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# The Use of Hedonic Models in the Analysis of Nuclear Facilities' Impacts on Property Values: A Survey of the Economic Literature

This project is funded by a grant from the US Department of Energy, Office of Environmental Management, Portsmouth/Paducah Project Office.

May 30, 2012

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## I. Introduction

The Hedonic Pricing method is an economic (and statistical) technique whereby the value of a non-priced good or service is determined by its economic impact on another good which is priced in a market. It provides a method of determining the value of an attribute (e.g. the level of pollution or the danger of a job) by calculating the extent to which that attribute is capitalized into the price of an effected asset such as private housing or an individual's salary. Because of the prevalence of non-priced externalities and public goods in the United States and elsewhere the Hedonic Pricing method has enjoyed considerable popularity over the last few decades, and, indeed, there are certain circumstances where it may be the only means available to measure the value of such goods. Nonetheless, there are a number of statistical challenges for researchers who use Hedonic regression, and it is important to be aware of its limitations when evaluating and interpreting the results of such models.

The purpose of this paper is threefold. First, we want to familiarize the reader with the hedonic method and point out the problems and shortcomings, which analysts and policy makers need to be aware of when working with and using the results of hedonic models. Second, we want to provide a survey of the existing literature in this field to show what these models have been used for in the past and where they can be usefully employed in the future. Third, and most specifically, we wish to show how the hedonic method has been used when evaluating the impacts of nuclear facilities and concerns about radioactivity on property values, housing choice, and economic welfare (as measured by consumers willingness to pay to avoid damages). In so doing we hope to not only provide a survey of the hedonic literature but to point out those instances where hedonic models would be most valuable in evaluating the economic impacts of nuclear facilities on surrounding properties' values.

The analysis proceeds as follows. In section II we present the basic economic theory behind hedonic models and describe the econometric modeling techniques used to quantify the impact of non-priced goods on the capitalized values of assets such as housing in a specific geographical area. The presentation will be intuitive in nature with some of the more technical issues relegated to an appendix. Next, in section III we conduct a general survey of the literature on this topic. In so doing we emphasize areas where hedonics has been most successfully used as well as circumstances where care should be taken when utilizing the empirical results. In section IV we survey that part of the literature that deals with the evaluation of radiation concerns and nuclear facilities. Finally, in section V we summarize our results and outline our conclusions.

## II. The Basic Theory Behind Hedonic Models

The basic aim of Hedonic models is to estimate the value of items like pollution or risk by examining their economic impact on other (priced) items such as housing or wages. "In the 'real world', as noted by Kolstad (2000, p. 323), "we are often confronted with bundles of goods with a single price for the whole bundle. Yet we are in fact interested in the price of an element of the bundle. For instance, we observe the prices of houses that are bought and sold. But a house consists of a bundle of characteristics such as the number of rooms, the neighborhood quality and the surrounding environmental quality. By observing the prices of many houses with differing characteristics, is it possible to back out the implicit value that is being placed on air quality (for instance)? Similarly, different occupations (jobs) have different characteristics, including the level of health or mortality risk. Typically, jobs with greater risks pay higher wages. By observing the wages associated with many different occupations, can we infer anything about how much workers value small changes in risk?"

The use of hedonics in economic analysis dates back to a 1971 article by Zvi Griliches. In that article Griliches proposed that automobiles could be viewed as a bundle of attributes. He then estimated the value of a given quality change (i.e. the changes in those attributes) by looking at the resulting changes in automobile prices. Grilliches early analysis was followed by a more formal analysis by Rosen (1974) while Freeman (1974) was the first to propose that this technique could be applied to measuring the value that individuals in the market put on environmental quality. Since that time the basic theory has been expanded in numerous articles (see, for example Palmquist 1991), and has been expanded in a number of directions. While the intuition behind the concept of hedonics is fairly straightforward, the actual economic formulation behind the concept can be fairly technical (see the attached appendix). Nevertheless, the basics behind this formulation can be presented in an uncomplicated manner within the framework of a basic supply and demand analysis.

Turning first to the demand side of the market, basic economic theory posits that an individual seeks to maximize their level of satisfaction or "utility" subject to some budgetary or income constraint. Hence, in their purchase of a house (for instance) an individual will buy that combination of rooms, floor space, neighborhood characteristics, and environmental quality etc. that will jointly give them the most satisfaction given the amount of money that they have budgeted for their purchase. Furthermore, the higher the level of one of these attributes (e.g. environmental quality) that they can attain, the more that they are willing to spend (other things equal) as long as it falls within their budget. Of course, consumers differ both as to their preferences and their incomes so different individuals will be willing to spend different amounts to gain satisfaction from these attributes.

Looking next at the supply side of the market, economic theory assumes that the firms that produce economic goods wish to maximize their profits, with profits defined as the revenues that they get for the goods minus the costs of producing those goods. The cost of producing goods depends on the level and quality of the inputs used, and, all things equal, the greater the quantity and quality of the inputs the higher the prices of the inputs and the greater the costs to the firm. In building a good such as a house the firm must choose a combination of attributes or characteristics such as number of rooms etc. Furthermore, it is assumed that all else equal, the location that the firm chooses to build the house will be more expensive the better the neighborhood and the higher the level of environmental quality. As with consumers, firms will choose to build houses with different sets of attributes (for example, houses with two versus three bedrooms, etc.).

The interaction of consumer demand and producer supply results in a market equilibrium. At equilibrium the products manufactured by producers and those demanded by consumers will match. Furthermore, since it is generally assumed that consumers differ in their income and their tastes they will choose products with different sets of attributes. Again, concentrating on housing and looking at environmental quality economic theory suggests that, all else equal, those houses with a higher level of environmental quality will fetch a higher price. Finally, most attributes that are consumed are subject to the "law of diminishing marginal utility". In other words as consumers buy more of an attribute the less "extra money" they are willing to pay for the last unit of that attribute. Hence, though a higher amount of environmental quality fetches a higher price, the added amount that they wish to buy goes down as quantity rises.

**Empirical Estimation**

Suppose that the level of environmental quality can be determined via some means. If, for example there is air pollution in a particular geographical area, we might be able to measure this by particulate or $SO_2$ levels in various parts of that area. Alternatively, if we are interested in the perceived risk of radiation contamination, we may wish to measure it by a house's distance from a particular nuclear facility. When the appropriate measure has been agreed upon it is then included as one of the factors believed to affect a good such as housing. An empirical economic model of housing prices then could, for example, (see Boardman et al. 2011) be written as:

1) P = f(CBD, SIZE, EQ, NBHD)

Where P stands for the price of housing, CBD is its distance from the central business district, SIZE is the size of the property, EQ stands for some measure of environmental quality, NBHD measure various neighborhood characteristics (e.g. level of crime, quality of schools, etc.). As Boardman et al (p. 354) point out, "This equation is called a *hedonic price function or implicit* *price function.* The change in the price of a house that results from a unit change in a particular attribute (i.e. the slope) is called the *hedonic price, implicit price, or rent differential* of the attribute."

In line with the theoretical assumption that these attributes increase the value of housing but increase that value at a decreasing rate, the hedonic pricing model is often estimated in a multiplicative form such as

2) $P = \beta_0 * CBD^{\beta 1} * SIZE^{\beta 2} * EQ^{\beta 3} * NBHD^{\beta 4}$

Where the β's are elasticities and measure the percentage change in housing price resulting from a one percent change in the quantity of the attribute in question. In the case of the multiplicative hedonic model given in equation (2), the hedonic price for the level of environmental quality is given by

3) $r_{eq} = (\beta_3 * P)/EQ > 0$

If we then take the natural logarithms of both sides of equation (2) this function becomes linear (in logs) and can readily be estimated via linear regression. Doing so allows the analyst to calculate the impact of a characteristic such as environmental quality on housing prices and thereby assign an economic value to the attribute[1] in question.

**Estimation Problems**

Unlike survey techniques, which attempt to elicit information on a consumer's willingness to pay for a public good or externality through interviews, the hedonic method has the advantage of evaluating actual choices that consumers make in an existing well-developed private market. Nevertheless, the econometric estimation of a given good's value through changes calculated in the price of related goods is not without its problems and challenges.

First, as pointed out in Boardman et al (2011) "people must know and understand the full implications of the externality or public good. For example, in order to use the hedonic pricing method to value pollution, families should know, prior to the purchase of their house, the level of pollution to which it is exposed and should also know the effect of different pollution levels on their health." This problem can be particularly troublesome for an item like radiation where the effects of long-term low-level exposure are so poorly understood. Second, the variables

[1] To be totally accurate the procedure described above is actually part one in a two part process. In the second stage the hedonic price derived in equation (3) is regressed on a number of consumer specific values ( such as income, socioeconomic, background etc as well as the level of environmental quality they consume) in order to estimate their willingness to pay for the good. Because of the difficulties in obtaining data for this and the inherent econometric estimation difficulties involved, however, this two step procedure is rarely employed. A description of the first step, then, is fully sufficient for our purposes.

included in a given hedonic equation must be measured correctly in order to give an accurate representation of the correlation between them. As an example, the value of a house may depend critically on the quality of its construction and the researcher may have little access to any information on this. The year of its construction may, in some cases, be used as a proxy for construction value but this may turn out to be a poor proxy thereby biasing the results of the model. Thus, it is important when constructing empirical models to obtain data on all relevant variables, choose the best proxies for those variables, and obtain as reliable estimates for the data as possible. Third, if we are using housing data, the data should contain a variety of different sizes and attributes so that the families involved can find the optimal combination or "bundle" of attributes that they are looking for.

Our theoretical analysis is predicated on the fact that consumers are, in some sense, optimizing the choice of the variable in question and without sufficient variation in property sizes, neighborhood characteristics, and environmental quality, this kind of optimization would be impossible[2]. Fourth, there may be what is termed "multicollinearity" problems in the data[3]. If, for example, large expensive houses were mainly located in pollution free areas (or areas which are far from a nuclear facility), and all of the houses where environmental quality was poor were small and inexpensive, it would be extremely difficult to separate out the effect of environmental quality alone when examining the price of houses. Similarly, if the areas where pollution levels are highest are also areas where crime levels are high we would also have a multicollinearity problem. Fifth, we might wish to estimate the impact of a nuclear site, for example, on neighboring house prices (nuclear site determines house prices), but the location of the nuclear site might have been chosen based on the house prices of the neighborhood (house prices determine nuclear site selection). This problem is referred to as "endogeneity" in the econometric literature and separating the direction of causality might be a challenging exercise.

## III. Hazardous Sites and House Prices

A large number of hedonic studies on the impact of hazardous sites on house prices have been produced since the 1970s. In order to summarize the findings from these studies and identify prevailing patterns, Braden et al. (2011) conducted a meta-analysis of 46 North American papers issued between 1971 and 2008. These papers generated 129 estimates that survive

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[2] Interestingly, this same concern enters when we are trying to evaluate a consumers' evaluation of risk by looking at market wage differentials. If there is insufficient variation in wages (due to union power, minimum wages etc) or the variety of jobs with different risk factors it is difficult to get an accurate gauge for the consumers' valuation of risk.

[3] The term multicollinearity refers to situations where two or more of the explanatory variables exhibit a linear dependency. In practical terms this occurs when two or more of the independent variables are highly correlated. If this correlation is severe it may be impossible to ferret out the independent effects of these variables with precision and reliability.

outlier diagnostics and produced an average decrease in property values of 6.37%. The studies encompass analysis of nonhazardous landfills, terrestrial sites contaminated by hazardous materials (both National Priority List (NPL) sites and non-NPL sites), aquatic sites contaminated by hazardous materials, and nuclear sites. The authors estimate an econometric model that describes the proportional price effect of the disamenities on house prices as a function of site characteristics, data characteristics and methodological variables.[4] The key results from Braden at al.'s analysis are that:

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

Braden et al. (2011) produce some results of particular interest to this review. First, they report that the negative impact on house values of proximity to a disamenity is 6.37%, a much smaller figure than often anticipated in surveys on risk perception. For example, Metz et al. (1997) report that "40% of residents near three Midwestern nuclear power plants believed that the values of homes within 50 miles would decrease, on average, by one fourth if it were announced that spent fuel would remain on-site for the foreseeable future" (p. 28). Second, among the hazardous sites included in all analyses, nuclear sites (along with terrestrial non-hazardous sites) were associated with the smallest impact on property values.

[4] These include type of disamenity, geographic location, inclusion on NPL, on-site job creation (which may compensate for a potential negative effect), stage of cleanup, property type, actual parcel sales vs value assessment, geographical range of the study, presence of multiple sites, sample size, inclusion of neighborhood characteristics as control variables, time trend, annual average interest rate for conventional 30-year mortgage, functional specification (linear versus non-linear), discrete versus continuous environmental indicator (such as existence of site versus distance from site), whether the paper was published (5 studies were prepared for government agencies and were not peer-reviewed), whether environmental indicator was statistically significant and whether the study accounted for spatial autocorrelation.

In a recent article using original data, Davis (2011) specializes to US power plants generating 100+ MW and investigates whether these affect neighboring house values and rents, as well as the demographics in those neighborhoods where they are located. In order to conduct his empirical exercise, Davis combines data on the attributes of power plants (US EPA's "Emissions and Generation Resource Integrated Database (eGrid)") with information on house values and house and block characteristics (restricted microdata from the decennial census block data for 1990 and 2010). Davis estimates that proximity to power plants decreases house values by 3% to 7% within 2 miles of the plants and the effect vanishes at greater distances. He also estimates that neighborhoods of power plants experience a decrease in mean household income, educational attainment, and the proportion of homes that is owner occupied. Both of these results are consistent with the predictions of the hedonic model discussed above. The first and most obvious implication of a hedonic model is that houses near a polluted site will fetch lower prices in the market. The perhaps less obvious implication of the hedonic model is that more polluted areas will offer an incentive for individuals with more tolerance to pollution to live there. This occurs because the hedonic model assumes individuals with different preferences and tolerance to pollution. Therefore, the price discount that is capitalized in the house values will attract those individuals with lower incomes and more tolerance to pollution. Finally, to put his results in perspective, Davis estimates that, on average, the aggregate reduction in the value of houses located within 2 miles from a power plant is $13.2 million. This is a small figure when compared to the $200 million that it costs to build a relatively small (100 MW) coal-burning power plant. A 100MW natural gas power plant costs $100 million to build.

Greenstone and Gallagher (2008) take a different approach to estimating the impact of amenities/disamenities on house prices. Their analysis is innovative in that they consider a large number of contaminated sites in the US and address important econometric shortcomings involved in the estimation of empirical hedonic models and typically overlooked in hedonic studies. For that reason, Greenstone and Gallagher's contribution deserves careful consideration in this review. The authors start by focusing on all the sites that are placed on the National Priority List (NPL) for cleanup. These sites were identified by the EPA as the most dangerous sites in the country and were scheduled for cleanup (following the Comprehensive Environmental Response, Compensation, and Liability Act – CERCLA/Superfund). First, Greenstone and Gallagher reproduced a conventional exercise in the literature by comparing the prices of houses located close to sites on the NPL to the prices of houses (from all the US) that were not near an NPL site. Hedonic theory suggests that if a contaminated site is cleaned up or is scheduled for a cleanup, then we would expect house prices in the neighborhood of this site to increase. The authors find a statistically and economically significant increase in house prices (up to 19%) if these houses are located near an NPL site. However, Greenstone and Gallagher indicate that there are serious reasons to doubt the reliability of this conventional approach. First, they point to the existence of many confounding variables that could also explain house price differentials when NPL and non-NPL sites are compared. Second, their results are unexpectedly sensitive to the delineation of neighborhoods of the NPL sites (own census tract versus three-mile radius) and third, the estimated effects vary greatly across competing econometric specifications (p. 982,983).

To address the problems with the conventional approach, Greenstone and Gallagher make use of the initial set of candidate sites to be listed on the first NPL produced in 1982, as well as the ranking system (Hazardous Ranking System – HRS) the EPA created to select the most hazardous sites to be cleaned up. The HRS assigned a score from 0 to 100 and the 400 sites with the highest scores (28.5 or higher) were placed on the initial NPL in 1982. The fact that the HRS produced a cutoff point (28.5) identified sites with scores just below and just above the cutoff. Greenstone and Gallagher show that the sites with scores between 16.5 and 40.5 are indeed similar in most dimensions measured in their data set and constitute comparable cases to assess the impact of the NPL on house prices. In sharp contrast to the results from the conventional approach described in the previous paragraph, estimation of the impact of NPL on house prices produces results that are neither economically nor statistically significant. That is, when focusing on more meaningful comparisons, the authors find that cleanup dictated by CERCLA (Superfund) does not generate benefits that translate into higher house prices.[5] These nil or negligible benefits are contrasted to the average cost of $43 million per Superfund cleanup.

Greenstone and Gallagher go on to estimate the impact of assignment of the NPL designations on the attributes of the households living near the NPL sites as well as on the supply of housing. Hedonic theory suggests that individuals demanding better environmental quality (such as families with young children) would be more likely to live near the cleaner sites. Furthermore, supply of housing is expected to increase in a now more desirable location. Neither effect is estimated to be significant, again casting doubt on the benefits produced by the Superfund cleanup.

In a different context, but using a similar approach based on quasi-experimental evidence, Chay and Greenstone (2005) estimate the impact of total suspended particles (TSPs) on house values. They specialize to the Clean Air Act Amendments, which classify counties as nonattainment areas if emissions are above pre-determined levels. This enables the researcher to identify similar counties with different attainment status and produce estimates of the effect of air pollution on house prices while avoiding estimation bias caused by omitted variables. Bias-inducing omitted variables are factors that influence house prices and also tend to be

[5] This result is placed in sharp contrast to the findings in the pre-existing literature. Kiel (1995) estimates that distance to Superfund sites is associated with $3000 to $6000 per mile. Similarly, Mendelsohn et al. (1992) estimate that proximity to polluted waters reduced property values by $7000 to $10000 (in 1989 prices) in New Bedford, MA. Kohlhase (1991) and Kektar (1992) estimate house price increases as Superfund sites are cleaned up.

correlated with pollution such as neighborhood crime rate, rate of urbanization and population density among others. If these variables are not observed by the researcher and are thus unaccounted for in a regression setting, the resulting relationship between pollution and house price will be biased and even go in the "wrong direction". Chay and Greenstone (2005) use a comprehensive data set for the United States and estimate that a 1% increase in TSP concentration leads to a 0.2% to 0.35% decrease in house values. To put these numbers in perspective, they report the average value of a house in nonattainment counties in the mid 1970s to be $86,900 (in 2001 dollars). These counties were subject to more stringent air quality regulations and experienced an increase in house price of roughly $2,400 per affected house as a consequence of resulting reductions in TSP concentrations.

In a forthcoming paper, Bajari et al. propose an alternative estimation approach for hedonic models designed to account for bias introduced by an important class of omitted variables: those that vary over time and are correlated with other explanatory variables in the model.[6] For example, house prices are affected by "curb appeal" and quality of landscaping, but the researcher can typically not measure these variables for each house. Furthermore, these omitted or unobserved variables are often correlated with other variables, such as air pollutants that affect human health and house characteristics such as surrounding trees and landscape.[7] Bajari et al. acknowledge the potential of quasi experiments like the ones analyzed by Greenstone and Gallager (2008) and Chay and Greenstone (2005) to account for omitted variables bias, but stress that econometric identification in hedonic models based on quasi-experimental variation is frequently not possible. This happens because quasi-randomness is either not available for many applications or might rely on very strong assumptions (such as the single and unified housing market in the entire United States assumed by Chay and Greenstone, 2005).

Bajari et al.'s identification approach relies on two assumptions in addition to the common assumption in hedonic models that values of attributes influence house prices. First, they assume that the omitted house attribute evolves as a linear function of past values and a random error (first or higher order Markov processes depending on the number of observation on sales of a given house). Second, they assume that individuals rationally predict the evolution of the omitted attributes. That is, conditional on current information available to the house buyer at a given point in time, he/she does not make systematic errors in predicting the

[6] Time invariant omitted variables can often be accounted for by fixed effects when panel data are available.
[7] For example. $SO_2$ emissions affect trees, ecosystems and building structures through acid rain.

evolution of the omitted attribute. These assumptions enable more reliable estimation of the impact of house attributes such as pollution on house prices.[8]

Finally, by using data on repeated house transactions in California's Bay Area between 1990 and 2006, Bajari et al. apply their econometric strategy to estimate the contribution of $SO_2$ (sulfur dioxide), PM10 (particulate matter) and $O_3$ (ground-level ozone) emissions to local house prices. Their results suggest that ignoring omitted variables that are correlated with other explanatory variables leads to biased estimation of the impact of pollution on house values. Depending on the estimation approach (cross-sectional or fixed effects) and the point in time for the cross-sectional estimation, the impact of emissions on house prices is significant and **positive** – the opposite of what hedonic theory would predict. In other cases, the negative effect of emissions on house prices is underestimated relative to their proposed approach. When Bajari et al. account for omitted variables using their novel framework, the effect of pollution is negative and statistically significant for all pollutants. They estimate elasticities of house prices with respect to PM10, $SO_2$ and $O_3$ to be -0.07, -0.18 and -0.6, respectively. That is, a 1% increase in PM10 led to a -0.07% decrease in house prices in the Bay Area during the 1990 – 2006 period. Similarly, 1% increases in $SO_2$ and $O_3$ implied 0.18% and 0.6% decreases in house prices, respectively, keeping everything else constant.

## IV. Nuclear Sites and House Prices

Several attempts to gauge the image of nuclear sites by the public suggest that these sites are subject to a strong negative image and reduce the preference for individuals to vacation and relocate in their vicinity. For example, Flynn et al. (1998) catalogued and analyzed news articles from local media in the Denver metropolitan area following an FBI raid of the Rocky Flats nuclear weapons facility motivated by environmental/safety violations. They documented a large number of articles on the facility with a strong negative connotation. The authors also surveyed local home buyers and observed that most placed lower value on property closer to the facility.[9]

At the opposite end of the spectrum, hedonic studies conducted by Nelson (1981) and Gamble and Downing (1982) failed to estimate a statistically significant impact of the Three Mile Island (TMI) nuclear power plant accident on local house prices. More recently, Bezdek and Wendling (2006) document ***positive*** impacts of nuclear facilities located in rural areas on house prices, income, school quality, job creation and local economic growth. The authors note five major

[8] More specifically, Bajari et al. specify a non-linear two stage least squares approach where house prices are regressed on lagged house prices as well as current and lagged house attributes.
[9] See also Slovic et al. (1991), Kunreuther and Easterling (1992) and Jenkins-Smith (1994).

reasons for this positive impact: 1) the facilities provide jobs and incomes for local residents, thus increasing the demand for housing near the nuclear sites; 2) the jobs and incomes generated by nuclear facilities often enable construction of better quality houses; 3) tax revenues generated by the facilities significantly improve local schools, thus increasing local house values; 4) tax revenues generated by the facilities lower the tax burden on local residential and commercial property; and 5) tax revenues generated by the facilities help fund better local infrastructure. These five sources of positive impacts of power plants on local house prices and economic indicators, the authors argue, outweigh potential value losses due to risk perceptions by house market participants. Although some of the positive effects reported in Bezdek and Wendling (2006) are quite large, an important limitation of their study is that they do not conduct a systematic analysis to assess the statistical significance of these effects. Finally, the authors note that the facilities in their study were located in economically depressed regions, thus biasing upwards their impact on local economic indicators. For that reason, they stress that their findings cannot be generalized to non-rural areas.

Clark et al. (1997) and Metz et al. (1997) focus on two nuclear power plants in California: Diablo Canyon near San Luis Obispo and Rancho Secco, a closed down power plant near Sacramento that was converted into a dry storage facility for spent nuclear fuel. These hedonic price studies do not find any significant detrimental effect of the nuclear sites on neighboring residential house prices. That is, they conclude "that any negative imagery associated with nuclear power plants or stored nuclear waste does not translate into significant detrimental influence on residential home prices in the immediate vicinity of the facilities studied" (Clark et al., 1997, p. 508).

Failure to estimate a negative impact of nuclear sites on local house prices and the estimation of positive impacts is likely to be due to omitted variables and the inability of these studies to separate the positive economic growth effect from the negative disamenities effect on house prices. In a different hedonic study, Gawande and Jenkins-Smith (2001) focus on house values along a route used to transport nuclear waste. These locations are less likely to benefit from the generation of jobs and economic growth (except perhaps for a relatively small number of jobs at the initial and end points of the transportation corridor), but might be left with the negative impact of proximity to nuclear waste. In their study, Gawande and Jenkins-Smith investigate the impact of shipments of spent nuclear fuel across three counties in South Carolina: Aiken, Berkeley and Charleston. Aiken and Berkeley counties are primarily rural, whereas Charleston is primarily urban. The initial point of departure for land transportation of the spent nuclear fuels in this study is either Berkeley or Charleston counties, whereas the final destination is the Department of Energy's Savannah River Site nuclear facility is located in Aiken, Allendale and Barnwell counties.

Gawande and Jenkins-Smith's analysis accounted for spatial autocorrelation[10] among house prices and focused on the nuclear waste shipments that took place between 1993 and 1996. Their results indicated that distance from the route mattered for property values in urban Charleston, suggesting a negative impact of proximity to transported nuclear waste. The authors estimate a 3% gain in property value for those houses that are 5 miles away from the route. The estimates for rural Aiken and Berkeley counties do not lend support to the hypothesis that transportation of nuclear waste lower property values. They estimate no effect in the case of Aiken County, perhaps because of the local residents' experience with the Savannah River Site facility, and ambiguous effects for Berkeley County, depending on the econometric specification they used. The lack of evidence supporting a negative house value effect in rural counties corroborates findings from other studies, whereas the significant negative effect in the more urban setting sheds light into possible determinants of the linkage between house prices and disamenities.

Noting that a number of studies including those of Gamble and Downing (1982) and Clark et al. (1997) failed to find a statistically significant positive distance gradient from nuclear facilities (which would support a negative externality hypothesis) Folland and Hough (2000) offer two possible explanations. "First", they state, "these few studies are really each single cases (or involve very few cases) even when hundreds of residential homes are evaluated. The public perceptions regarding reactor safety may be general, affected by or dependent on the broadcast media, which conveys the views of experts, community leaders and news of energy company behavior. In one locality, the company's reputation may purvey excellent safety, in another there may even have been an accident. Second, one may err by embedding hypotheses that prescribe how the local people perceive distance to relate to risk. Should someone living five miles from the reactor site feel more at risk than someone living 15 miles away? The embedded hypothesis that the nuclear externality would necessarily affect the distance gradient could prove false, the risk being experienced generally throughout the area."

In their study then, Folland and Hough propose a slightly different way to determine the presence of negative externalities caused by the presence of nuclear facilities. Rather than focusing on the disamenities caused by the psychological or health effects of the exposure to the risk of an accident they posit what they term an "asset depreciation approach". Looking at farmland, they argue that the expected damage from a possible nuclear accident reduces the value of the land to generate profits. This reduction is then capitalized into the value of the land

[10] Spatial autocorrelation refers to observations that co-vary in space. For example, the value of houses tends to be correlated to the values of other houses in the same neighborhood. This could happen, for example, because realtors use the value of "comparable houses" to set asking prices for specific houses. The values of comparable houses, in turn, are likely to influence final market prices. Failing to account for spatial autocorrelation creates problems for estimation and inference in econometrics.

and is reflected in a lowering of the landowners' reservation price for selling the land. To state this somewhat differently, instead of studying the impacts of nuclear facilities on household owners utility, Folland and Hough concentrate on these facilities' impacts on expected profitability on farm assets. Furthermore, in order avoid concentrating on any single case they look at a cross section of 494 market areas throughout the U.S. over the years 1945, 1950, 1954, 1959, 1964, 1978, 1987 and 1992. Average farmland values in this panel data set were posited as a function of a number of variables including the value of agricultural goods, population density (to account for urban encroachment) and the presence of a nuclear facility in the area. Their findings indicated that nuclear facilities did have a negative impact on farm prices with this impact falling with the presence of newer (and presumably safer) vintages of nuclear power plants.

## V. Summary and Conclusion

In this review, we first described the hedonic price method for estimation of the value of an environmental amenity or disamenity, for which no separate market exist. The hedonic approach focuses on a multi-attribute good, such as a house, and attempts to estimate the value of a single attribute, such as distance to a contaminated site. Although the theoretical foundation of the hedonic model is well established and accepted, empirical implementation is far from straightforward. Even when data on house prices, pollution and several determinants of house prices are available, efforts to empirically estimate the linkage between the environment and house prices are likely to be undermined by the omission of essential information. This omission can impose serious questions on the validity of empirical results when the unobserved determinants of house prices are correlated with the environmental variable. For example, pollution might be correlated with variables that are not readily available (such as "curb appeal", crime rate, population density and landscaping), but are still important in determining house prices. In some cases, peculiarities of the available data and the environmental problem enable the use of strategies to circumvent the omitted variables bias. However, most existing studies suffer from this omission bias as recent empirical papers have demonstrated.

We also reviewed hedonic studies on the impact of proximity to nuclear sites on property values. Although public perception suggests large losses to property values in the vicinity of nuclear sites, empirical studies suggest small and sometimes positive effects. This possibly surprising result might result from 1) omitted variable bias discussed above (such as nuclear site selection based on rural status and low property values) and 2) failure to separate the negative contamination effect from the often positive effects associated with job creation, tax collection and economic stimulus created by the operation of large nuclear facilities. Even when nuclear sites do not contribute substantially to the local economy, the impact of proximity to (potential) nuclear contamination on house values was estimated to be either nil or relatively small (such as a 3% decrease in house prices in the more urban Charleston, SC area).

As we consider the Piketon plant in light of the existing literature, we start from the point that the area might be perceived as a contaminated site. Therefore, as proper cleanup and disposal of toxic/radioactive waste we might expect house values to increase in the vicinity of the site. However, the literature suggests that this effect might be small or negligible. To the extent that toxic waste is spread in a large area and decontamination and disposal concentrates the waste in a single smaller area, houses closer to the disposal site might experience a value loss. The size of the decrease in the price of these houses depends on how safe disposal and storage is and how the information on safety is communicated to the public. Depending on how cleanup, disposal and communication take place, these houses might even experience a price increase relative to how they are perceived today. In either case, price changes are likely to be small.

**Technical Appendix**

The goal of this appendix is to further elaborate on the theory of hedonic valuation described in section II. In doing so, we closely follow the exposition in Rosen (1974). Consider an individual that derives utility from consumption of a good with several attributes z = ($z_1$, $z_2$, …, $z_n$) and a composite good x. In our context, we think of z as a house with n attributes, such as number of rooms, square footage, proximity to a school of a given quality, location in a neighborhood with a given crime index, proximity to a contaminated site, etc. Likewise, we can think of x as "all other goods". Formally, individual *k* has a utility function $u_k(x,z_1, …, z_n)$. Furthermore, we assume this individual seeks to maximize his/her utility subject to his/her budget constraint:

$$\max_{x,z_i} u(x, z_1, \dots, z_n) \quad subject\ to \quad I = x + p(z)$$

Here, we normalize the price of the good x to 1, *I* stands for income and *p(z)* is the price paid for the multi-attribute good (house). We are interested in the contribution of the $j^{th}$ attribute $z_j$ to the price of the house *p(z)*, that is $\frac{\partial p(z)}{\partial z_j}$.

Another way to characterize the consumer's problem that is more informative for our purposes is to define the maximum amount θ that the consumer is willing to pay (bid) for a house and rewrite the budget constraint and utility functions as follows:

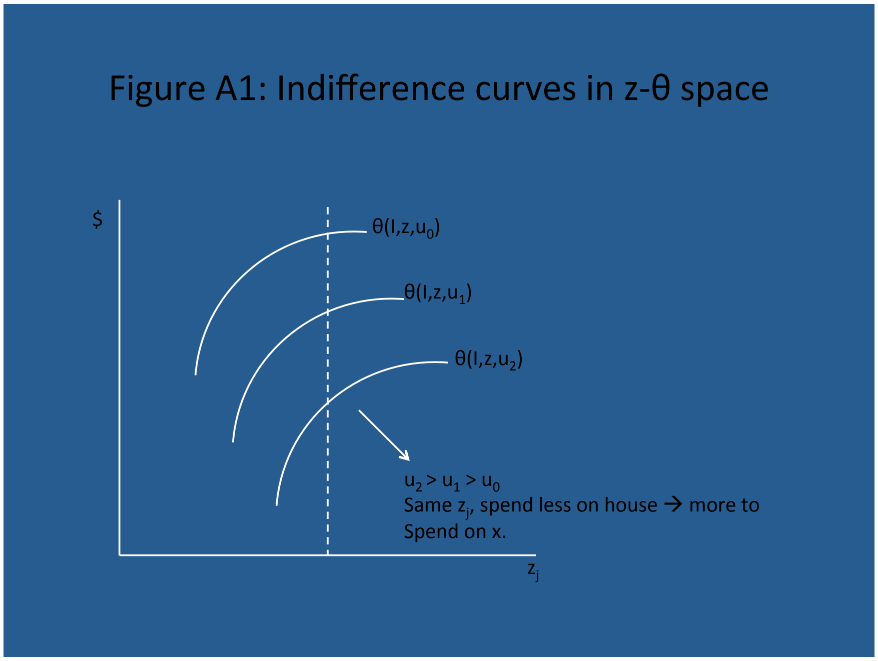
$$I = x + \theta \;\rightarrow\; x = I - \theta$$

$$u(I - \theta, z_1, \dots, z_n)$$

Next, hold utility and all $z_i$ constant, except for the $z_j$ we are interested in (distance from a contaminated site). This will define the indifference curve

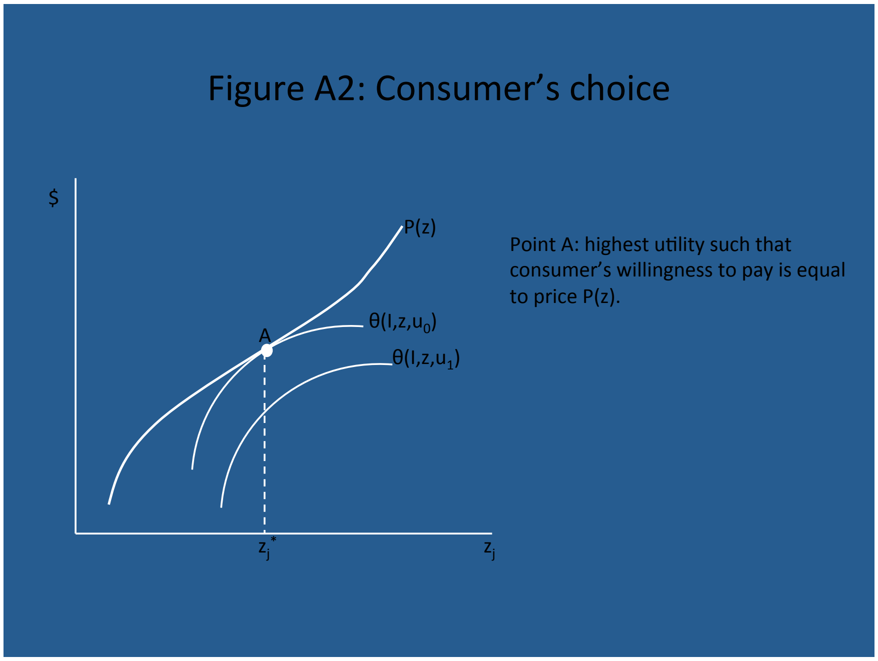
$$u\left(I - \theta, \overline{z_1}, \overline{z_2}, \dots, z_j, \dots, \overline{z_n}\right) = u_0$$

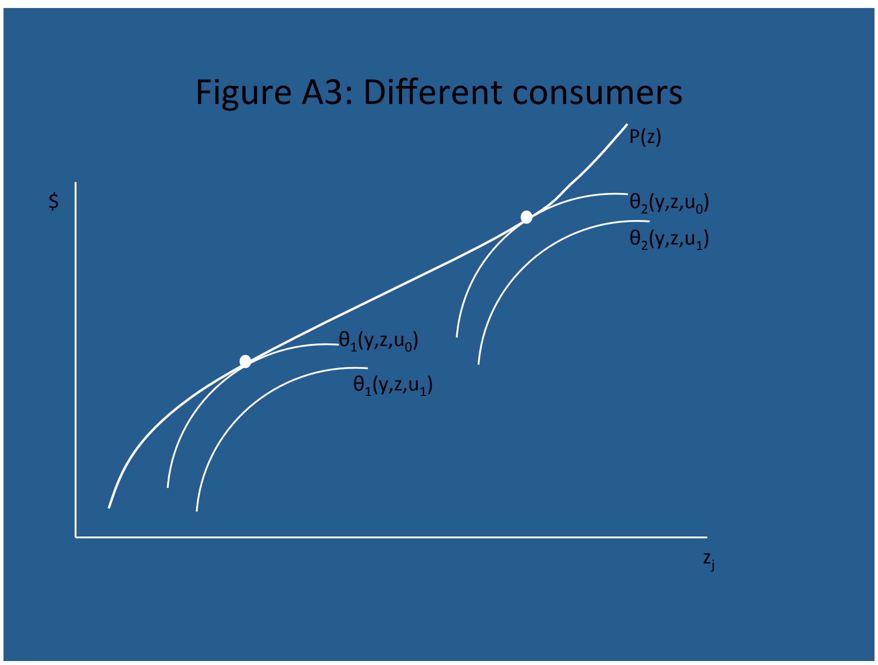
for some constant utility level $u_0$. Repeat this procedure for each possible utility level to produce a family of indifference curves that associate levels of $z_j$ to different willingness to pay θ. If we solve the above equation for θ, we obtain the bid function $\theta(I,z,u_0)$ for a house, where z represents the vector of house attributes, where only $z_j$ is allowed to vary. Notice that by specifying how much an individual bids for a house, instantly determines how much income is left to be spent on x. Figure 1 depicts three indifference curves given by the above expression, one for each level of utility. Some aspects to notice from this figure are as follows. First, bid functions increase at a decreasing rate. This is a consequence of usual assumptions on utility functions, which are beyond the scope of this review. Second, indifference curves located more towards the south-east of the graph depict higher levels of utility. To see that, notice that if the same level of $z_j$ can be obtained with lower expenditures θ (along the vertical dashed line in Figure A1), then more resources are leftover to be spent on x and utility will increase.




Third, we will assume that individuals wish to maximize utility when they make their consumption choices, meaning that the consumer will attempt to make choices so as to attain the indifference curve that is as far out in the south-east direction as possible. What limits the consumer's choice in addition to his income is the schedule of house prices for houses with different levels of the attribute $z_j$.

Figure A2 depicts an upward sloping curve relating levels of the attribute $z_j$ to house prices p(z). The positive slope of p(z) reflects the assumption that houses with more $z_j$ fetch a higher price in the market. Figure A2 also depicts the quality $z_j^*$ of a house that the individual will choose to maximize his/her utility subject to his/her income and price schedule p(z) that he/she encounters in the market. Figure A3 repeats the same exercise, but for two different types of consumer. Consumer 1 has bid functions $\theta_1$(.) and consumer 2 has bid functions $\theta_2$(.). Because of differences among these consumers they end up picking different houses with different $z_j$. Differences among consumers could be a consequence of different incomes or different preferences for the environment. For example, we would expect an individual (household) that has young children to, everything else equal, choose houses in cleaner locations (larger $z_j$ meaning, for example, larger distances from a contaminated site).

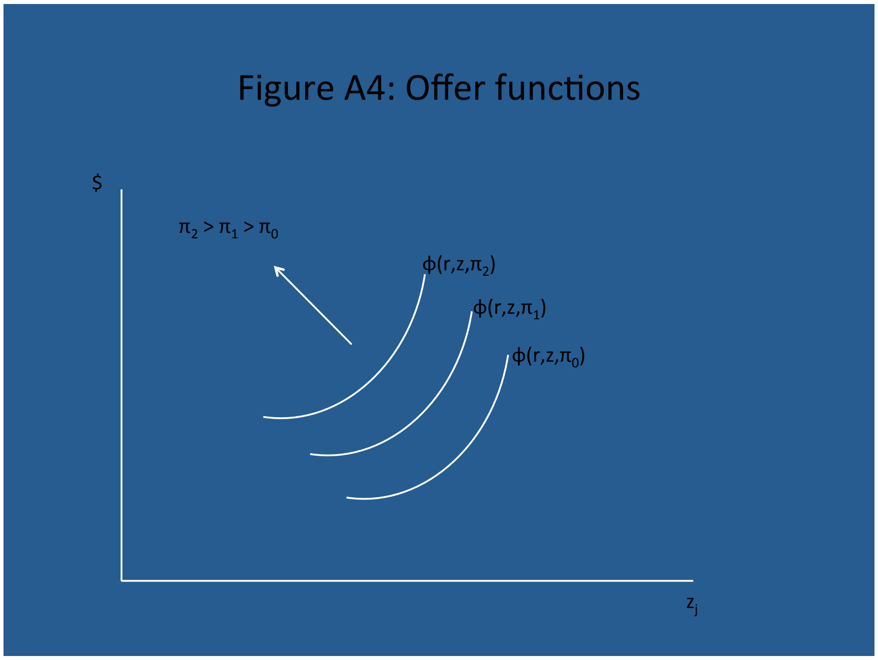


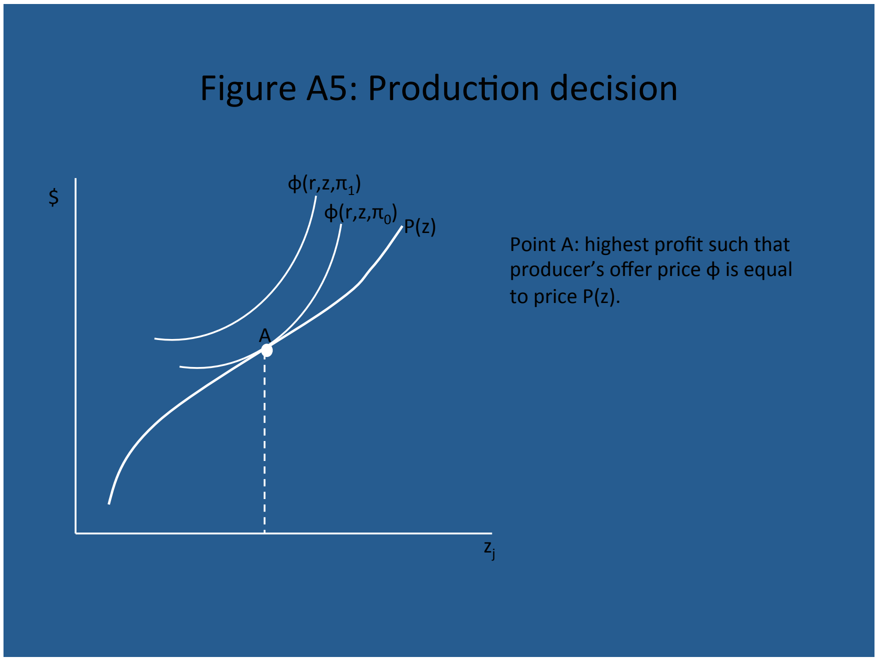

At the other end of the market, we have producers of houses (builders, real estate agents or simple sellers in general) that wish to maximize profits π:

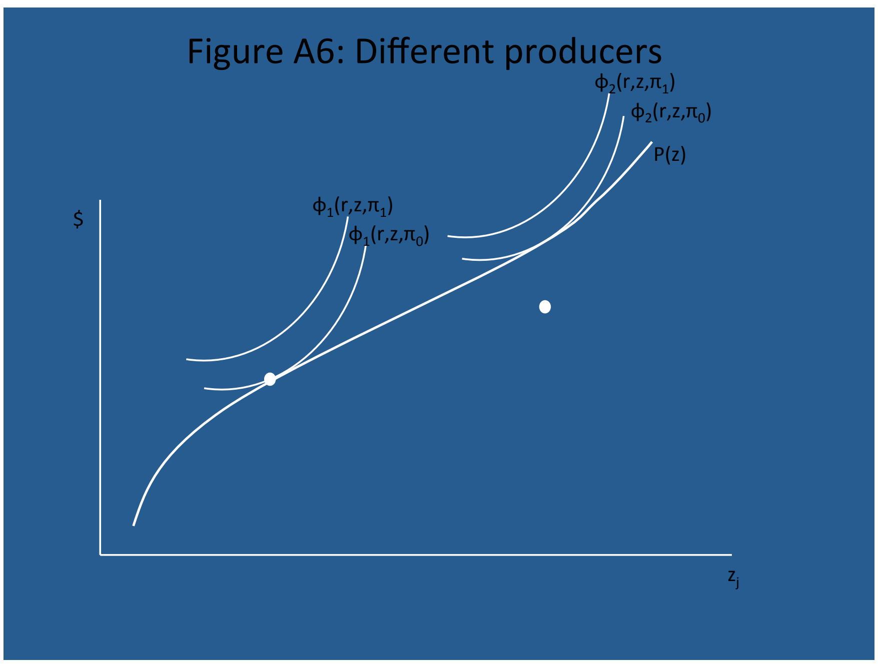
$$\max_{z_j} \ \pi = \emptyset - c(r, z)$$

Here, r denotes input prices, z denotes the vector of attributes of the house, of which we assume only $z_j$ is allowed to vary, and $\phi$ is the price the house producer offers the house for. For a given level of profits $\pi_0$, we can solve for an offer curve $\phi(r,z,\pi_0)$ that associates an offer price for each level of $z_j$ required to produce a profit $\pi_0$. We then repeat the same procedure for other profit levels and plot the offer or isoprofit curves on the $\phi$-$z_j$ plane as in Figure A4.

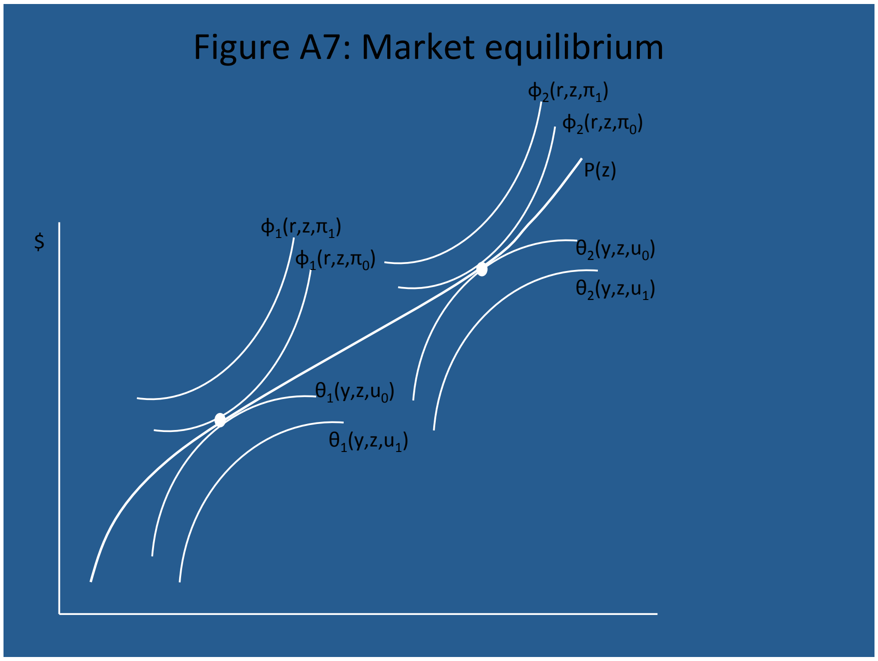



Notice first that each offer curve increases at an increasing rate. This is a consequence of assumptions on increasing opportunity costs in the production of houses. Second, offer curves reflect higher profits as we move in the north-west direction. This is because offering a house with the same level of $z_j$ for a higher price would imply higher profits. Lastly, we assume house producers wish to maximize profits, thus attempting to locate on the highest offer curve possible. Given the house price schedule p(z) producers encounter in the market, Figure A5 depicts the level of $z_j$ a producer would choose to produce with his/her house in order to maximize his/her profit. Figure A6 shows how two different producers with different cost structures would choose to produce different houses with different levels of $z_j$.



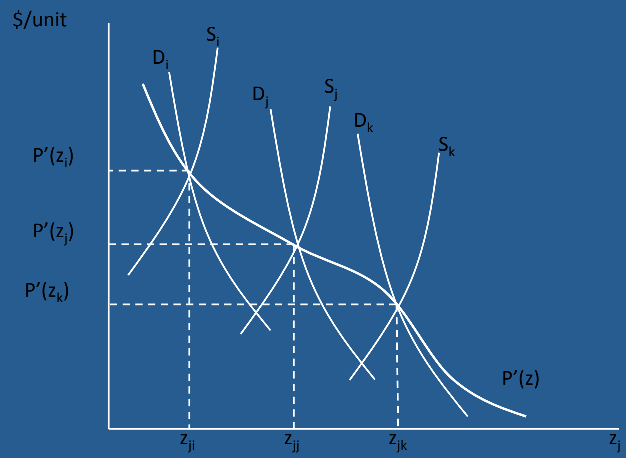

We are now in a position where we can characterize market equilibrium as depicted in Figure A7. At equilibrium, for each house sold for a given level of $z_j$ there is a bid function and an offer curve that is tangent to each other and to the house price function p(z). This tangency condition is of major importance to hedonic studies as it highlights the valuation of the non-market good $z_j$ that is attached to the market good (house). That is, for each house sold, the slope of the bid function represents the value a consumer of the house places on a small increase in $z_j$ (environmental quality). At that point, the valuation of $z_j$ by the consumer coincides with the valuation by the producer. The valuation by the producer is the minimum amount a producer would ask to produce a house with an additional unit of $z_i$.




That is, the slope of the offer curve represents the cost of producing one additional unit of $z_j$ (environmental quality). These, in turn, are equal to the slope of the house price function p(z), or simply $\frac{\partial p(z)}{\partial z_j}$. That is, the value the market places on one additional unit of $z_j$ (environmental quality) for each level of $z_j$. This is the theoretical foundation for an econometric hedonic estimation exercise. The estimated hedonic price function p(z) in a well specified econometric model is the basis for the estimation of the value of a small increase in environmental quality, $\frac{\partial p(z)}{\partial z_j}$. Estimation of $\frac{\partial p(z)}{\partial z_j}$ is the first step in an econometric hedonic exercise.

In general, $\frac{\partial p(z)}{\partial z_j}$ will be a function assigning a dollar value to each level of $z_j$. This could be viewed as "synthetic data" on equilibrium prices and quantities of $z_j$ stemming from the interaction between supply and demand by different consumers and producers of houses (see Figure A8).

Figure A8: Hedonics – supply and demand for attribute $z_j$




These "synthetic data" could then be used, in principle, in a second step of the hedonic exercise to estimate average demand and supply of $z_j$. Once the average demand for $z_j$ is estimated in this second step, we can calculate social losses due to increased pollution as the area under the demand curve between two levels of $z_j$. However, this second step is rarely estimated in hedonic studies due to econometric identification problems and the immense data requirements it imposes on the researcher (data on characteristics of each individual buyer and seller of houses). All hedonic papers discussed is this review estimate the first step of the hedonic estimation exercise and use the results as approximations for the actual losses from proximity to a contaminated site.

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