Housing Prices, Pollution and Trends in the Value of a Statistical Life

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The value of a statistical life (VSL) may be revealed by home buyers, assuming that consumers reveal their willingness to pay for clean air amenities, that life-saving is the principal amenity, and that consumers are informed of the marginal risk of death due to air pollution. The first assumption is the basis of a number of hedonic housing studies, many of which fail to reveal a willingness to pay for clean-air amenities. Considering the markets that do reveal a plausible willingness to pay, the VSL magnitudes imply that home-buyers either grossly overestimate the marginal risk of death or they are less concerned with life-saving than with other environmental amenities. In either case, housing markets do not reveal a credible VSL. (JEL H0, I1, R21)

Keywords: VSL; Value of a Statistical Life; Hedonic Housing Studies; Air Pollution.

Despite broad acceptance of the role of government in programs to ensure public safety, there is considerable disagreement about how to compute the benefits of such programs. Against this backdrop, those who make and implement public policy are faced with the macabre task of placing a monetary value on a human life.

Schelling (1968) championed the notion that life-saving need not be morally motivated, moving computation of the value of a statistical life (VSL) into the purview of positive economics. Following Schelling, market-based studies have tended to focus on either labor markets or goods markets.[1]

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[1]There is also a body of literature on non-market approaches to VSL. See, for example, Jones-Lee (1982).

This paper considers valuation from the housing market. The VSL is derived from the marginal risk of death from air pollution (MROD) and from the marginal willingness to pay for a home with reduced air pollution (MWTP). The VSL for nine urban areas – Boston, Chicago, Kansas City, Los Angeles, Milwaukee, New York, San Francisco, St. Louis and Washington – is calculated using epidemiological MROD data and MWTP from eighteen hedonic studies. These VSL values have means ranging from -$8 million to $164 million. Negative values and wide ranges are the result of uncertainty in the hedonic MWTP studies, while the overall magnitudes can be attributed to very small MROD values. The MROD, MWTP and VSL for Pittsburgh are compared with those from a previous study by Portney (1981). Taken with the historical context of the earlier results, the comparison suggests that the earlier VSL was overstated, and was probably more a result of exogenous forces than consumer preference.

1. Background

Market-based VSL studies typically examine either a labor market or a goods market. In labor markets, the equilibrium wage for a hazardous occupation incorporates the worker's willingness-to-accept (WTA) price for an increase in the probability of death. Early labor-market studies include those by Smith (1974) and Thaler and Rosen (1975). For a lengthy list of labor market studies as well as an excellent historical overview see Viscusi and Aldy (2003).

Goods-market studies relate the VSL to a consumer's willingness-to-pay (WTP) for quality-of-life improvements, such as automobile safety features and reduced health risks from air pollution. Markets studied include automobile safety equipment (Blomquist, 1979; Carlin and Sandy, 1991; Blomquist et al., 1996), automobiles (Atkinson and Halvorsen, 1990; Dreyfus and Viscusi, 1995), smoke detectors (Dardis, 1980; Garbacz, 1989), housing (Bailey et al., 1963; Portney, 1981; Smith and Huang, 1995; Gayer et al., 2000), cigarettes (Ippolito and Ippolito, 1984), and bicycle helmets (Jenkins et al., 2001).

This paper examines consumer WTP for reduced air pollution in multiple housing markets within the United States and the VSL based on the pollution-related mortality rate in that market. The results are compared with Portney's housing-market VSL from 1981.

2. The Housing Market and VSL

The three most important attributes of real estate are location, location and location (Barron's Educational Series, Inc., 2000). Hedonic housing studies face the daunting task of separating how much each of these contributes to the value of a home. Additionally, there are intrinsic inefficiencies in the housing market[2]. Despite these hurdles, however,

[2]Housing is neither homogeneous nor completely differentiated, there is imperfect information, transaction costs are high, and most consumers participate in very few transactions.

researchers have endeavored to find evidence of a consumer-revealed WTP for cleaner air and other environmental amenities.

Assuming that life-saving overshadows any other expected benefit from cleaner air, consumers' marginal willingness to pay (MWTP) for cleaner air is also their MWTP for a reduction in the marginal risk of death (MROD) due to air pollution. Portney's approach is to invert the MROD, giving the population for which, statistically, one life is saved with a marginal reduction in pollution. This population's total annualized MWTP is inferred as the VSL. Portney observes that household MWTP is the WTP so that no member of the household die from pollution, meaning that household MROD is the marginal risk of any one household member dying.[3] That is

$$VSL = \frac{\rho \bullet MWTP}{MROD_{household}}$$

where

$$\begin{aligned} \rho &= \text{interest rate} \\ MWTP &= \text{MWTP for a reduction in pollution} \\ MROD_{household} &= \text{household MROD from a reduction in pollution} \end{aligned}$$

MWTP data in this paper are taken from Smith and Huang (1993). MROD data are taken from the Internet-based Health and Air Pollution Surveillance System (iHAPSS)[4] and three associated papers: Samet et al. (2000), Bell et al. (2004), and Dominici et al. (2005). The following sections describe these data, then use them to compute the VSL for the nine study areas for which there are both MWTP and MROD data.

2.1. Marginal Willingness to Pay (MWTP) for Reduced Air Pollution

Smith and Huang survey thirty-seven housing price and pollution hedonic studies conducted between 1964 and 1978. Their meta-analysis produces a model of MWTP for a reduction in air pollution that is intended to combine disparate market valuations into a single model and facilitate extrapolation to other markets. Smith and Huang cite eighteen studies covering nine metropolitan areas for which there are also iHAPSS data: Boston, Chicago, Kansas City, Los Angeles, Milwaukee, New York, San Francisco, St Louis and Washington. These studies are listed in Table 1, along with four composite studies for which iHAPSS includes all of the component metropolitan areas. The metropolitan areas included in these studies are shown in Table 2. VSL values will be computed for these study areas.

[3] See Appendix C

[4] http://www.ihapss.jhsph.edu iHAPSS is funded by the Health Effects Institute (http://www.healtheffects.org) and is hosted and maintained by the Department of Biostatistics at the Johns Hopkins Bloomberg School of Public Health.

Table 1: Studies from Smith and Huang (1995) used in this paper (ID from the source).

ID	Study	Metropolitan Area
3	Bender, Gronberg and Hwang (1980)	Chicago
5	Nelson (1978)	Washington
6	Anderson and Crocker (1971)	Washington
6	Anderson and Crocker (1971)	Kansas City
6	Anderson and Crocker (1971)	St. Louis
7	Smith (1978)	Chicago
8	Krumm (1980)	Chicago
11	Li and Brown (1980)	Boston
13	Polinsky and Rubinfeld (1977)	St. Louis
15	Palmquist (1984)	Multiple cities
16	Brookshire *et al* (1979)	Southern California Air Basin
20	Palmquist (1982)	Multiple cities
21	Palmquist (1983)	Multiple cities
22	Atkinson and Crocker (1982)	Chicago
24	Brookshire et al. (1982)	Los Angeles
27	McDonald (1980)	Chicago
28	Berry (1976)	Chicago
29	Jackson (1979)	Milwaukee
31	Appel (1980)	New York
32	Soskin (1979)	Washington
37	Brucato *et al* (1990)	Los Angeles
37	Brucato *et al* (1990)	San Francisco

Table 2: Composite studies from Smith and Huang (1995) used in this paper.

Study	Metropolitan Areas
Palmquist (1984)	Miami, Houston, Atlanta, Denver, Seattle, Louisville, Oklahoma City
Brookshire et al. (1979)	Los Angeles and Orange counties
Palmquist (1982)	Minneapolis, Houston, Dallas, San Francisco, Miami, Los Angeles, Portland, Chicago, Philadelphia, Atlanta, Anaheim, Washington, Cincinnati, San Bernardino, Indianapolis, St. Louis, Baltimore, Detroit, Denver, Tacoma
Palmquist (1983)	Chicago, Los Angeles, Philadelphia, San Bernardino, Portland, Denver, Detroit, Dallas, Washington, Indianapolis, Houston, St Louis, Cincinnati, San Francisco

The meta-model estimates a MWTP for reduced air pollution in Pittsburgh of \$124.50 (2007 dollars) per μg/m^3 total suspended particles (TSP) (Smith and Huang, 1995, Table 3). Portney's source for MWTP estimates \$44 (2007 dollars) per μg/m^3 TSP (Spore, 1972, page 99)[5]. This is a log-linear model that regresses 1970 Census homeowner-valuations against property attributes by census tract for Allegheny County (for which Pittsburgh is the urban center). Property attributes include air quality (dustfall and SO_2), household demographics (income, household size), physical attributes (house size, age, lot size), and neighborhood attributes (distance from city center, distance from major highway, taxes, race, substandard housing, open space).

2.2. Marginal Risk of Death (MROD) from Air Pollution

Gregor (1977), Portney's source of MROD data, infers a causal relation between elevated TSP and increased mortality for Allegheny County. Schwartz and Dockery (1992) find a significant increase in same-day and next-day mortality associated with increased levels of TSP for Philadelphia between 1973 and 1980. Additionally, they find significant associations between elevated TSP and cause of death, specifically chronic obstructive pulmonary disease, pneumonia, and cardiovascular disease. The Health Effects Institute funded the Particle Epidemiology Evaluation Project in 1994 to further evaluate the Philadelphia results along with similar studies of Central Utah; St. Louis, Missouri; Eastern Tennessee;

[5] 200 1970 dollars for a 5 ton/square mile/month reduction in dustfall. This is converted to TSP based on the mean dustfall in 1969 of 33.908 tons/square mile/month (Spore, 1972, Table 2-B), a mean TSP in 1969 of 164.8 μg/m^3 (U. S. Enivronmental Protection Agency, 1969) and a deflator of 5.34.(U. S. Bureau of Labor Statistics, 1968–2007).

Birmingham, Alabama; and Santa Clara County, California.(Samet et al., 1995)

Ultimately, the Particle Epidemiology Evaluation Project was unable to make unequivocal the connection between TSP and mortality, citing two specific problems: how measurement errors in large-area TSP monitoring impact individual dosimetry, and the effect of mortality displacement (Samet et al., 1997). Mortality displacement - moving forward by a day or two a death that would have occurred in the absence of elevated air pollution - is observed following the London Fog of 1952 and other catastrophic air pollution events (Beaver, 1953). Some authors suggest that increased mortality associated with air pollution may be attributed entirely to mortality displacement, or harvesting, as they call it (Schimmel and Murawski, 1976).

The Health Effects Institute initiated the National Morbidity, Mortality, and Air Pollution Study in 1996 to address the shortcomings of the Particle Epidemiology Evaluation Project (Samet and Zanobetti, 2000, page 5). The study began with 20 cities and grew to include the 100 largest cities in the U.S. by the time the data and results were made available online in the form of iHAPSS. To address measurement error, the authors incorporate error corrections based on studies of the relationship between large-area ambient measures of pollution and the exposure of individuals who may spend much of their life indoors (Samet and Zanobetti, 2000, page 7). To address mortality displacement effects, two time-series approaches are used (Samet and Zanobetti, 2000, page 44). The objective is to eliminate short-time-scale affects (mortality displacement) and long-time-scale effects (seasonality, viral outbreaks, improved treatments,) leaving mortality attributable solely to elevated air pollution.

The iHAPSS data span the period from 1987 to 1994. Comparing iHAPSS data with Gregor's requires unit conversions and aggregation. Gregor reported the MROD in terms of TSP, while iHAPSS uses PM_{10}, the measure of airborne particles smaller than $10\mu m$. Although the EPA uses a standard conversion from TSP to PM_{10} of 0.55, the actual ratio in Pittsburgh varies from 90 percent in 1986 (the second year for there are PM_{10} data) to 57 percent in 2000. Gregor reports MROD by age group and gender for the white population only[6], and there are two aggregation issues as a consequence. First, iHAPPS does not break down mortality rates by gender or race. Second, although iHAPSS subjects are divided into three age groups, no age-specific results are reported, presumably because "...previous univariate analysis stratified according to age showed no age-associated trend." (Samet et al., 2000, p1744) Weighting Gregor's age and gender specific marginal rates by the relative populations in Allegheny County based on the 1970 Census, the overall MROD is 2.00 per 100,000. The comparable iHAPSS result is 0.2734[7] per 100,000.

[6]Gregor states that this is because only nine percent of Allegheny County was non-white in 1970. According to the 1970 Census, nearly 21 percent of Pittsburgh was non-white, meaning that less than four percent of suburban Allegheny County was non-white. What Gregor was witnessing was that non-whites were not participating - or could not participate - in the market for cleaner suburban air.

[7]Marginal rate of 0.2198 percent per $\mu g/m^3$ PM_{10} (Samet et al., 2000) converted to TSP based on mean annual ratio of PM_{10} to TSP of 0.60 (U. S. Enivronmental Protection Agency, 1987-1994) and total death rate of 74.6 per 100,000 (Samet et al., 2000).

The Gregor model is linear, while the iHAPSS model is log-linear. Also, both air quality and mortality rates are quite different between the two study periods. The mean annual TSP for Allegheny County was 149.4 μg/m^3 between 1968 and 1972 (Gregor's data), while it was 56.07 μg/m^3 between 1987 and 1994 (iHAPSS data)[8]. The overall annual death rates per 100,000 for Allegheny County in 1970 and 1990 were 975 and 313, respectively.

As mentioned at the beginning of this section, the measure of interest is household MROD, which can be approximated as the sum of each household member's MROD[9]. According to the 1970 Census, mean household size in Allegheny County was 3.1. Using Gregor's data, the age and gender makeup of the household may be considered. Using either study, for a household of three, household MROD is simply three times the mean individual MROD.

2.3. Computing VSL

Smith and Huang provide ranges of MWTP, while the MROD data from iHAPPS are given as mean and standard error. These ranges are reflected in the calculated VSL values shown in Table 3. The outer range gives a lowest bound on VSL by dividing the lower bound on MWTP by mean plus standard error MROD, and a highest bound by dividing the upper bound on MWTP by mean minus standard error MROD. The inner range has bounds at mean MWTP divided by mean plus-or-minus standard error MROD. Mean VSL is mean MWTP divided by mean MROD. These ranges are depicted graphically in Figure 1.

Of the 22 calculations presented in Table 3, two yield a negative mean VSL. Of the remaining mean VSL values, nine are below \$12M, while the remaining eleven range from \$22.13M to \$164.02M. Chicago, the most-represented city in the study, has mean VSL values in all three groups, including both the negative values. The composite studies straddle the \$12M demarcation, as do the Washington studies. For comparison, in their meta-analysis of occupational risk models, Viscusi and Aldy found a VSL range from \$6.6M to \$9.2M (2007 dollars) for U.S. samples.

3. The Significance of the Housing-Market VSL

With values ranging from large negative numbers to positive infinity, the VSL calculations shown in Table 3 fail to support the assertion that life-saving is the principal component of consumers' home-buying preference for environmental amenities. Table 4 shows the population, rate of death, and median household income for the urban areas studied. The small size of the data set precludes drawing definitive conclusions, but regression found

[8]TSP data from U. S. Enivronmental Protection Agency.
[9]See Appendix C

Table 3: VSL Calculations

City	MWTP[a]			MROD[b]		VSL[c]		
	min	mean	max	mean	std err	lower	mean	upper
Boston	4.91	12.27	19.64	0.00024	0.00012	0.35	1.31	4.24
Chicago	290.55	358.00	425.45	0.00020	0.00008	29.25	40.82	67.56
Chicago	210.91	231.00	251.09	0.00020	0.00008	17.23	26.34	47.38
Chicago	52.73	52.73	52.73	0.00020	0.00008	4.31	6.01	9.95
Chicago	665.82	665.82	665.82	0.00020	0.00008	54.39	75.92	125.64
Chicago	−436	−72.73	290.55	0.00020	0.00008	−35.62	−8.29	54.83
Chicago	−2.51	−2.51	−2.51	0.00020	0.00008	−0.2	−0.29	−0.47
Kansas City	29.82	43.64	57.45	0.00022	0.00012	2.21	4.99	14.39
Los Angeles	271.27	271.27	271.27	0.00022	0.00010	27.55	40.36	75.43
Los Angeles	255.82	301.18	346.55	0.00022	0.00010	25.98	44.81	96.37
Milwaukee	1002.55	1002.55	1002.55	0.00013	0.00017	71.24	159.8	∞
Palmquist (1984)	0.73	158.27	315.82	0.00022	0.00005	0.08	22.13	55.83
Palmquist (1982)	−162.73	17.64	198.00	0.00022	0.00003	−18.66	2.32	30.55
Palmquist (1983)	−138.36	20.36	179.09	0.00022	0.00004	−15.37	2.66	28.51
New York	289.09	318.45	347.82	0.00027	0.00013	16.91	27.23	55.25
San Francisco	909.45	909.45	909.45	0.00018	0.00011	67.38	110.01	299.56
So. Cal. Air Basin	1049.45	1049.45	1049.45	0.00022	0.00008	119.4	164.02	261.87
St. Louis	30.91	45.18	59.45	0.00022	0.00011	1.4	3.09	8.26
St. Louis	64.91	66.91	68.91	0.00022	0.00011	2.94	4.58	9.57
Washington	0	1383.64	2767.27	0.00023	0.00011	0	103.01	406.07
Washington	−8.91	149.45	307.82	0.00023	0.00011	−0.44	11.13	45.17
Washington	134.36	134.36	134.36	0.00023	0.00011	6.7	10	19.72

[a]MWTP (marginal willingness to pay) in 2007 dollars per $\mu g/m^3$ reduction in PM_{10}. From Smith and Huang with 0.55 conversion from TSP to PM_{10} (Smith and Huang, 1995, Table 3).

[b]MROD (marginal risk of death) in deaths per day per $\mu g/m^3$ increase in PM_{10}. From Bell et al. (2004).

[c]VSL (value of a statistical life) in millions of 2007 dollars. Computed from the change in the probability (as a result of a one $\mu g/m^3$ change in PM_{10} pollution) of at least one death among a household of three people all with the same pollution-related mortality risks. Annualized using an eight percent interest rate (1995 Freddie Mac).

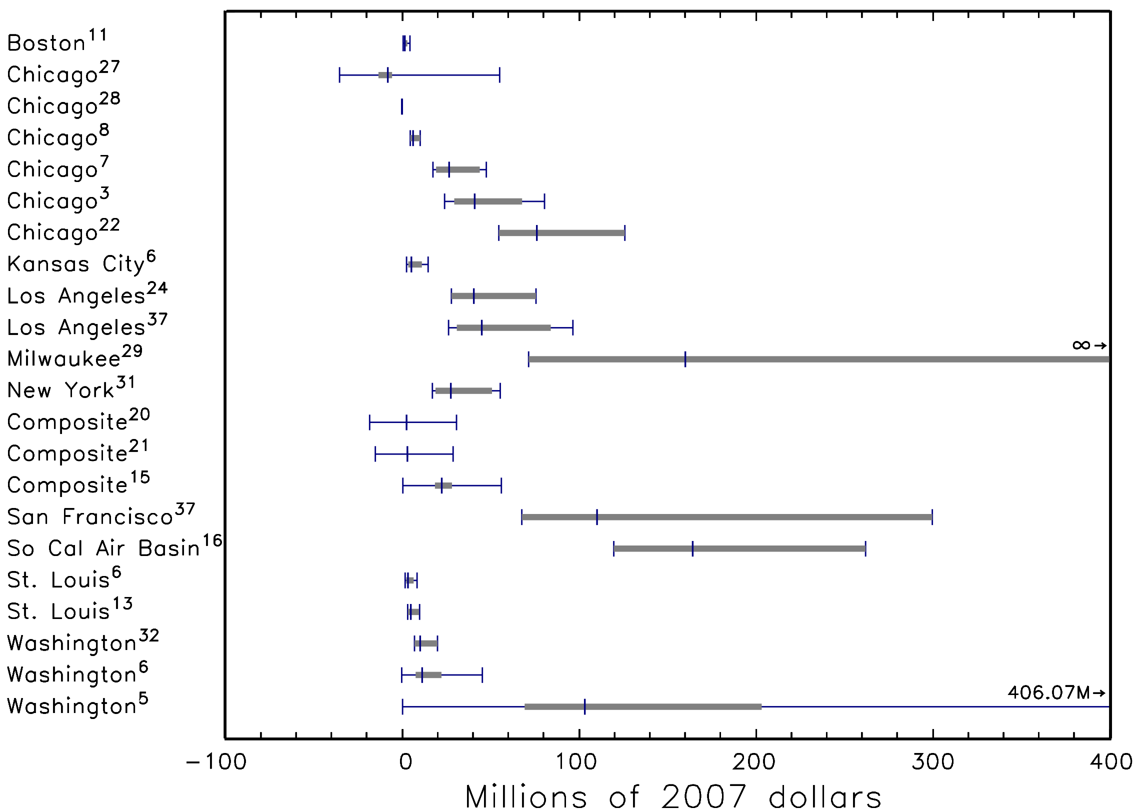

Figure 1: VSL Ranges. The thick vertical line is the mean VSL. The thick horizontal line is plus or minus one standard error in MROD about the mean. The thin horizontal line is the extent from the minimum MWTP divided by mean MROD plus one standard error, to maximum MWTP divided by mean MROD minus one standard error. The numeric superscripts refer to ID in Table 1.

Table 4: Population, ROD and median household income (1990).

City	population[a]	deaths per day[b]	ROD per 100,000	median household income[c]
Boston	689,807	4.0	0.57987234	$49,096
Chicago	5,376,741	34.9	0.64909208	$54,564
Kansas City	912,667	5.5	0.60262944	$50,102
Los Angeles	9,519,338	44.6	0.46851997	$58,392
Milwaukee	940,164	6.6	0.70200518	$46,538
Palmquist (1984)	11,633,357	56.1	0.48223398	$49,465
Palmquist (1982)	43,153,482	227.9	0.52811497	$53,872
Palmquist (1983)	33,592,751	179.8	0.53523452	$52,761
New York	8,931,737	58.3	0.65272858	$52,826
San Francisco	776,733	5.4	0.69521959	$55,801
SoCal Air Basin	12,365,627	54.6	0.44154655	$62,603
St. Louis	348,189	3.4	0.97648116	$32,495
Washington	572,059	5.1	0.89151643	$51,314

[a]Population from Smith and Huang (1995).
[b]Deaths per day from Bell et al. (2004).
[c]Median household income from U. S. Census Bureau (1995), stated in 2007 dollars.

no significant relationship between VSL and population, rate of death, median household income, or any combination of them.

It is instructive to examine Portney's results in a) a VSL context and b) a market context. At the time he reported VSL values of $376k to $541k, published VSL values ranged from $452k to $1.24M. Over the next two decades, however, market-based studies pushed the upper end of the scale to $11.9M, leaving Portney's result at the lowest end of the range (Figure 2). Furthermore, Portney argues that it is appropriate to report household VSL (see Section 2.2), for which he reports a VSL of $140k.

Portney, however, used 1970 TSP data to convert Spore's 1969 dust-fall data. TSP values were 35 percent higher in 1969 than 1970. Based on 1969 data, Portney's individual VSL range is $283k to $406k, with a household VSL of $75k.[10] Using 1969 TSP data, Portney's individual VSL range is well below that of Thaler and Rosen.

The market context is an extension of the broader historical context. The inset in Figure 3 illustrates population trends for Pittsburgh and suburban Allegheny County throughout the twentieth century. The period from 1930 to 1970 saw the flight to the suburbs, some of which, presumably, was motivated by consumer preference for clean air environmental amenities. By 1970, however, that trend was overtaken by the flight from the Rust Belt -

[10]See Appendix A.

industry and jobs were leaving the region in large numbers.

In reference to the work of Ridker and Henning (1967b) - upon which all subsequent hedonic housing studies are based - Freeman (1971) criticizes two aspects of these studies. First, that it's not possible to isolate a preference for clean-air amenities *ceteris paribus* given that air pollution levels are changing. Second, that the models do not isolate demand factors from supply factors. This second point is the motivation for the composite studies by Palmquist (1982, 1983, 1984). It is clear from Figure 3 that *ceteris paribus* does not apply, either in terms of air pollution levels or in terms of housing-market equilibrium, although it could be argued that the population exodus diminishes the impact of supply factors.

Finally, there is no evidence that consumers possess MROD information or that they act on it if they do. Considerable research has shown that information on air quality affects the preference of home-buyers for clean-air amenities (Oberholzer-Gee and Mitsunari, 2006). The increasing availability of air quality information for Allegheny County in the 1970s depicted in Figure 3 is evidence that home-buyers had this information. It is unknown, however, if there was general knowledge of Gregor's MROD results at the time. To assert that home-buyers acted on that information is to argue that, in the midst of a rapidly collapsing local economy, their preference for clean-air amenities was driven by a 0.00008 percent reduction in the absolute risk of death, or the 0.009 percent marginal reduction it represents.

4. Conclusion

Hedonic housing-market studies reveal both large variation and large uncertainty in home-buyers' willingness to pay (WTP) for clean-air amenities. These variations and uncertainties propagate to the value of a statistical life (VSL). VSL values - which range from large negative numbers to positive infinity - do not vary significantly based on urban area attributes such as population, risk of death or median household income. Furthermore, the marginal risk of death (MROD) from air pollution is small: from 0.0013 percent to 0.0027 percent per $\mu g/m^3$ PM_{10} for the urban areas discussed. That life-saving is the principal component of home-buyer preference for clean-air amenities - the rationale for computing VSL from these data - appears unlikely. Finally, the apparent early success of computing the VSL from housing-market data may be an artifact of exogenous historical trends.

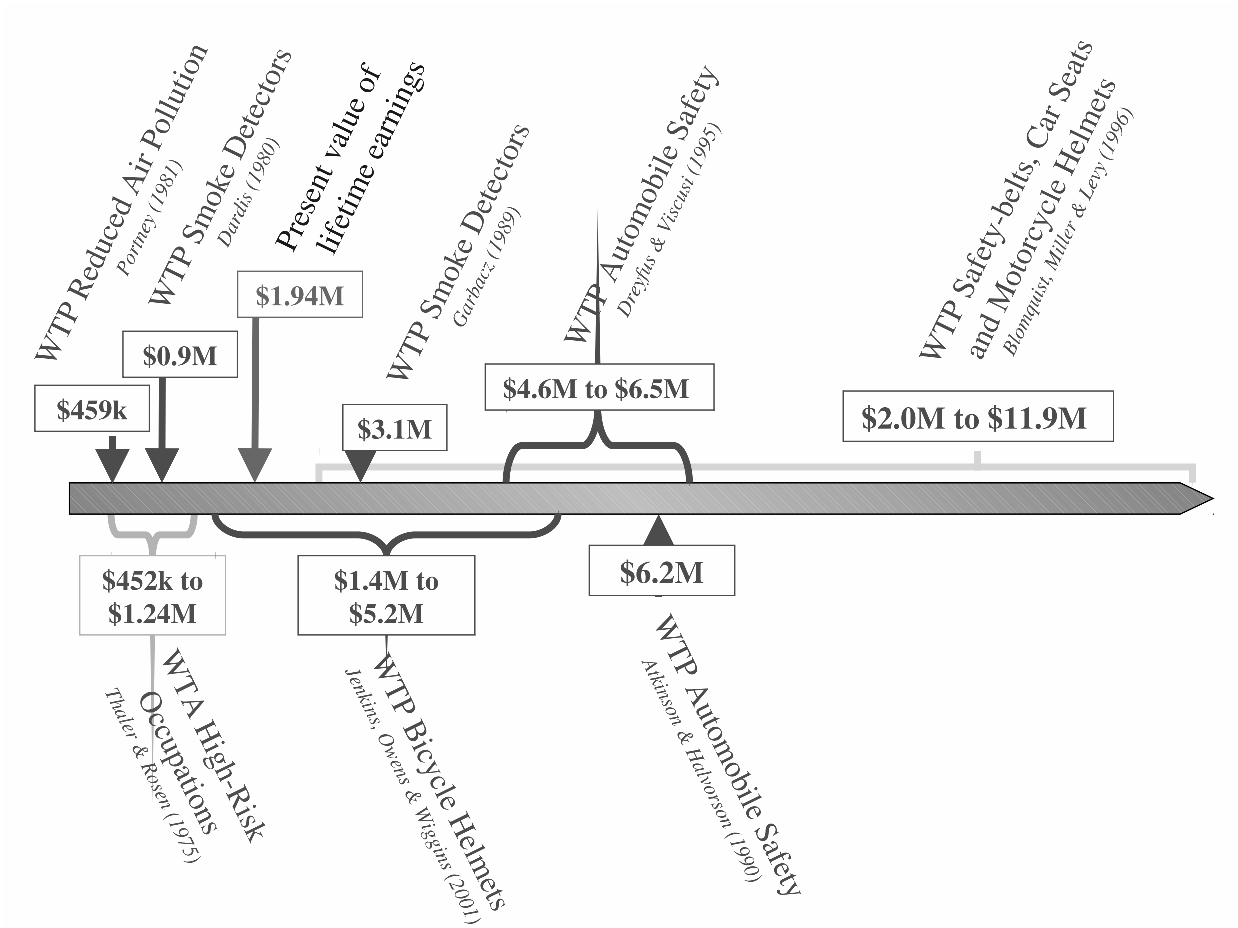

Figure 2: VSL Comparison. $459k is the average of $541k for a white female under 45 and $376k for a white male under 45 (Portney, 1981). Present value of lifetime earnings from Census Bureau report CPS 2007, Table 1. All values in 2007 dollars.

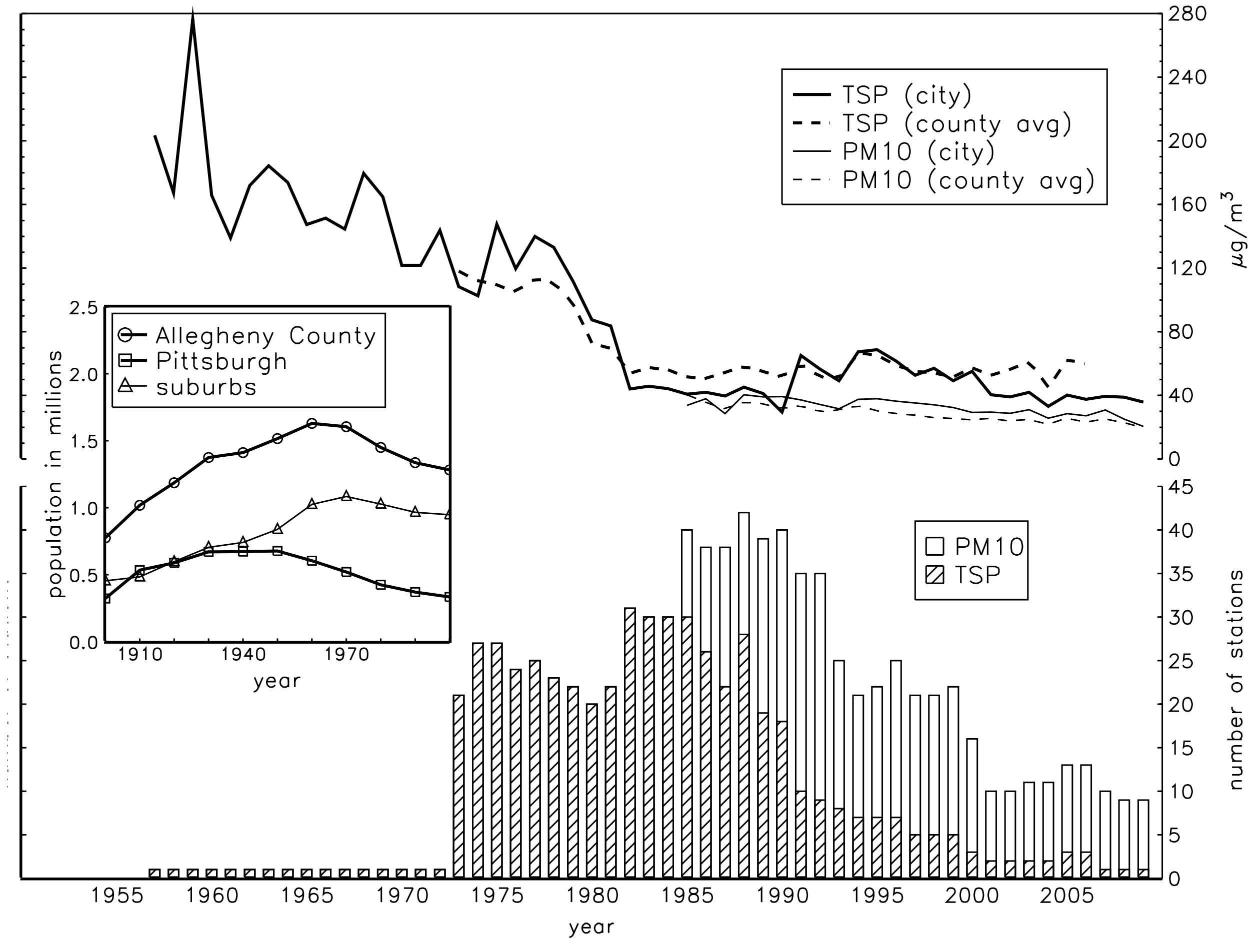

Figure 3: Allegheny County particulate air pollution and the number of EPA monitoring stations from 1957 to 2009. (The single TSP station before 1973 and after 2006 is in downtown Pittsburgh and is indicated as *city*. For periods in which there are data from more than one station, all monitoring stations in Allegheny County are averaged and indicated as *county avg.* In addition to EPA monitors,Spore (1972) reports that Allegheny County Bureau of Air Pollution Control operated 52 dust-fall monitoring stations in 1969 and Gregor (1977) reports the county operated four TSP monitors in 1968, going up to 14 in 1972. Inset: Allegheny County and Pittsburgh population from 1900 to 2000. The difference is indicated as *suburbs*.

A. The VSL for Pittsburgh: Gregor and Spore

Portney's source of home value as a function of air quality (Spore, 1972) reported marginal property costs of up to \$200 (in 1970 dollars) for dustfall of 5 tons per square mile per month. This is 15 percent of the 1969 mean dustfall (Spore, 1972, Table 2-B), which extrapolates to a change of 24 μg/m^3 in total suspended particles (TSP). Portney, however, uses 18 μg/m^3, which is 15 percent of 121.8, the mean TSP for 1970.

Portney's approach is to assume that the inverse of the risk of death (MROD times a 15 percent reduction in TSP) yields the population for which one statistical life is saved. This population is multiplied by the annualized MWTP for a 18 μg/m^3 reduction in TSP to get a revealed VSL.

Portney's source of MROD data gives MROD (risk of death per 100,000 per year per μg/m^3 TSP) of 0.349 for females under 45 years of age, and 0.500 for males under 45 (Gregor, 1977, Table 6). Risk of death for an 18 μg/m^3 reduction in TSP in each case:

$$\Delta ROD_{\text{female}<45} = 18 \times \tfrac{0.349}{100{,}000} = 6.28 \times 10^{-5}$$
$$\Delta ROD_{\text{male}<45} = 18 \times \tfrac{0.500}{100{,}000} = 9.00 \times 10^{-5}$$

Inverting gives populations of

$$P_{\text{female}<45} = 1/6.28 \times 10^{-5} = 15,900$$

$$P_{\text{male}<45} = 1/9.00 \times 10^{-5} = 11,100$$

These are the populations in which one statistical life is saved with an 18 μg/m^3 reduction in TSP.

With a WTP of \$335 per household Spore (1972, p 99) for an 18 μg/m^3 reduction in TSP annualized at 10 percent (1978 Freddie Mac rate), this is an annual WTP of about \$34. The VSL for a single home buyer is

$$VSL_{\text{female}<45} = \$34 \times 15,900 \approx \$541,000$$
$$VSL_{\text{male}<45} = \$34 \times 11,100 \approx \$376,000$$

Portney points out that any benefits from a choice of home location accrue to all members of the household. The reduction in household ROD for a family of husband, wife and male child resulting from an 18 μg/m^3 reduction in TSP is the sum of their individual MRODs[11]:

$$6.28 \times 10^{-5} + 9.00 \times 10^{-5} + 9.00 \times 10^{-5} \approx 2.43 \times 10^{-4}$$

The number of households for which a statistical life is saved with an 18 μg/m^3 reduction in TSP is

$$1/2.43 \times 10^{-4} \approx 4,120$$

and a statistical life saved is valued at

[11] See Appendix C

$$\$34 \times 4,120 \approx \$140,000$$

in 1978 dollars[12] or $445,000 in 2007 dollars[13]. This is about 37 percent of the occupational-risk VSL found by Thaler and Rosen (1975).

Based on Gregor's results and 1970 census data, the population-weighted mean MROD for the total population is 2.00 per 100,000 per μg/m^3. If the average household is made up of three random individuals, the household MROD is 6.00 per 100,000 per μg/m^3. For an 18 μg/m^3 reduction of TSP, the population for which a statistical life is saved is 926 households, yielding a VSL of $31,500 in 1978 dollars, or $100,100 in 2007 dollars.

As pointed out at the beginning of this appendix, the appropriate marginal change in TSP is 24 μg/m^3. In this case, the VSL is $406k for white women under 45 and $283k for white men under 45, for a random three-member household VSL of $75k (2007 dollars).

B. The VSL for Pittsburgh: iHAPSS and Smith and Huang

The iHAPSS Bayesian estimator for the MROD in Pittsburgh is 0.2198 percent for an increase of 10 μg/m^3 PM_{10}. The mortality rate for Pittsburgh from Samet et al. (2000) is 1028 per 100,000 per annum.

$$\frac{0.002198\frac{1028}{100{,}000}\text{reduction in risk}}{10\ \mu\text{g/m}^3\text{ reduction in PM}_{10}} = 2.26 \times 10^{-6}\text{ per }\mu\text{g/m}^3\text{ reduction in risk}$$

The reduction in household risk of death for a family of three is three times this[14], or 6.78×10^{-6} per μg/m^3 reduction in PM_{10}.

This must be expressed in terms of TSP to compare it with the results from Portney (Appendix A). The EPA assumes that PM_{10} constitutes 55 percent of TSP. That is, in 1994, an 18μg/m^3 reduction in TSP was equivalent to approximately 9μg/m^3 reduction in PM_{10}. The change in ROD is

$$\Delta ROD = 9 \times \left(2.26 \times 10^{-6}\right) = 2.03 \times 10^{-5}$$

This is 8.4 percent of Gregor's estimate. If this represents a real reduction, it may reflect a non-linear relation of mortality to TSP (which decreased from 149.4 μg/m^3 to 56.07 μg/m^3 between the 1968-1972 average and the 1987-1994 average). Additionally,Gregor's model is for Allegheny County only, during a period of high pollution, while the iHAPSS model is national. Some of the difference may also be an artifact of the change from

[12] Portney's result is slightly different, an apparent effect of truncating the risk reduction for women under 45 at 6×10^{-5}. This leads to a VSL for a single woman under 45 of $567,000, and a household VSL of $142,000.

[13] Portney quotes all dollar amounts as adjusted to 1978. This paper adjusts those dollar amounts to 2007 dollars using a CPI deflator of 3.18 (U. S. Bureau of Labor Statistics, 1968–2007).

[14] See Appendix C

tracking TSP to tracking PM_{10}, which went from 78 percent of TSP in 1985, the first year for which there are PM_{10} data for Allegheny County, to 55 percent in 1994.

The MWTP for Pittsburgh is \$124.50 per μg/m^3 TSP in 2007 dollars (Table **??**) or \$159.60 per μg/m^3 PM_{10}, based on the 1985 ratio. Thus, annualized at the 1985 Freddie Mac rate of 13 percent

$$VSL = 0.13 \frac{\$159.60}{2.26 \times 10^{-6}} = \$9,180,000$$

This is consistent with the results for the meta-study cities (Table 3) and nearly sixty-five times greater than Portney's (Appendix A).

C. Calculating household MROD

The risk that at least one member of the household dies is

$$ROD_{household} = 1 - \prod_i (1 - ROD_i)$$

Thus, the marginal change in household risk of death is

$$\text{MROD}_{\text{household}} = \sum_i MROD_i \prod_{j \neq i} (1 - ROD_j)$$

Treating individual risk of death probabilities as very small, (average ROD for the cities in this study is 0.00228), results in the simplification

$$MROD_{household} \approx \sum_i MROD_i$$

The mean MROD for the cities in this study is 0.0002145. For a household of three with identical ROD and MROD, this approximation introduces less than 0.5 percent error.

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