

In this section, I present the estimates of the relationship between the price of a house and its distance from the nuclear plant. I present a range of estimates, from a low elasticity of 0.026 to a high of 0.104, using four different variations of the model. With these estimates in hand, I then proceed to calculate estimated damages associated with the nuclear plant. I further calculate these estimated damages using several different cutoff distances (D_C) as described in section III. I also estimate the benefits of the Pilgrim green space using a similar method and compare them with the estimated damages of the power plant.

VI. 1. Regression Estimation

The initial model (model 1) includes the control variables listed in Tables 1 and 2. Column 1 of Table 3 shows the results of this regression. For purposes of space, the results for most control variables have been omitted, and only the following variables have been presented (all in logarithmic form): number of relevant *Boston Globe* articles in year of sale,[8] and the distances to the Pilgrim nuclear plant, the shore, the state park, and the green space.

Since this is a log-log model, these coefficients can be interpreted as elasticities. The results from this model imply that a 1% increase in distance from the nuclear plant would increase the price of a house by 0.0442% (*ceteris paribus*). This coefficient is significant at the 95% level. The sign of this

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[8] While all of the models presented in this paper include a media coverage independent variable, removing this variable from the models does not substantially change results.

coefficient is sensible—increasing distance from the plant reduces the exposure to the negative externality of the nuclear plant, and so people should be willing to pay a premium for it. Further, the magnitude seems roughly appropriate as well; to put this in perspective, the compare this with the coefficient of the control variable for Log(Finished Area in Square Feet) of 0.3123 or the coefficient of the Log(Shore distance) variable of -0.0588. Thus, proximity to the nuclear plant appears to have a somewhat weaker impact on house prices than proximity to the shore does, but the effect is much weaker than that of having a larger house (in finished area).

Table 3. Regression Results

Dependent Variable: Log(Real House Price)

	Coefficient			
	(1)	(2)	(3)	(4)
Log(Pilgrim Distance)	0.0442**	0.0260	0.1040***	0.0861***
	(2.39)	(1.45)	(5.65)	(4.82)
Log(*Globe* articles)	0.0179***	0.0163***	0.0188***	0.0195***
	(4.96)	(3.19)	(5.12)	(3.74)
Log(Shore Distance)	-0.0588***	-0.0641***	-0.0685***	-0.074***
	(-14.03)	(-15.80)	(-16.31)	(-18.22)
Log(Pilgrim Green Space Distance)	-0.0327***	-0.0239***	-0.0564***	-0.0476***
	(-3.89)	(-2.93)	(-6.76)	(-5.87)
Constant	9.32***	9.52***	7.71***	7.94***
	(23.63)	(24.91)	(19.38)	(20.57)
No. of House Style Indicators	48	48	9	9
Year Fixed Effects?	No	Yes	No	Yes
R-squared	0.6138	0.6392	0.5976	0.6232
Adjusted R-squared	0.6096	0.6348	0.5947	0.6199
No. observations	10428	10428	10428	10428

t-statistics in parentheses

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively

The other coefficients reported are interesting as well. The coefficient on (the log of) distance from the shore has the expected sign and a sensible magnitude: a 1% increase in distance from the shore decreases house prices by 0.0588%. The coefficient on the distance from the Pilgrim green space similarly has the expected sign and magnitude.

Of these, the anomalous coefficient is the one on the logarithm of *Boston Globe* articles. According to this model, a 1% increase in *Globe* articles discussing the dangers of the Pilgrim nuclear plant in the year of a house sale is associated with an *increase* in the sale price of a house by 0.0179% (significant at the 99% level). The sign on this coefficient is certainly counterintuitive, as one would expect that media coverage of the risks of nuclear power would increase the salience of nuclear risks and hence drive down house prices in Plymouth. One possible explanation for this result is that the *Globe* article variable is highly correlated with year-specific price shocks. In order to control for this possibility, I add year fixed effects to this initial model. The results of this model are presented in column 2 of Table 3.

As the table shows, the inclusion of year fixed effects does not substantially change the coefficient on the media coverage variable. The sign and significance of this coefficient are still troubling, with a 1% increase in media coverage being associated with a 0.0163% increase in house sale price. This anomalous result is explored more in the Appendix but put aside for the moment because of the lack of clear explanation, even under models 3 and 4.

The inclusion of year fixed effects also reduces the estimated magnitude and significance of the coefficient on the Log(Pilgrim Distance) variable relative to model 1. Model 1 shows an estimated elasticity of price to distance of 0.0442, significant at the 95% level, whereas in model 2 this estimated elasticity falls to a statistically insignificant 0.0260. As models 3 and 4 illustrate, this is the least significant and smallest estimated elasticity of all reasonable model specifications, and so I use it as a lower bound for the elasticity of price to distance when estimating damages.

Another issue with model 1 is the inclusion of a large number of House Style indicators. Forty-eight house style indicators (e.g. "Contemporary Colonial" or "Raised Ranch") are used in the initial model, but most homebuyers could not likely identify the differences between more than a handful of different build styles. Many of these style variables unnecessarily differentiate between house types that are nearly identical by most reasonable judgments. As an extreme example, these style variables differentiate between thirteen different types of townhouses. Since there are a small number of observations for many of these finely differentiated variables, correlations picked up in the model may not reflect true homebuyer preferences. Condensing these thirteen different Townhouse variables into a single Townhouse indicator variable arguably better represents the level of detail that consumers take into account when purchasing a house. In model 3 I use the control variables of model 1, replacing the 48 house style indicators with nine condensed style dummies: Cape, Colonial, Condo, Contemporary, Cottage, Gambrel, Garrison, Ranch, and Townhouse. As 90.3% of the sample fits into one of these nine categories, broad style effects would still be captured with these variables. I estimate this model both without and with year fixed effects in columns 3 and 4, respectively.

The estimated elasticity of price to distance is sensitive to the parameterization of house style, increasing substantially when the condensed style indicators are used. This model implies that a 1% increase in distance from the nuclear plant increases house price by 0.104% (significant at the 99% level). Since this model does not attempt to control for fine differences in house styles, it finds stronger statistical significance of the variables of interest. It is somewhat worrying that the magnitude of this estimated elasticity is so sensitive to the choice of this controlling for house style. However, I have chosen to present these models to demonstrate the largest amount of volatility seen from these kinds of choices. The other variables of interest seem to be little affected by the inclusion of the nine house style indicators.

Including year fixed effects (column 4) results in a lower estimated elasticity of price to distance (0.0861) relative to model 3. However, this elasticity is still higher than the estimates from models 1 and 2.

The four models presented in Table 3 show that the estimated elasticity of price to distance is quite sensitive to model specification. While the sign on the coefficient for each distance variable was in the expected direction, the magnitude varied significantly. The four estimated elasticities of price to distance were

0.0260, 0.0442, 0.0861, and 0.1040. I use each of these elasticities in the damage calculations to give a sense of the range of possible damages, depending on which specification one deems most reasonable. These figures cannot be compared directly to the literature, since past studies have not generally used the same log-log functional form. However, most of these coefficients are statistically significant, in contrast to the findings of some past authors such as Nelson (1981) who found no significant effect, but consistent with others like Folland & Hough (2000) who found a 10% average drop in house prices near nuclear plants. The magnitudes are roughly in line with other studies that estimate the effect of power plants on house prices. For instance, Blomquist (1974) found that the elasticity of house price to distance from electrical power plants (not just nuclear plants) was about 0.09.

Since model 4 controls for year fixed effects and uses "common sense" controls for house style, I argue that it is the most reasonable approach. While the 48 different house style indicators may more accurately control for fine differences in houses, the group of nine condensed style indicators more accurately reflect the degree of detail that homebuyers generally take into account when considering house style. Consequently, I choose to use the elasticity from model 4, 0.0861, when focusing on specific estimates. However, I also calculate damages for the other three models to provide a range of estimates in case the model 4's specification is deemed incorrect.

VI. 2. Damage Estimation

Using these results and the damage calculation methodology outlined in section III, I find the predicted price-distance relationships graphed in Figure 10. This figure demonstrates graphically the large difference that small changes in estimated elasticities can make in the predicted price-distance relationship, especially at small distances. The three horizontal lines represent different cutoffs for the assumed "safe" group of houses. Clearly, damage estimates to the choice of distance cutoff for "safe" groups.

Cutoff 1 seems inappropriately low. Indeed, this would be using houses that are only 0.14 km, 0.77 km, 2.48 km, or 3.07 km away from the nuclear plant (depending on the elasticity chosen) as a "safe" group, while the data suggests that the price-distance relationship appears to remain strong beyond these distances. The other two distance cutoffs seem more appropriate but still produce very different damage estimates. Keeping in mind that the vertical distance between a point on the price line and the horizontal control cutoff line roughly represents the estimated damages to a house due to the nuclear plant, Figure 10 illustrates how the choices of elasticity and distance cutoff (and the interaction of the two) affect estimated damages.

Figure 10.

Predicted House Prices with Varying Elasticities

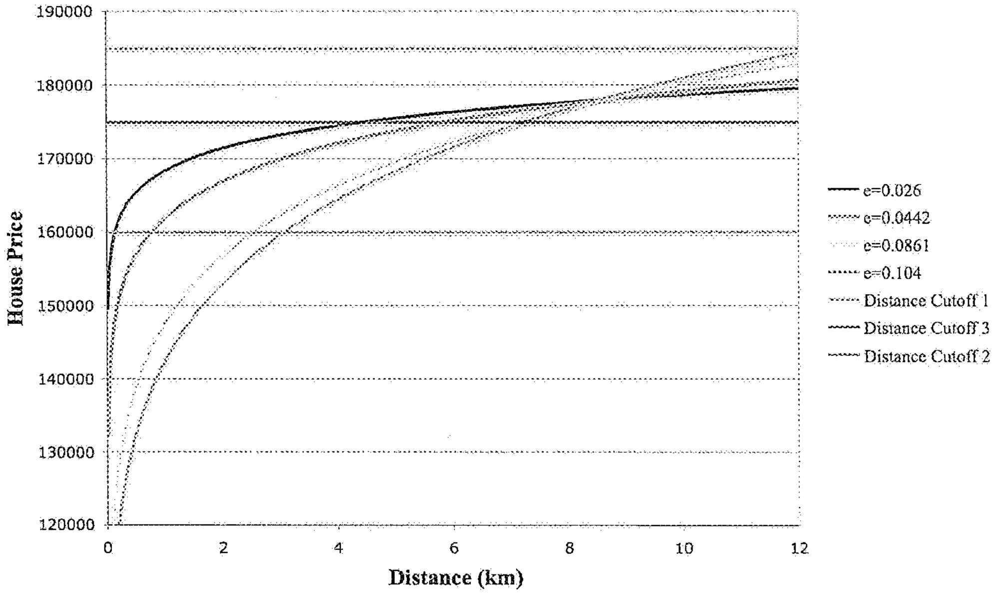

Figure 11 illustrates the relationship between damages and distance at a 10 km cutoff distance. This graph is constructed by solving for the predicted price of each house at 10 km within each model and subtracting from this the predicted price of each house as a function of its distance from the plant. Notice in Figure 11 that for larger estimated elasticities (as opposed to smaller ones), the estimated damages for houses within 10 km of the plant are larger.

Figure 11.

Damages with Varying Elasticies. Cutoff Distance: 10 km

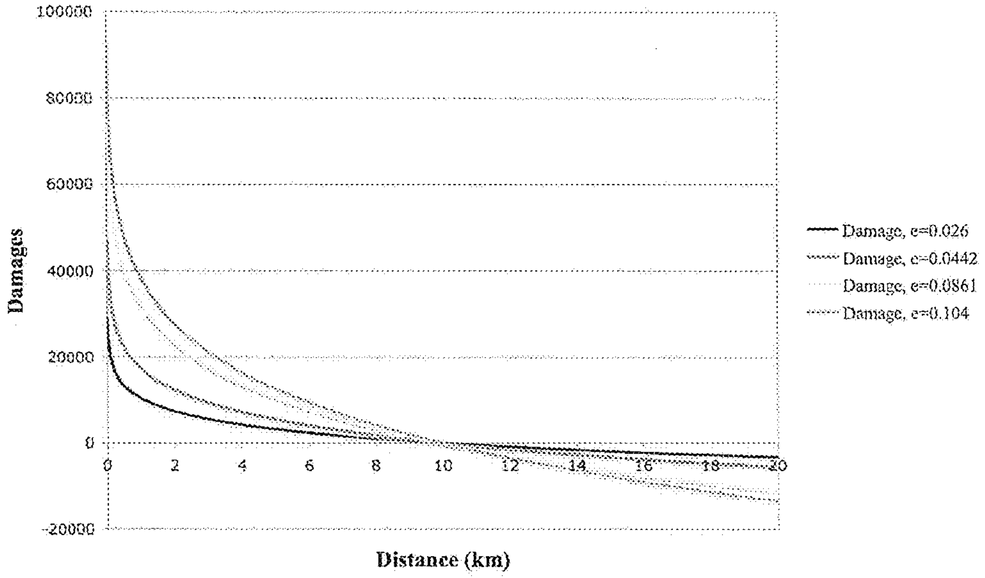

Table 4 presents the estimated damages for a variety of elasticities and distance cutoffs. These estimates are sensitive to the choice of distance cutoff, and narrowing down one's choice of estimate necessitates determining "reasonable" distance cutoffs. I find the most reasonable cutoffs by using the following method. I replace the distance variable in the model with a series of dummy variables representing distance from the corresponding location (for example, PilgrimDistance$_1$ through PilgrimDistance$_{21}$). PilgrimDistance$_i$ is set equal to one if the observation's distance from the Pilgrim nuclear plant is between *i* and *i – 1,* and zero otherwise. The distance *i* at which the coefficients on PilgrimDistance$_i$ and PilgrimDistance$_{i+1}$ are not significantly different from each other is considered the reasonable cutoff distance. This method results in an estimated appropriate distance cutoff of 8 km for the nuclear plant. As such, the most reliable the damage estimates should be the ones using roughly these cutoffs. The columns with "reasonable" distance cutoffs are highlighted in yellow, where reasonable cutoffs are defined as those within a certain range of the 8 km figure.

This 8 km cutoff seems somewhat reasonable. During the Three Mile Island accident, children and pregnant or nursing mothers within a 5 mile (8 km) radius of the plant were evacuated, and others within 10 miles (16 km) were cautioned to stay indoors. The NRC has two "emergency planning zones" (EPZs) around nuclear plants that specify courses of action in case of a nuclear accident. The smaller of these two zones is the "Plume Exposure Pathway EPZ" (in which the exposure to radioactive materials through direct inhalation is a significant risk), which extends to about 10 miles (16 km) from the nuclear plant. A larger zone beyond this 10 mile radius designates the area where inhalation is not a significant risk, but exposure through ingestion of contaminated food or water is a threat. At the Chernobyl catastrophe, individuals within a maximum of 32 km were evacuated.

A comparison of the 8 km cutoff with the numbers presented above suggests that 8 km may be a lower bound for the true effect of the nuclear plant. There are two explanations for the generally higher distances used by the NRC and in the event of accidents. First, individuals may underestimate the geographical extent of the nuclear risks, causing the price of distance capitalized into house prices to diminish before the risk fully disappears. A second explanation is that the NRC and disaster relief workers overestimate or overstate the extent of the risks. If they were to understate these risks, they would likely be blamed after an accident for failing to sufficiently prepare for an accident, so overstating them may be preferable to reduce the chance of being accused of negligence.

The table presents various estimated based on different parameters for distance cutoffs and price-distance elasticities. Which measure is deemed correct depends on one's interpretation of the appropriate values of these parameters. The lowest estimate, using the parameters $D_C = 4km$ and $e = 0.0260$, is an average of \$2,123 per house and \$3.6 million total damages. The highest estimate presented, using $D_C = 12km$ and $e = 0.1040$, is an average of \$11,937 per house and \$158.4 million total damages. These are relatively extreme estimates; more reasonable parameter choices result in more moderate estimates. The parameters of $D_C = 8km$ and $e = 0.0861$, which as previously argued appear to be the most reasonable, results in an average damage estimate of \$7,940 per house and \$52.9 million in aggregate. To give a sense of the size of these damages, this would be roughly equivalent to \$1,024 in damages per person, based on Plymouth's population count from the 2000 Census of 51,701 people.

A comparison of these figures to Folland & Hough (2000) is instructive: while they estimate that the installation of a nuclear plant reduces house prices by about 10%, my estimates amount to only about 4% of average house prices (4% =

$7,940/$198,078, since $198,078 is the mean sample house price). Even the most extreme damage estimate of $11,937 per house only amounts to 6% of average house prices.

Table 4. Damages

Year 2000 Dollars

Price-Distance Elasticity		**Distance cutoff (km)**				
		4 km	**6 km**	**8 km**	**10 km**	**12 km**
e = 0.026 (Model 2)	**Mean Damage per House**	$2,122.99	$2,263.44	$2,344.40	$2,562.51	$2,886.22
	No. of obs. damaged	924	2014	4002	5936	7418
	Aggregate Damages	**$3,587,697.04**	**$7,876,147.79**	**$15,611,773.99**	**$26,364,358.16**	**$38,337,900.47**
e = 0.0442 (Model 1)	**Mean Damage per House**	$3,646.42	$3,892.17	$4,021.91	$4,391.46	$4,946.29
	No. of obs. damaged	924	2014	4002	5936	7418
	Aggregate Damages	**$6,172,990.82**	**$13,566,392.62**	**$26,821,800.20**	**$45,209,792.88**	**$65,722,582.42**
e = 0.0861 (Model 4)	**Mean Damage per House**	$7,176.83	$7,668.34	$7,939.52	$8.698.35	$9.821.30
	No. of obs. damaged	924	2014	4002	5936	7418
	Aggregate Damages	**$12,157,779.48**	**$26,735,789.58**	**$52,924,408.98**	**$89,420,141.44**	**$130,224,102.70**
e = 0.1040 (Model 3)	**Mean Damage per House**	$8,750.00	$9,357.96	$9,662.51	$10,573.11	$11,937.44
	No. of obs. damaged	924	2014	4002	5936	7418
	Aggregate Damages	**$14,849,548.56**	**$32,684,480.96**	**$64,517,202.48**	**$108,787,944.16**	**$158,372,890.58**

Figure 12. Heat Map of Pilgrim Damages

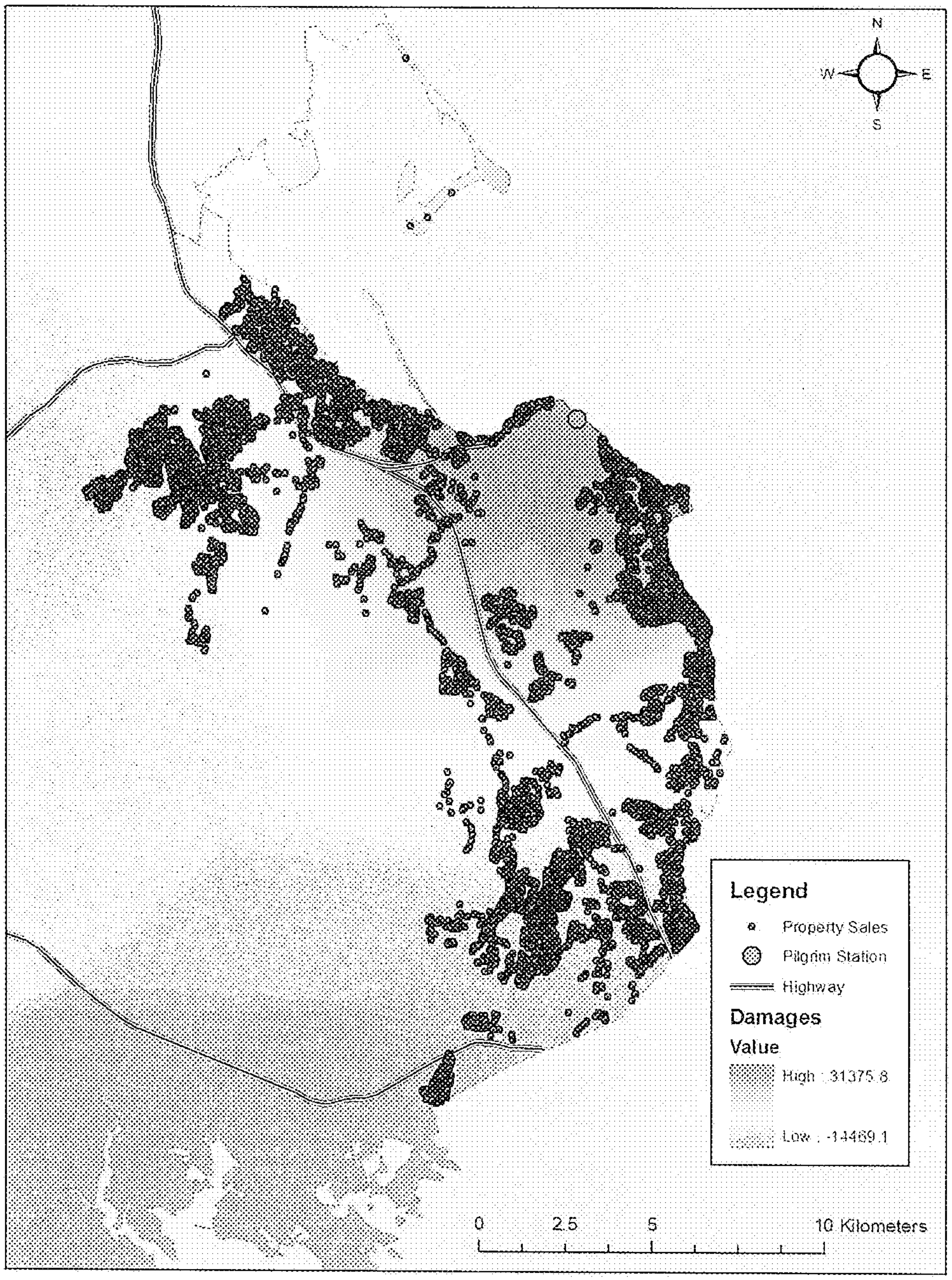

Figure 12 shows the spatial distribution of these damages in the form of a heat map using model 4's elasticity estimate, $e = 0.0861$. This map illustrates visually the rate at which damages dissipate with distance. "Redder" areas correspond to higher damages due to the nuclear plant. With increasing distance from the plant, these damages fall and the color correspondingly becomes greener. Different elasticity choices would show the same basic trend, except that the damages would taper off more or less quickly. Also note that beyond a certain distance, houses are considered "negatively damaged" due to the choice of distance cutoff, and are represented as green. As previously noted, these "negative damages" are not included in Table 4, and a map that corresponded to this choice would not have a continually "greening" trend beyond that distance beyond the cutoff, as Figure 12 does. Figure 12 includes this greening trend to show the degree to which estimated damages fall quickly near the plant but slowly farther away, as intuition would imply.

With these damage estimates in mind, I turn to the question of interpreting these numbers in the context of the costs associated with the risks of nuclear power. These external costs can be measured as the willingness to pay to avoid the risks of nuclear power. As argued in section III, if consumers are rational, the price of avoiding the risks of nuclear power (as represented by the estimates presented above) should be less than or equal to the representative consumer's willingness to pay. Since the per-house damages represent the degree to which houses are more expensive farther from the nuclear plant, these per-house damages reflect the price of avoiding nuclear power. Thus, the per-house damages provide an estimate of the willingness to pay of a household unit to avoid nuclear risks. Aggregating these damages among all houses (and scaling them appropriately, as described in section III) then provides a lower bound of the aggregate willingness to pay of affected households to avoid the risks posed by Pilgrim Station. As a result, the estimated aggregate positive damages can be considered lower bounds for the aggregate disvalue placed on the risks associated with the nuclear plant. Thus, the external benefits from the complete elimination of nuclear risk would be in the range of $7.9 million to $108.8 million, using reasonable parameters, with the choice estimate being $52.9 million.

However, caution should be used when applying this estimate. This number does not represent *net* economic benefits, since the nuclear plant presumably creates value in its electricity production, and if shut down it would have to be replaced with another source of energy, an issue discussed further in section VII. If this assumption is unrealistic, then the true effect of shutting down the nuclear plant on the welfare of Plymouth residents may differ.

VI. 3. Benefit Estimation: The Green Space

As previously mentioned, Entergy Corporation owns a wooded green space surrounding the nuclear plant that it is keeping undeveloped for tax reasons. This green space creates a buffer between the plant and the local community as well as acting as a source of outdoor recreation for Plymouth residents. Proximity to this green space generates a positive externality that is capitalized into house prices, as evidenced by the significant effect found in the regression results.

Using the same process used to calculate damages above, I have calculated the benefits of the green space using each model's parameters. These results are presented in Table 5. The most reasonable distance cutoff of 5 km is obtained through the same method used to find the 8 km cutoff for the nuclear plant. Estimates using roughly this cutoff are once again highlighted in yellow. The most conservative estimate is about $25.9 million in aggregate benefits. The highest estimate is $128.4 million in aggregate benefits. More moderate parameter choices still result in substantial estimated benefits, many around $33-110 million. Using model 4 and the most reasonable distance cutoff of 5 km, my choice estimate is benefits of $11,759 per house on average, and $78.8 million in aggregate.

Table 5. Green Space Benefits

Year 2000 Dollars

Price-Distance Elasticity		Distance cutoff (km) 3 km	4 km	5 km	6 km	7 km
e = -0.0239 (Model 2)	Mean Benefit per House	$6,335.31	$6,165.22	$6,084.51	$5,945.93	$5,436.73
	No. of obs. benefiting	3011	3878	4691	5547	6875
	Total Benefits	**$25,908,450.60**	**$33,134,120.63**	**$40,754,155.50**	**$48,552,402.86**	**$56,489,200.63**
e = -0.0327 (Model 1)	Mean Benefit per House	$8,593.60	$8,356.76	$8,242.27	$8,050.57	$7,357.93
	No. of obs. benefiting	3011	3878	4691	5547	6875
	Total Benefits	**$35,186,546.00**	**$44,970,800.42**	**$55,280,526.58**	**$65,830,631.13**	**$76,571,617.32**
e = -0.0476 (Model 4)	Mean Benefit per House	$12,262.59	$11,919.51	$11,758.47	$11,490.87	$10,510.03
	No. of obs. benefiting	3011	3878	4691	5547	6875
	Total Benefits	**$50,138,118.15**	**$64,072,703.80**	**$78,798,761.26**	**$93,914,925.72**	**$109,328,450.00**
e = -0.0564 (Model 3)	Mean Benefit per House	$14,412.65	$13,998.17	$13,800.09	$13,479.27	$12,323.29
	No. of obs. benefiting	3011	3878	4691	5547	6875
	Total Net Benefits	**$59,021,802.66**	**$75,368,813.66**	**$92,632,004.25**	**$110,353,293.81**	**$128,409,531.25**

Note: Average per-house benefits are decreasing with the distance cutoff. This is because higher cutoffs include more houses with small benefits, bringing down the mean but nevertheless increasing aggregate benefits.

Figure 13. Heat Map of Green Space Benefits

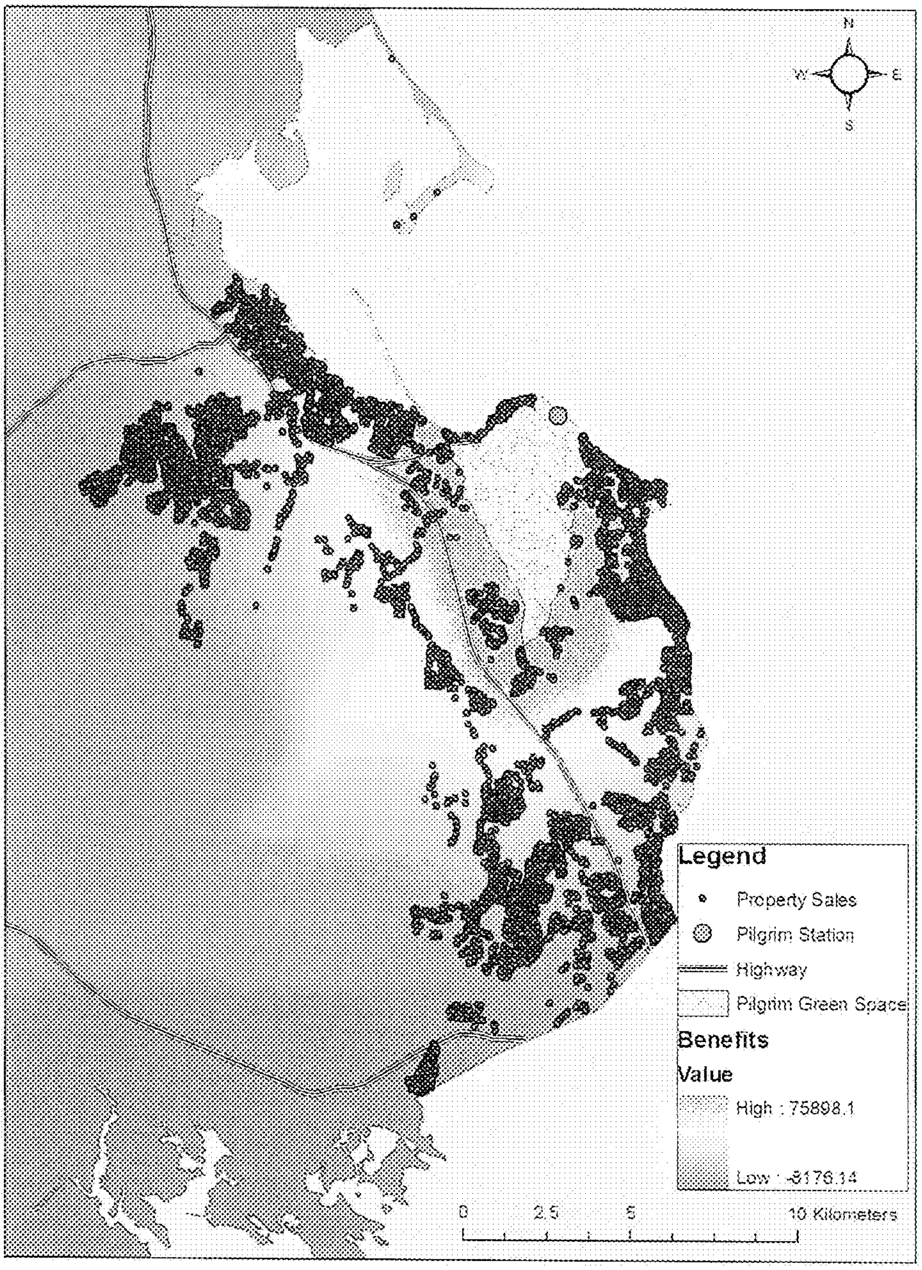

Figure 13 shows a heat map (akin to Figure 12) representing the spatial distribution of the benefits of the green space using model 4's elasticities. In this map, greener areas correspond to higher green space benefits, with redder areas indicating areas that benefit less or are even possibly considered "negatively benefiting" by distance to the green space. While the above benefit estimates exclude these "negative benefits," the map includes them to show the degree to which the benefits fall quickly with distance near the green space, but fall slower farther away.

One may be tempted to directly compare the benefits of the green space with the damages of the nuclear plant, but this exercise would be meaningless. The only reason to compare the two would be if their fates were inextricably linked, meaning closing the nuclear plant would necessarily imply developing the green space. There is no reason to think this is so. If the local government were to close Pilgrim Station to gain the $52.9 million in benefits, it could simply zone the green space to protect it from development, or even seize it using eminent domain.

Results Summary

Under a wide range of parameter choices for my estimates, the Pilgrim nuclear plant significantly harms local house prices. Using the reasonable parameters of $D_C = 8km$ and $e = 0.0861$ results in $52.9 million in aggregate damages attributable to the risks of nuclear power. Hence, consumers disvalue the negative externality of the risk of nuclear accidents, as they are willing to pay significant amounts to avoid it (from $2,123 to $11,937 per house on average, depending upon the parameters chosen).[9] However, the green space surrounding the nuclear plant and owned by its parent company generates a significant positive externality, amounting to able $78.8 million using the same model and a 5 km distance cutoff. This suggests that the green space provides a beneficial role in providing a buffer between the plant and the community, as well as providing recreational benefits to residents. This finding can inform future policy decisions regarding the placement of potential future nuclear plants, since creating an undeveloped green space around a new plant can help mitigate the damages from the risk it poses to the community.

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[9] Estimates from Table 4.

VII. Discussion

In this section, I discuss issues with the methodology and data that may bias my results or cause them to misrepresent the true economic damages of the negative externality. Also discussed is the degree to which the public perception of risk embodied in house prices accurately reflects the true risks posed by the nuclear plant, and whether or not this matters.

VII. 1. Potential Problems and Biases

The estimates presented above make several assumptions that are potentially incorrect and may bias my results. The issues discussed in this section are the collinearity problems posed by the inclusion of several location-based variables in the model, the need for and choice of a distance cutoff, the realistic price-distance relationships after the plant's closure, the existence of "employment effects," implicit liability and insurance, the issue of price estimates understating willingness to pay, and the costs of replacement electricity generation methods.

Several independent variables are highly correlated, most notably the variables representing the distance from the nuclear plant and from the green space or shore. This fact poses potential collinearity issues which would lead to large standard errors. Fortunately, there exist houses near the coast but not near the plant and there exist houses that are near the green space but not near the plant. This variation in the data allows reasonably precise estimates, with most specifications resulting in statistical significance at the 99% level for the variables in interest.

The damage and benefit estimates above have assumed that the plant's closure would result in all house prices reverting to a constant level at D_C (holding all else constant). This level would be invariant to the plant, meaning that the price-distance elasticity would go to zero. This assumption could be unrealistic for several reasons.

First, the choice of a distance cutoff D_C significantly affects the estimated damages and benefits, as the reader can observe in Tables 4 and 5. The need for a distance cutoff is apparent since I must compare each house's price with its hypothetically "unaffected" price, and this "unaffected" price cannot be chosen arbitrarily. For example, choosing the price level of houses in Plymouth that are the farthest from the plant within the dataset (~20.5 km away) would lead to large damage estimates. This choice would not be wise because it would mean that damage estimates would only be limited by the size of the dataset; if my dataset included houses in the neighboring town, this method would lead to even larger damage estimates simply due to the strictly increasing logarithmic functional form assumed. In reality, we know that beyond some distance the nuclear plant should stop having an effect on house prices, but the basic logarithmic functional form does not capture this.

As a result, I need a distance cutoff to find a price level to which I can compare houses found to be affected by the nuclear plant. Basing the cutoff on the extent (in distance) to which the nuclear plant significantly affects house prices in the data provides a useful estimate of where house prices cease to be affected by the nuclear plant. These unaffected house prices are the ones that should be used for comparison, which is why I focus on them in my analysis above.

Second, there may be an unobserved, non-nuclear related relationship between house price and distance from the plant. If this were the case, closing the plant would cause prices to revert to the level corresponding to this relationship, whereas my methodology assumes that the elasticity would revert to zero. For example, if the plant were located in a "bad" part of town, then prices would still rise with distance even after the plant was closed. This means that the elasticity observed in my models is not due to the plant alone but also due to the plant's placement in a bad part of town. As a result, the plant's closure will not cause the price-distance elasticity to go to zero, but instead would simply decrease it. This problem does not seem likely because aspects of the local community that are most likely to cause these issues (e.g. percent Caucasian, percent of houses vacant) are observed and controlled for within the model. Further, being near the coast, the area around the plant is relatively affluent, so if anything the observed price-distance relationship is biased downward, leading the damage estimates to understate the true damages.

A related problem could also be significant. The closure of the plant may not cause the price-distance elasticity to go to zero because closing the plant may not cure all of the sources of the negative externalities. For example, after the closure of other nuclear plants in the past, nuclear waste continued to be stored on-site. This storage can continue to pose a negative externality. Indeed, one study found that media attention regarding the storage of nuclear waste at a non-operating plant increased the salience of this negative externality, reducing house prices (Metz *et al* 1997). As a result, the price-distance relationship may not go to zero after the plant's closure as some of the negative externality remains. In this circumstance, the benefits from closing the plant will in fact be lower, although the damages of its creation would be unaffected by this issue.[10]

In sum, the assumption that the price-distance elasticities go to zero with the removal of the source (the plant or green space) could be unrealistic and bias results. However, it is not clear which direction this bias would go, since the "nice neighborhood" effect could bias the observed relationship in one direction, whereas the "persisting externality" effect could bias it in the other.

Another issue is the possibility of "employment effects," that is, boons to local house prices due to employment opportunities at the nuclear plant, as workers more highly value houses near the location of their jobs at the plant. In theory, this could offset some of the damages to house prices, suggesting that people actually disvalue the risks of nuclear power more than the price-distance relationship directly implies. Despite this theoretical problem, it does not seem problematic for my estimates since there is evidence that nuclear plants do not result in significant employment effects (Rephann 1997). This is due to that fact that nuclear plants are a capital-intensive business that employs relatively few

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[10] On a public policy note, it may be unwise to systematically consider benefits on these grounds when deciding whether or not to allow a plant to operate. Doing so could potentially cause plants to avoid closure by irreversibly contaminating the surrounding land rather than containing their waste. This is clearly an undesirable activity.

workers. In particular, Pilgrim Station employs about 580 permanent workers, which amounts to about 1.1% of the population of the town of Plymouth, although not all of its workers necessarily live in the town.

There are two more related issues that must be considered: nuclear plant liability and implicit government guarantees. Interpreting the my results as measuring the value placed on the risks of nuclear power may be misleading since the nuclear power plant is liable for damages in the event of a nuclear accident, though this liability is limited by the Price-Anderson act and the corporate structure. If homebuyers take into account the fact that the nuclear plant will compensate them for damages in the event of an accident, they will have a form of insurance against nuclear risks. This will reduce the fear of living near the nuclear plant, mitigating the effect of distance on home prices. As a result, my results may not capture the full amount that Plymouth residents disvalue the risks of living near a nuclear plant, and as a result my estimates of the true valuation of these risks could be biased downward.

However, to the extent that nuclear plant is liable for damages in the event of a catastrophe, the externality of nuclear risk is internalized. If consumers are rational and markets are efficient, proximity to the nuclear plant should only harm local house prices to the extent that the externality is not fully internalized. Thus, a significant observed effect (as I find) reflects un-internalized externalities, which are the effects that matter for economic efficiency. Thus, the issue of plant liability for damages should not be a problem in interpreting results as important for economic efficiency or for the benefits of closing the plant.

There is also possibility that an implicit guarantee of government assistance would also act as an insurance policy, also biasing my damage estimates downward. This issue could be problematic since it does not represent internalization of the risks of nuclear power. Rather, in the event of an accident the damage is simply shifted from Plymouth residents to the government (and hence taxpayers).

Another issue that must be remembered was covered in section III: that the estimates presented here are based on house *prices*. Figures 2 and 3 demonstrate how prices will understate willingness to pay since there is also consumer surplus. The representative consumer is willing to pay *at least* this price to avoid the risks, but he or she may also be willing to pay much more for the inframarginal units of distance and hence risk reduction. To the extent that the consumer did not have to pay this amount, he or she enjoys consumer surplus that is not being captured by the price-distance relationship. This means that the true willingness to pay to avoid the risks of nuclear power, and hence the true disvalue placed on these risks, is greater than (or equal to) damages implied by the price itself. Thus, price-based damage estimates are a lower bound for the damages attributable to the nuclear plant and for the benefits attributable to the green space.

The cost of replacing the energy currently produced by Pilgrim Station is another important issue. The electricity that the plant currently generates would have to be replaced through some other means, necessitating another source of energy of some sort, such as a coal plant or windmills. Environmentally friendly methods are generally more expensive than nuclear power, so their use would be costly and lead to higher energy costs for Plymouth residents. This would likely depress house prices in Plymouth as well, with homebuyers seeking other areas with lower costs of living. Other methods of generating electricity such as coal plants generate negative externalities as well, so choosing this route would simply be substituting one externality for another. Either way, Plymouth residents would suffer some costs if the nuclear plant were to close: either from higher energy costs and lower house prices, or from further negative externalities from other dirty forms of power. Thus, the decision to close the plant must be based not only on the benefits of closing the plant, but also on the costs of the alternative sources of energy.

Finally, the issue of spatial autocorrelation[11] was tested for, and was found to be a very significant issue. The symptom of spatial autocorrelation would be incorrect standard errors, leading to faulty inference. Correcting for this would lead to more efficient inference regarding the statistical significance of the estimated coefficients, but fortunately it would not bias the magnitude of these estimates. An extension of this research could be done by estimating the models while correcting for spatial autocorrelation.

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[11] Spatial autocorrelation is when a model's residuals are correlated with location.

VII. 2. Inaccurate Public Perception of Risk

Another issue is the potential lack of information and/or rationality among homebuyers in Plymouth, issues which could lead to inaccurate public perception of risk and hence inaccurate personal assessments of how much one really values the risks posed by the nuclear plant. Rational people with full information will make accurate valuations of the risks of nuclear power based on their own utility functions, resulting in an optimal willingness to pay for distance from the plant that reflects their preferences. However, if people have incorrect information that overstates (understates) the risks of nuclear power, they will in practice be willing to pay more (less) than the optimal amount. Likewise, if they are irrational and respond wildly to new information (accurate or not), there is no reason to expect their revealed willingness to pay to reflect their true preferences. As such, irrationality or imperfect information regarding the risks of nuclear power may bias my results. If people are irrationally sensitive (insensitive) to information about nuclear power, or their information sources are biased to overstate (understate) these risks, then their revealed willingness to pay as found in my results may overstate (understate) their true, rational valuations. This issue casts doubt on the usefulness of using damages to property values to accurately assess individuals' true valuations of the risks of nuclear power.

However, as Gawande and Jenkins-Smith point out, from a legal standpoint it does not matter whether these damages to property values stem from reasonable perceptions of risk (Gawande and Jenkins-Smith 2001). Indeed, residents of affected homes are still worse off when their property depreciates, whether it is due to rationally or irrationally perceived risks. The effects on property values may not represent true *economic* damages if public perceptions of risk are inaccurate, but they are damages to the local community nonetheless in the form of the depreciation of local properties.

I put this issue aside for three reasons. First, it is not clear in which direction the bias will be. While one can imagine that people may systematically overestimate the risks of nuclear power, it is also conceivable that they underestimate it. If some people vastly underestimate risk (say, because they forget to consider the plant's location in their home purchasing decision)), this will increase housing demand and hence house prices near the plant beyond what rational individuals would find optimal. The observed price-distance relationship in this case would understate damages. Second, it is methodologically and philosophically difficult (if not impossible) to un-arbitrarily correct for this if one deems it a problem. Third, it is still a matter of debate among economists and philosophers regarding which preferences should matter for welfare: those revealed by agents (whether they be considered rational or not) or the underlying (yet amorphous) enlightened, rational preferences that people supposedly have.

VIII. Conclusion

I use a hedonic model to estimate the value that individuals place on the risks of nuclear power around Pilgrim Station in Plymouth, Massachusetts. This study is motivated by the controversial issue of the renewal of the plant's license, which is set to expire in 2012, as well as the larger issue of the role of nuclear power in fighting fossil-fuel induced climate change. In making a policy decision regarding the continued operation of the plant, both costs and benefits of renewing the license must be measured and compared, and the disvalue placed on the negative externalities posed by the nuclear plant constitutes an important cost to be measured. I find that homebuyers place significant value on avoiding the risks of nuclear power and that these valuations are capitalized into property values. The price-distance elasticity for the nuclear plant is estimated at 0.0861 (significant at the 99% level), extending to about 8 km. Using the regression results and reasonable parameters, I find that the damages due to the nuclear plant (and hence the benefits from its closure) are around $7,940 per affected house, aggregating to $52.9 million, or $1,024 per Plymouth resident on average.

I also measure the positive externality generated by the green space that surrounds Pilgrim Station. The price-distance elasticity for the green space is estimated to be -0.0476 (significant at the 99% level), extending to about 5 km. I present a range of estimates, but using the most reasonable model and parameters, the benefits attributable to the green space are about $11,758 per affected house, and $78.8 million in aggregate.

I also find anomalous results regarding the effect of media coverage, with the number of *Boston Globe* articles discussing accidents at or the dangers of the Pilgrim Nuclear Generating Station being significantly positively correlated with house prices, with a statistically significant elasticity of 0.0195. The positive significant relationship holds even after controlling for year fixed effects. This anomalous media effect is explored more in the Appendix to this paper.

As previously discussed, one may be tempted to compare the damages of the nuclear plant and the benefits of the green space, but this comparison would have little meaning. Policy decisions regarding the status of the green space and the nuclear plant can be made independently. I conclude that there would be substantial external benefits to the closure of the Pilgrim nuclear plant. To make a policy decision regarding the potential closure of Pilgrim Station, these benefits must be weighed carefully with the costs, the most important of which being those associated with the production of electricity to replace that foregone by closing the nuclear plant.

Appendix

This appendix contains some explorations into the data that are not crucial to the main thrust of my thesis: the estimation of the damages attributable to Pilgrim Station. These explorations include an expanded look at the impact of the media variable on house prices, an impact that was counter-intuitively found to be positive and significant in the main models. I also test to see if the price-distance elasticity varies over time and with the median age of the community. While I do not solve the mystery of the anomalous effect of media attention, I find that the price-distance elasticity is negatively related with time and with the median age of the community.

A.1. Media-Distance Interaction

The anomalous positive relationship between house price and media coverage is perplexing. One hypothesis that could theoretically explain this is that more media coverage intensifies the premium placed upon safe housing, pushing up house prices further away from the plant and driving prices down near it. If enough of these safe houses are affected strongly enough, then this positive effect due to media coverage may swamp the negative effects near the plant. If this were the case, then one should see a differing relationship between price and media for houses at different distances from the plant. Specifically, houses near the plant should be adversely affected by media coverage whereas houses far away should be positively affected.

To test this hypothesis, I create a standardized interaction variable between *Log(Pilgrim Distance)* and *Log(Globe Articles)* (as well as standardizing the variables themselves). The standardization of the variables is meant to ease the interpretation of the interaction variable. These standardized variables are denoted *Z[Log(Pilgrim Distance)], Z[Log(Globe Articles)],* and *Z[Log(Distance)]xZ[Log(Globe)] Interaction*. If my hypothesis is correct, the coefficient β on the interaction variable should be positive. Since my variables are standardized, houses one standard deviation above the mean distance from the plant will have a *Z[Log(Pilgrim Distance)]* of 1, so increasing *Log(Globe articles*) by one standard deviation will change the logarithm of house prices by β. By contrast, houses relatively close to the plant (one standard deviation below the mean) will have a *Z[Log(Pilgrim Distance)]* of -1, so for these houses increasing *Log(Globe articles*) by one standard deviation will change log-house prices by $(-1)\beta$. Since house prices far away should benefit from more media attention (and house prices nearby should be reduced) under my hypothesis, β is expected to be positive.

Running the regression from model 4 with these standardized variables results in the coefficients reported in Table A1. Once again, the expectation about the effect of media coverage is contradicted by the data. The coefficient on the interaction variable is negative and significant at the 99% level, suggesting that, not only is media attention positively associated with house prices, but that this effect is stronger nearby the plant. Indeed, for houses significantly far away from the nuclear plant (beyond about 2 standard deviations above the mean distance), increasing *Log(Globe articles)* is actually associated with lower house prices, the opposite of what one would expect the effect of the interaction between the two to be.[12]

Table A1. Regression Results for Model A1
Dependent Variable: Log(Real House Price)

	Coefficient (1)	 (2)
Z[Log(Pilgrim Distance)]	0.0448*** (4.82)	0.0440*** (4.73)
Z[Log(*Globe* articles)]	0.0166*** (3.74)	0.0167*** (3.77)
Z[Log(Distance)]xZ[Log(*Globe*)] Interaction		-0.0083*** (-2.76)
Constant	8.176*** (21.17)	8.170*** (21.16)
R-squared	0.6232	0.6234
Adjusted R-squared	0.6199	0.6201
No. observations	10,428	10,428

t-statistics in parentheses
*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively

A.2. Lagged and Cumulative Media Effects

A second hypothesis to explain the anomalous results is that using the number of *Boston Globe* articles in the year of the sale does not accurately

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[12] For example, let *Z[Log(Pilgrim Distance)] = 3*, indicating houses very far away from the plant (~22 km away). Then the rate of change of *Log(Real House Price)* with respect to *Z[Log(Globe articles)]* is 0.0167–0.0083(3) = -0.0082, meaning increasing media attention hurts prices for distant, "safe" homes.

represent the speed or mechanism through which the media transmits information. A more realistic model may use the number of *Boston Globe* articles in the previous year as the meaningful measure of media attention.

Log(Lag Globe articles), representing the amount of media attention in the year preceding the sale, is introduced into model 4, and the regression results are presented in Table A2. Again, the effect of the media attention on house prices is positive and statistically significant, with a 1% increase in media attention being associated with roughly a 0.015% increase in house prices. Investigating the interaction of the lagged effect yields the same conclusion as in model A1. The lagged media effect is positive and stronger for houses closer to the nuclear plant, counter to intuition, although this effect is less robust than before (only significant at the 90% level).

Table A2. Regression Results for Model A2

Dependent Variable: Log(Real House Price)

	Coefficient		
	(1)	(2)	(3)
Log(Pilgrim Distance)	0.0868*** (4.85)	0.0868*** (4.85)	
Log(*Globe* articles)	0.0128** (2.24)		
Log(Lag *Globe* articles)	0.0153*** (2.99)	0.0152*** (2.96)	
Z[Log(Pilgrim Distance)]			0.0446*** (4.79)
Z[Log(Lag *Globe* articles)]			0.0131*** (2.94)
Z[Log(Distance)]xZ[Log(Lag *Globe* articles)]			-0.0050* (-1.66)
Constant	10.657*** (24.16)	10.700*** (24.28)	9.680*** (21.97)
R-squared	0.6265	0.6265	0.6266
Adjusted R-squared	0.6233	0.6233	0.6233
No. observations	10,299	10,299	10,299

t-statistics in parentheses

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively

A.3. Cumulative Media Effects

Model A3 examines the idea that media effects may accumulate over time. The mechanism through which media attention is hypothesized to adversely affect house prices is by gradually increasing public knowledge of the risks of nuclear power. This knowledge probably does not significantly evaporate over time;

instead, continuing media attention as time progresses could lead to accumulating knowledge about the risks of nuclear power, increasing the effect of the nuclear plant on house prices.

To account for this, model A3 introduces a variable called *Log(Cumulative Globe Articles)* which is the logarithm of the total number of *Boston Globe* articles published since 1992 (the beginning of my sample) that seriously discuss the risks of Pilgrim Station. Table A3 presents the results, once again finding a strong significant positive relationship between cumulative media attention and house prices. Of course, since the cumulative media variable is naturally increasing with time, and the housing boom corresponds to a similar time period, this strong significant coefficient could simply be picking up time effects, even though Year-fixed effects are included in the model.

When *Log(Globe articles)* is included in the model, it is driven to insignificance, but this is unsurprising given the collinearity between the single-year and cumulative media variables. The distance-cumulative media interaction variable produces estimated coefficients similar to those found in models A1 and A2, with a robust, counter-intuitive sign.

Table A3. Regression Results for Model A3

Dependent Variable: Log(Real House Price)

	Coefficient		
	(1)	(2)	(3)
Log(Pilgrim Distance)	0.0861***	0.0861***	
	(4.82)	(4.82)	
Log(*Globe* articles)	-0.0044		
	(-0.77)		
Log(Cumulative *Globe* articles)	0.0830***	0.0593***	
	(7.77)	(5.97)	
Z[Log(Pilgrim Distance)]			0.0430***
			(4.63)
Z[Log(Cumulative *Globe* articles)]			0.0344***
			(5.90)
Z[Log(Distance)]xZ[Log(Cum. *Globe*)]			-0.0129***
			(-4.35)
Constant	7.568***	7.628***	8.103***
	(19.49)	(19.62)	(21.01)
R-squared	0.6232	0.6232	0.6238
Adjusted R-squared	0.6199	0.6199	0.6205
No. observations	10428	10428	10428

t-statistics in parentheses

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively

While these models are interesting, they do not change the counter-intuitive finding that media attention is robustly related in house prices in a counter-intuitive way. Not only is media attention oddly associated with higher house prices in Plymouth in general, but this relationship also appears to be strongest near the nuclear plant, in the exact area where one would expect media attention to most harm house prices.

A.4. Time-varying Price-Distance Relationships

Another question of interest is whether or not the price-distance relationship changes over time. In the 1980s and early 1990s, Pilgrim Station was considered one of the worst run nuclear plants in the United States according to the Nuclear Regulatory Commission. Since then, it has solved many of its safety problems, and the NRC has upgraded its rating. If homebuyers take this reduction in risk into account, then the price-distance relationship could have decreased over time, as Pilgrim became less risky to live near.

To investigate the changing relationship over time, model A4 uses an interaction variable for year of sale and distance from Pilgrim Station. The coefficient on the interaction variable is negative and significant at the 99% level, meaning that the strength of the price-distance relationship is decreasing with time. For example, according to this model, the estimated price-distance elasticity in 2009 would be estimated to be 0.0497. By contrast, this model would imply a price-distance elasticity of 0.1386 in 1993.

Table A4. Regression Results for Model A4

Dependent Variable: Log(Real House Price)

	Coefficient	
	(1)	(2)
Log(Pilgrim Distance)	0.0932***	0.0900***
	(5.18)	(5.00)
Z[Year]	0.0790***	0.1294***
	(21.90)	(10.10)
Z[Log(Distance)]xZ[Year]		-0.0236***
		(-4.10)
Constant	7.908***	7.910***
	(20.32)	(20.34)
R-squared	0.6154	0.6160
Adjusted R-squared	0.6126	0.6132
No. observations	10,428	10,428

Note: Year fixed effects were removed from this model.
t-statistics in parentheses
*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively

This evidence is consistent with the hypothesis that Pilgrim Station's improving safety record was reflected in house prices, as homebuyers took into account the reduced risk in their decisions. However, it is also possible that this relationship is driven by other factors that were changing over this time. For example, if the desirability of proximity to the shore changed over the years due to changing environmental or social factors, then the correlation found in this model could be biased, with the change in the plant's price-distance elasticity reflecting changes in the shore's price-distance elasticity.

However, if the decline in the price-distance elasticity over time is truly due entirely to the plant's improved safety record, it has interesting implications for estimating damages. If one wants to estimate the benefits of closing the plant, then one should use today's smaller elasticity of 0.0497, since those are the damages that would be alleviated by the plant's closure. This could mean that the estimates based on the entire sample (0.0861 for the basic version of this model) could be too large, since the sample includes houses sold when the plant posed more of a risk. On the other hand, if one wants to determine legal damages to past homeowners in Plymouth, then one should use the estimated damages based on the price-distance elasticity in the year of the house's sale, since that was the time that they realized the damages of the sale in the form of lower house value. Of course, it is very difficult to tell if the decline in the price-distance elasticity over the past 17 years is due entirely to the nuclear plant's improving safety record or due to other changes in the housing market in Plymouth, making it difficult to determine whether or not using these different elasticities would be correct.

A.5. Age-Distance Interactions

The disvalue an individual places on living near the nuclear plant may vary from person to person. One reason for this is differing expectations about the likelihood of a nuclear meltdown during the time that one expects to spend living at the house. While one cannot easily directly observe individuals' beliefs about this likelihood, it seems reasonable to assume that the elderly are less likely to experience a nuclear meltdown in their remaining lifetime than the young. Thus, one may expect the premium placed upon risk (and hence the magnitude of the price-distance elasticity) to be smaller for communities with more elderly residents.

To test this hypothesis, model A5 includes an interaction variable between *Log(Pilgrim Distance)* and the median age of the Census Block. As one can see in

Table A5, the coefficient on this variable is negative and significant at the 95% level, implying that house prices in communities with older residents are less sensitive to distance from the nuclear plant. Specifically, increasing the Census Block's median age by 1 standard deviation (4.33 years) reduces the elasticity by 0.014. This is consistent with the above story about the elderly having a lower probability of experiencing a meltdown, but it is also consistent with several other hypotheses. For example, lower risk-aversion among older communities could explain this finding. Also, young people are more likely to be worried about the long-term effect of radiation on their children or on pregnant women, issues that are not as relevant to the elderly. Interestingly, it is also possible that the fall in the elasticity over time as found in model A4 above is driven at least in part by the gradual aging of the population.

Table A5. Regression Results for Model A5

Dependent Variable: Log(Real House Price)

	Coefficient	
	(1)	(2)
Log(Pilgrim Distance)	0.1067*** (5.91)	0.1102*** (6.09)
Z[Log(Median Census Block Age)]	0.0400*** (7.10)	0.0679*** (5.44)
Log(Distance)xZ[Log(Med. Age)]		-0.0140** (-2.51)
Constant	7.526*** (19.33)	7.537*** (19.36)
R-squared	0.6250	0.6252
Adjusted R-squared	0.6217	0.6219
No. observations	10,428	10,428

t-statistics in parentheses

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively

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