JOURNAL OF URBAN ECONOMICS 8, 236–254 (1980)

Inter-city Wage Differentials and the Value of Air Quality[1]

M. L. CROPPER AND A. S. ARRIAGA-SALINAS

Department of Economics, University of Southern California, University Park, Los Angeles, California 90007

Received February 6, 1979; revised April 30, 1979

This paper proposes a method of valuing air quality based on differences in wages among cities. Using an urban location model it is shown that the supply of labor to any city increases with the real wage and with air quality in the business district. If individuals have log-linear utility functions then the value at home and at work of an equal proportionate reduction in pollution throughout the city can be computed from the coefficients of the labor supply function. The computations are illustrated for one-digit labor supply functions estimated from 1970 Census data.

Policymakers, to determine pollution standards, must have estimates of consumers' willingness to pay for clean air. In the literature there have developed two methods of computing willingness to pay—the residential property value approach and an approach based on differences in wages across cities.[2] The rationale behind the property value approach is that if individuals are mobile, land prices adjust to compensate for differences in site-specific amenities. Part of the variation in land prices within a city can therefore be attributed to differences in air quality, with the remaining variation explained by other characteristics of housing sites—age of the neighborhood, quality of schools, access to business and shopping districts. A commonly acknowledged difficulty with the property value approach is that it fails to capture the value of clean air at locations other than the residence. For example, individuals presumably place a value on air quality where they work, yet this is not reflected in residential property values. A second problem with the approach is that air quality may not vary significantly within a city, making it difficult to obtain reliable estimates of willingness to pay.

[1]This research was supported by USEPA Grant R805059010.

[2]Other approaches include measuring the cleaning costs associated with air pollution and measuring the effects of pollution on mortality rates. Neither of these, however, measures willingness to pay—the money one can take away from an individual without changing his utility.

0094-1190/80/050236-19$02.00/0

Both difficulties suggest that one estimate the value of clean air using differences in wage rates across cities. Several studies [2, 3, 4, 5, 10] have attempted to explain cross-sectional wage differences using environmental variables, prices, and population. Although these studies are designed to measure effects of city size and congestion, pollution is usually included as an explanatory variable and its coefficient interpreted as marginal willingness to pay for clean air.

There are several difficulties with this approach which have made it suspect as a method of valuing air quality. In estimating the hedonic wage equation it is usually assumed that pollution and other amenities are the same throughout each SMSA. This is more objectionable than the assumption that amenities are uniform throughout a census tract, and one would like to know the resulting direction of bias. Second, it is often pointed out that the prices of housing and local goods also adjust to compensate for differences in amenities. The implication is that estimates based on wage differentials understate the benefits of pollution reduction, although this result has not been demonstrated formally. A related question concerns the comparability of wage and property value estimates. Should wage-based estimates of willingness to pay be added to property value estimates or do they supersede them? To answer this question requires a model which incorporates the spatial dimension of cities. This paper develops such a model and uses it to obtain estimates of willingness to pay for clean air.

In the model developed in Section I, workers choose the city in which they live and their location within the city. Equilibrium conditions in the land market lead to an equation in which the real acceptance wage in city i is a function of employment and amenities in that city. By specifying the form of individuals' utility functions one can relate the coefficients of the labor supply function to the parameters of the utility function, which may be used to compute willingness to pay.

The model shows previous criticisms of the wage-based approach to be invalid. Since the coefficient of pollution in the utility function is exactly identified from the coefficients of the labor supply function, the wage-differential approach does not underestimate willingness to pay. Furthermore, if pollution at any point in the city can be expressed as the product of pollution in the business district and a dispersion function, then the acceptance wage may be expressed solely as a function of amenities in the central business district (CBD). The fact that pollution varies spatially need not, therefore, cause problems for estimation. Finally, the labor supply function measures the disutility, both at work and at home, of pollutants generated in the CBD. Wage-based estimates of willingness to pay can therefore be used in place of property value estimates and have the additional advantage that they measure the value of air quality at work.

I. AN EQUILIBRIUM MODEL OF URBAN LOCATION[3]

A. The Spatial Organization of Cities

Although each city in the model may be of arbitrary shape, all industry in the city must be concentrated in the CBD, whose boundary is determined by zoning laws. The size of the city is fixed in the short run. Since the CBD is small relative to the city, it can be treated as though it were a point whose land, therefore, sells at a single price. Locations within the city are indexed by their distance, k, from the CBD, and the land price, which varies with k, is denoted $r_i(k)$.

In the residential areas of the city live workers who commute to the CBD. Landowners and capitalists live outside of city boundaries.

To describe the spatial distribution of amenities in the city the level of amenity i at location k, $A_i(k)$, is written as the product of amenity i in the CBD, A_i, and a dispersion function,

$$A_i(k) = A_i a(k). \tag{1}$$

Equation (1) assumes the spatial distribution of each amenity to be symmetric with respect to direction from the CBD. This assumption is accurate for air pollution since pollutants generated in the CBD usually disperse symmetrically with distance.[4] Casual observation suggests that crime rates also vary with distance from the city center, and hence that (1) is appropriate. Equation (1) further assumes that the spatial distribution of amenities is similar in all cities. This is a strong assumption but urban location theory is based on such observed regularities in the pattern of amenities: population density and congestion usually decrease with distance from the CBD, whereas income, which is correlated with neighborhood characteristics, increases. The implications of heterogeneous dispersion functions are discussed in III.B.

B. Assumptions Regarding Workers

To simplify the exposition we assume that all workers are identical, and receive a wage of w_i per period. (The case of different occupations is treated in Appendix A.) Each period the worker makes a fixed number of trips from his home to the CBD. Rather than treat the cost of these trips as fixed, we view transportation as another purchased good. The disutility associated with commuting is captured by including distance from the CBD in the utility function.

[3]The model outlined here is similar to the urban location models of Solow [11], Polinsky and Rubinfeld [6, 7] and Polinsky and Shavell [8].

[4]If the dispersion pattern depends on weather conditions $a(k)$ can be multiplied by a function of wind velocity or precipitation, measured in the CBD.

Each worker is assumed to have a log-linear utility function defined over his housing site, q, local goods, x, and imports, y. Utility is also received from pollution at the residence, $P_i a(k)$, in the CBD, P_i, and from local amenities. (To simplify notation only air pollution is included in the utility function.)

Since local amenities are given, utility

$$U_i = Bq^{\beta}x^{\alpha_1}y^{\alpha_2}P_i^{-\eta}[P_i a(k)]^{-\delta}k^{-\xi}, \qquad \alpha_1 + \alpha_2 + \beta = 1 \tag{2}$$

varies, for constant q, x, and y, with city (i) and neighborhood (k). For any (i, k) maximum utility is determined by choosing q, x and y to maximize (2) subject to

$$w_i = r_i(k)q + p_{1i}x + p_{2i}y, \tag{3}$$

where the prices of land, local goods, and imports are taken as given. The solution yields demand functions for residential land and for x and y. When substituted into (2) these yield the indirect utility function,

$$V_i(k) = Cw_i r_i(k)^{-\beta}p_{1i}^{-\alpha_1}p_{2i}^{-\alpha_2}P_i^{-\eta-\delta}a(k)^{-\delta}k^{-\xi}, \qquad C = B\beta^{\beta}\alpha_1^{\alpha_1}\alpha_2^{\alpha_2}, \tag{4}$$

which gives utility at each (i, k) as a function of site-specific amenities, income and prices.

Since individuals are mobile, utility levels in equilibrium must be everywhere identical. If each city is small relative to the country, $V_i(k)$ may be treated as exogenous and the equilibrium condition written $V_i(k) = V^*$ for all i and k. Worker mobility thus implies that rents, wages and the prices of local goods adjust to compensate for differences in air quality. This suggests that variation in land prices or wages be used to estimate $\eta + \delta$, the marginal value of clean air.

To use land prices to estimate $\eta + \delta$, (4) may be solved for $r_i(k)$ to give maximum willingness to pay for land at location k,

$$r_i(k) = (C/V^*)^{1/\beta}w_i^{1/\beta}p_{1i}^{-\alpha_1/\beta}p_{2i}^{-\alpha_2/\beta}P_i^{-(\eta+\delta)/\beta}a(k)^{-\delta/\beta}k^{-\xi/\beta}. \tag{5}$$

Since land is sold to the highest bidder, (5) also represents the equilibrium rent function. It is (5), with i constant and $\eta = 0$, that is used by Polinsky and Rubinfeld [6] to estimate parameters α_i, β, and δ of the utility function.[5] This approach, however, does not permit estimation of the value

[5]In Polinsky and Rubinfeld's work both income and amenities are allowed to vary by census tract.

of air quality in the CBD. Furthermore, it does not yield consistent estimates of α_i, β, and δ if wages and land values are simultaneously determined.

The wage differential approach uses (5) to derive the supply function of labor. In equilibrium, the population (labor force) in city i must be such that demand for land at each k equals supply. Equivalently, if $s(k)$ is the supply of land at k, the number of persons living at $k, n(k)$, must satisfy

$$n(k) = \frac{s(k)r_i(k)}{\beta w_i}. \tag{6}$$

Substituting for $r_i(k)$ from (5) and integrating from $k = 0$ to $k = \bar{k}_i$, the farthest point from the CBD, yields the number of workers as a function of amenities and the wage,

$$N_i = \int_0^{\bar{k}_i} n(k)\,dk = M w_i^{(1-\beta)/\beta} p_{1i}^{-\alpha_1/\beta} p_{2i}^{-\alpha_2/\beta} P_i^{-(\eta+\delta)/\beta} f(\bar{k}_i), \tag{7}$$

where $M = s(k)\beta^{-1}(C/V^*)^{1/\beta}$ and $f(\bar{k}_i) = \int_0^{\bar{k}_i} k^{-\xi/\beta} a(k)^{-\delta/\beta}\,dk.$

For estimation it is convenient to write (7) in the form

$$\begin{gathered}(w_i/\tilde{P}_i)^* = c + \frac{\beta}{1-\beta}N_i^* + \frac{\eta+\delta}{1-\beta}P_i^* - F(\bar{k}_i),\\ \tilde{P}_i \equiv p_{1i}^{\alpha_1/(1-\beta)} p_{2i}^{\alpha_2/(1-\beta)},\end{gathered} \tag{8}$$

where asterisks denote logarithms. Equation (8) expresses the real acceptance wage in city i as a function of employment and pollution. The acceptance wage increases with N_i since, if land is fixed, an increase in N_i raises rents and thus income necessary to maintain V^*. Amenities such as sunshine enter (8) with negative coefficients, whereas disamenities increase the acceptance wage. Note that due to the multiplicative utility function only amenities in the CBD appear in the supply function. The dispersion function $a(k)$, which captures the fact that amenities vary spatially, is incorporated in $F(\bar{k}_i)$. Since $\bar{k}_i$ is assumed exogenous, the $\{\bar{k}_i\}$ may be regarded as independent drawings from a probability distribution and the $\{F(\bar{k}_i)\}$ as error terms which are independently and identically distributed (i.i.d.) for all i.

To obtain consistent estimates of $\eta + \delta$ (8) will be estimated by two-stage least squares (2SLS) and the resulting coefficients used to solve for $\widehat{\eta + \sigma}$.

C. Assumptions Regarding Firms

The remainder of the model describes production decisions of firms and equilibrium conditions in output and factor markets. This completes the simultaneous equation system and motivates the excluded exogenous variables used in 2SLS estimation.

In each city there is a production function for industry X and industry Y. The Y production function in city i may be written

$$Y_i = D_2 N_{2\,i}^{a} L_{2\,i}^{b} K_{2\,i}^{c} S_{2\,i}^{d} E_{2\,i}^{f}, \qquad a + b + c + d < 1, \tag{9}$$

where $L_{2\,i}$ denotes land and raw material inputs, $N_{2\,i}$, labor inputs, $K_{2\,i}$, capital goods, $S_{2\,i}$, pollution generated by the industry and E_{2i} environmental goods such as climate. Population, N_i, may also enter the production function as a proxy for agglomeration economies.

We assume that both industries behave as price-takers in all markets. Thus, given output price, input prices, and a tax on effluents, each industry determines profit maximizing levels of inputs L, N, and K and a level of emissions, S.[6]

Although each industry regards input and output prices as exogenous, the wage, land price in the CBD, and the price of local goods are determined by equilibrium conditions in product and factor markets. Equating the aggregate demand for land to the size of the CBD, the aggregate demand for labor to the right-hand side of (7) and the supply of X to the aggregate demand for X yields three equations which may be solved for the land price, the wage, and the price of X. The equilibrium level of employment is found by substituting the equilibrium wage into (7) and the quantity of local goods produced obtained by substituting $p_{1\,i}$ into the aggregate demand function for X. Environmental goods which depend on output or on population are also determined by market equilibrium conditions. In particular, pollution in the CBD (P_i) is a function of industrial emissions ($S_{1\,i} + S_{2\,i}$) and weather conditions.

In the model demand for labor depends on the parameters of the production function and on input and output prices. To identify the labor supply function some of these prices are treated as exogenous. Specifically, exports are assumed to sell in a national market at price $\bar{p}$. The price received by firms equals $\bar{p}$ less shipping costs. Since the latter depend on distance and on topography, the demand for labor is higher in cities close to output markets which have access to cheap transportation.[7] The delivered cost of natural resources and capital goods, assumed exogenous to city i, depends on proximity to input markets. Finally, the demand for labor is

[6] A necessary condition for each industry to operate in city i is that it earn non-negative profits. Profits may differ from city to city in locational equilibrium just as industry size may differ among cities.

[7] The location of the national market is endogenous to the urban location model; however, if cities are small, it is exogenous to any one city. Transportation costs per mile are also assumed exogenous to each city.

higher in cities where land prices are low. Although land price in the CBD is endogenous, it is affected by the size of the CBD and by the property tax rate, both of which are government-determined and treated as exogenous in the short run.

II. ESTIMATION OF THE MODEL

A. Labor Market Considerations

Before estimation, the model of section I must be modified to incorporate factors other than amenities which cause wage rates to vary. An important source of variation are differences in the occupational mix. In Appendix A the model is modified to allow for these differences. It is assumed that there are several occupational groups and that tastes differ from one group to another. This leads to a set of labor supply functions of the form

$$(w_{ij}/\tilde{P}_{ij})^* = c_j + \frac{\beta_j}{1-\beta_j} N_{ij}^* + \frac{\eta_j + \delta_j}{1-\beta_j} P_i^* + \epsilon_{ij}, \tag{10}$$

where w_j denotes the wage in occupation j and N_{ij} the level of employment in the occupation in city i. Subject to qualifications noted in Appendix A, (10) can be used to estimate the coefficient of air pollution in the utility function for members of group j.

Estimating supply functions for specific occupations does not take account of all factors which cause wage rates to differ among cities. Union membership is an important determinant of wage rates for blue-collar workers and varies regionally. Average earnings also vary due to differences in education and job experience and because of racial discrimination.

To control for unionization average earnings are replaced by the non-union wage, calculated from the formula[8]

$$\bar{w} = (1-a)w_{\text{non-union}} + aw_{\text{union}}, \tag{11}$$

where a represents the percentage of workers in unions. Since data on union membership and on the ratio of union to non-union wages are available by occupation, this adjustment is made in all equations for blue-collar workers.

A different procedure is used for human capital variables. In the model education and experience can be viewed as exogenous factors which affect productivity and thus enter the demand function for labor. Race may be treated as a characteristic which firms believe to affect productivity. This

[8]This formula is valid only if the w's are sample averages. Since our data pertain to median earnings, (11) holds only aproximately.

suggests that average age of the workforce, years of schooling and percent non-white be used as excluded exogenous variables in estimating (10).[9]

Finally, wage rates may vary due to disequilibrium movements in workers and firms. For example, an increase in the demand for labor in city i puts upward pressure on the wage and causes an inflow of workers into the city. To allow for this the net migration rate is included in the labor supply function.

B. Empirical Specification

In Tables 1 and 2, (10) is estimated using 2SLS with the real wage, employment, and air pollution treated as endogenous. Variables which affect the demand for labor—proximity to input and output markets, the property tax rate, measures of human capital—are used as excluded exogenous variables. To indicate accessibility of natural resources acres of commercial timberland, value added in mining and value of farm products are measured for the state containing city i. Proximity to output markets is represented by the percent of exports (by weight) shipped at least 500 miles from each city. A dummy variable equal to 1 if the city is a port indicates availability of cheap transportation.

Results in Table 1 are presented for one-digit occupations, as defined by the Bureau of the Census [17]. All data are for 1969–1970. The sample, which is determined by availability of pollution and price data, consists of the 28 cities in Appendix B.

In the equations for white-collar workers the dependent variable is median earnings of men who worked 50–52 weeks in 1969. For blue-collar workers median earnings are adjusted using (11) for differences in union membership. The wage variable for all occupations is deflated by the BLS intermediate-budget cost of living index, with the price of housing removed from the index.[10] In each occupation the employment variable is number of men with earnings in 1969.

The empirical counterparts of pollutants generated by firms are total suspended particulates and sulfur dioxide. Unfortunately, these pollutants are so highly correlated that the sign of one is perverse if both are included

[9]To test the significance of human capital variables money earnings in each occupation (adjusted for union membership) were regressed on average age of workers in the occupation, on percent non-white in the occupation and on average school years of all men. In each case years of schooling (unavailable by occupation) was insignificant. Average age of the workforce, however, was positive and significant for all but two occupations. For laborers and service workers percent non-white was significant, with the expected negative sign. The latter variables were used as excluded exogenous variables in occupations for which they appeared significant.

[10]The BLS index measures the cost of a market basket rather than weighting the price of each good by the percent of the budget spent on it. In revising the index the cost of shelter was subtracted from the cost of the market basket.

TABLE 1

Labor Supply Functions, Mean of SO_2 as Pollution Variable[a]

	All earners	Professional workers	Non-farm managers	Sales workers	Clerical workers
Constant	5.3028***	3.6120**	5.0071***	3.4306*	3.4875**
	(1.4216)	(1.5818)	(1.6746)	(1.9937)	(1.5794)
Employment	0.0277*	0.0118	0.0206	0.0322	0.0050
	(0.0188)	(0.0215)	(0.0224)	(0.0244)	(0.0200)
SO_2 (arith. mean)	0.0263*	0.0332*	0.0388**	0.0232	0.0313*
	(0.0188)	(0.0210)	(0.0216)	(0.0240)	(0.0210)
July temperature	− 0.4879***	− 0.0478	− 0.1421	− 0.0176	− 0.2622**
	(0.1305)	(0.1474)	(0.1537)	(0.1825)	(0.1449)
Wind velocity	− 0.0704	− 0.0882*	− 0.0937*	− 0.0382	− 0.0304
	(0.0593)	(0.0659)	(0.0698)	(0.0823)	(0.0661)
Doctors/100,000	− 0.1488**	− 0.0831	− 0.0802	− 0.0086	− 0.0790
	(0.0689)	(0.0755)	(0.0825)	(0.0989)	(0.0769)
Hosp. beds/100,000	− 0.0513*	− 0.0346	− 0.0253	− 0.0523	− 0.0477
	(0.0363)	(0.0393)	(0.0437)	(0.0524)	(0.0398)
Crimes/100,000	0.0702**	0.0887**	0.0639*	0.0450	0.0570*
	(0.0343)	(0.0385)	(0.0406)	(0.0482)	(0.0382)
Female/male employment	− 0.1831*	− 0.1618	− 0.0539	− 0.1300	− 0.2756**
	(0.1298)	(0.1447)	(0.1538)	(0.1822)	(0.1454)
Coastal Dummy	− 0.0718***	− 0.0315	− 0.0794***	− 0.1014***	− 0.0491**
	(0.0243)	(0.0275)	(0.0286)	(0.0338)	(0.0273)
Net migration	0.0022**	0.0036***	0.0030**	0.0026*	0.0017
	(0.0012)	(0.0014)	(0.0014)	(0.0017)	(0.0013)
R^2	0.7873	0.7037	0.6599	0.6086	0.5947
n	27	27	27	27	27

in the equation. For this reason SO_2 is the only pollution variable used. Other pollutants (NO_x, CO), which must be included to obtain an unbiased coefficient SO_2, are omitted for lack of data. The coefficient of SO_2 therefore represents the effects of particulates and, possibly, automobile pollutants.

Since it is unclear how pollution is perceived, three measures of SO_2 are used. In Table 1, SO_2 is measured by its annual arithmetic mean. The second highest recorded value of SO_2 is used to test the hypothesis that individuals are more sensitive to extreme values than to annual averages. To capture the notion that individuals do not make fine distinctions among pollution levels, a dichotomous variable corresponding to the city's EPA priority ranking appears in Table 2. In the utility function this variable = 1 if the city is ranked priority 1 or 2 (worst air quality) and = 0 if the city has better air quality.

TABLE 1 — *Continued*

	Craftsmen	Operatives[b]	Non-farm Laborers	Service Workers
Constant	4.3419**	2.4042*	6.4412***	7.8618***
	(1.7232)	(1.5790)	(1.4466)	(2.2571)
Employment	0.0360**	0.0014	0.0344**	0.0386*
	(0.0200)	(0.0163)	(0.0143)	(0.0242)
SO_2 (arith. mean)	0.0185	0.0242*	0.0340**	0.0488**
	(0.0192)	(0.0179)	(0.0150)	(0.0250)
July temperature	− 0.4680***	− 0.4339***	− 0.8984***	− 0.8524***
	(0.1583)	(0.1441)	(0.1332)	(0.2117)
Wind velocity	− 0.0904	− 0.0352	0.0314	0.0342
	(0.0695)	(0.0635)	(0.0575)	(0.0899)
Doctors/100,000	− 0.1241*	− 0.0401	− 0.1657**	− 0.2321**
	(0.0814)	(0.0736)	(0.0680)	(0.1071)
Hosp. beds/100,000	− 0.0439	− 0.1021***	0.0014	− 0.0267
	(0.0407)	(0.0368)	(0.0338)	(0.0529)
Crimes/100,000	0.0496	0.0048	0.0385	0.0832*
	(0.0414)	(0.0374)	(0.0347)	(0.0554)
Female/male	− 0.3349**	− 0.5548***	− 0.2327**	− 0.0220
employment	(0.1459)	(0.1356)	(0.1217)	(0.1905)
Coastal dummy	− 0.0869***	− 0.0410*	− 0.0293	− 0.0054
	(0.0299)	(0.0262)	(0.0250)	(0.0398)
R^2	0.7508	0.7998	0.8873	0.7366
n	28	28	28	28

[a]All variables are in natural logarithms; *** (**) (*) denotes coefficient asymptotically significant at the 0.01 (0.05) (0.10) level, one-tailed test.
[b]Includes transport and non-transport operatives.

The exogenous variables in the labor supply function are environmental factors which affect location decisions. Crime and climate are two such variables for which data are readily available. Crime is measured by the number of violent and property crimes per 100,000. The coefficient of this variable represents the psychic disutility of crime since insurance costs are included in the cost of living index. Of the one dozen climate variables considered only two, average July temperature and wind velocity, appear in the final regressions.[11] July temperature acts as a proxy for warm

[11]The climate variables considered were average January temperature, average July temperature, number of freezing days, average snowfall, relative humidity, the Temperature Humidity Index, wind velocity, the wind chill factor, precipitation, sunshine, (July temperature) × (humidity) and (January humidity)/(January temperature).

TABLE 2
Labor Supply Functions, Alternate Pollution Variables

	Non-farm managers	Non-farm managers	Clerical workers	Operatives	Non-farm laborers	Service workers
Constant	4.9646***	4.6070***	3.1375**	2.1237*	6.0940***	7.3117***
	(1.4165)	(1.6804)	(1.5654)	(1.5481)	(1.4547)	(2.2245)
Employment	0.0473***	0.0285	0.0073	− 0.0002	0.0351**	0.0432**
	(0.0135)	(0.0221)	(0.0193)	(0.0158)	(0.0143)	(0.0238)
SO_2 (Extreme value)		0.0285*	0.0288*	0.0268*	0.0334**	0.0414*
		(0.0211)	(0.0203)	(0.0171)	(0.0150)	(0.0243)
SO_2 (Priority ranking)	0.0618**					
	(0.0305)					
July temperature	− 0.0752	− 0.1080	− 0.2342*	− 0.4094***	− 0.8654***	− 0.8043***
	(0.1306)	(0.1536)	(0.1432)	(0.1403)	(0.1343)	(0.2099)
Wind velocity	− 0.1014*	− 0.1126*	− 0.0432	− 0.0443	0.0170	0.0137
	(0.0584)	(0.0685)	(0.0640)	(0.0609)	(0.0575)	(0.0891)
Doctors/100,000	− 0.1181*	− 0.0759	− 0.0762	− 0.0393	− 0.1614**	− 0.2181**
	(0.0730)	(0.0829)	(0.0764)	(0.0712)	(0.0682)	(0.1060)
Hosp. beds/100,000	0.0074	− 0.0188	− 0.0445	− 0.1005***	0.0036	− 0.0258
	(0.0374)	(0.0436)	(0.0394)	(0.0359)	(0.0341)	(0.0531)
Crimes/100,000	0.0641**	0.0587*	0.0549*	0.0057	0.0366	0.0748*
	(0.0344)	(0.0406)	(0.0378)	(0.0362)	(0.0347)	(0.0547)
Female/male employment	− 0.0363	− 0.0913	− 0.3059**	− 0.5752***	− 0.2586**	− 0.0692
	(0.1318)	(0.1531)	(0.1428)	(0.1325)	(0.1215)	(0.1859)
Coastal dummy	− 0.0836***	− 0.0795***	− 0.0472*	− 0.0368*	− 0.0261	− 0.0051
	(0.0239)	(0.0292)	(0.0276)	(0.0261)	(0.0257)	(0.0406)
Net migration	0.0027**	0.0029**	0.0018*			
	(0.0011)	(0.0014)	(0.0013)			
R^2	0.7562	0.6561	0.5994	0.8094	0.8856	0.7372
n	27	27	27	28	28	28

year-round temperatures. Since July temperature is higher in the South, it may also represent the large supply of unskilled labor in Southern cities.[12] The significance of wind velocity is probably due to its effect on air quality.

The regression equations include no direct measures of amenities and disamenities associated with urbanization. In the context of the model amenities which are a function of city size (congestion, availability of goods and services) must be treated as endogenous; however, the small sample makes it difficult to include additional endogenous variables. This problem is resolved by allowing employment to represent some of the effects of city size. The only measures of scale amenities explicitly included in the labor supply function are indexes of health facilities—number of hospital beds per 100,000 and number of doctors per 100,000. Because these variables are income-inelastic they can more reasonably be regarded as exogenous than can other goods and services.

Scenic beauty and availability of recreation facilities also play a part in location decisions. Unfortunately, scenic locations are usually associated with parks and beaches, making the effects of the two difficult to separate. The coastal dummy variable appearing in the regressions should be interpreted as a proxy for both recreational and aesthetic amenities.

Employment opportunities also affect location decisions. In the model, employment opportunities are captured by the wage rate. In reality, markets are imperfect and individuals must consider the probability of being unemployed. For married men the relevant variables are the unemployment rate in one's own occupation and employment opportunites for women. If the ratio of women to men in the labor force were identical in all cities, the ratio of women to men actually employed would indicate availability of jobs for women. This variable, first suggested by Getz and Huang [2], is used below. Unemployment rates for one-digit occupations are unavailable for the year 1970. The aggregate unemployment rate, insignificant in preliminary regressions, was deleted from the labor supply function.

C. Results

Tables 1 and 2 present our results for nine one-digit occupations. For clerical and blue-collar workers, variables generally have expected signs, and in each equation several amenities are asymptotically significant at conventional levels. The regressions are not as successful in explaining location decisions of higher-paid white-collar workers, possibly because job-related amenities are more important for this group. It is also possible that white-collar workers are less mobile because of specialized skills. This

[12] Regional dummy variables, which are at best proxies for amenities, were excluded from the regression because of their high correlation with direct amenity measures.

hypothesis is supported by our results for net migration. The net migration variable is insignificant for clerical and blue-collar workers, but is quite significant for professional workers, managers, and salesmen, suggesting that the latter groups are not in locational equilibrium.

For clerical and blue-collar workers temperature, city size and health facilities are important in the choice of residence. The negative coefficient of July temperature implies that individuals prefer warmer to colder climates, and agrees with results obtained by Hoch [3]. July temperature may also reflect higher summer temperatures and lower blue-collar wages in the South. Employment, significant for three out of four blue-collar occupations and for clerical workers, represents the effects of population on land prices, as well as scale amenities and disamenities. Once the former effect is removed, city size is an amenity for the occupations in Table 1. [13] Finally, at least one of the two health variables is significant for all blue-collar occupations. Doctors/100,000, however, may proxy scenic and cultural amenities since doctors appear to locate in more desirable cities (New York, San Francisco, Denver) and avoid places lacking urban amenities.

Among white-collar workers crime and scenic amenities are important environmental goods.

Our most important results concern pollution. Air pollution has the expected positive sign in all equations and is significant, in some form, for all occupations except salesworkers and craftsmen. SO_2 however is highly correlated with employment and its coefficient may therefore be unreliable. Of the three pollution variables the mean of SO_2 performs best, followed by the second highest recorded value. The least significant is the dichotomous EPA priority ranking. (To save space, only significant results are reported for the latter variables.) As expected, the coefficient of the pollution dummy is the largest of the three, since a change in priority ranking represents a larger change in SO_2 than a 1% reduction in the mean. Individuals appear to be more sensitive to the mean of SO_2 than to extreme values, although this result is not uniform among occupations. The implications of pollution coefficients for willingness to pay are considered below.

III. DEFINITION AND MEASUREMENT OF WILLINGNESS TO PAY

A. Definition of Willingness to Pay

In view of (1) we can consider only an equal proportionate change in air pollution throughout the city, such as might be achieved by taxing firm

[13] If γ is the coefficient of N_i in the utility function then the coefficient of employment in the labor supply function is $(\beta - \gamma)/(1 - \beta)$. For plausible values of β Table I implies that $\gamma > 0$, i.e., that city size, on net, is an amenity.

emissions in the CBD. Willingness to pay for this change may be defined, following Polinsky and Rubinfeld [6], as the largest amount of income which can be taken away from an individual and leave his utility unchanged. This amount, Δw_i, is defined implicitly by

$$Cw_i r_i(k)^{-\beta} p_{1i}^{-\alpha_1} p_{2i}^{-\alpha_2} P_i^{-(\eta+\delta)} a(k)^{-\delta} k^{-\xi}$$
$$= C(\hat{w}_i - \Delta w_i)\hat{r}_i(k)^{-\beta} \hat{p}_{1i}^{-\alpha_1} \hat{p}_{2i}^{-\alpha_2} (P_i - \Delta P_i)^{-(\eta+\delta)} a(k)^{-\delta} k^{-\xi}, \tag{12}$$

where $\hat{}$'s denote after-tax prices. If general equilibrium effects of the effluent tax are small enough to be ignored, (12) may be simplified to

$$\Delta w_i = w_i\left[1 - (1 + m)^{\eta+\delta}\right], \qquad m = \Delta P_i / P_i, \tag{13}$$

and willingness to pay computed solely from knowledge of income and the coefficient of P_i in the utility function.[14]

In the case of a dichotomous pollution variable willingness to pay for an improvement in priority ranking from 1 ($P_i = 1$) to 0 ($P_i = 0$) is given by

$$\Delta w_i = w_i(1 - e^{-\zeta}), \tag{14}$$

when the dichotomous pollution variable enters the utility function in the form $\exp(-\zeta P_i)$.

Note that for each occupation Δw_{ij} must be multiplied by N_{ij} and this quantity summed over all occupations to determine aggregate willingness to pay.

B. Possible Biases in Estimating Willingness to Pay

To compute willingness to pay requires an estimate of $\eta + \delta$, the coefficient of air quality in the utility function. Two estimation problems may arise. If the fraction of income spent on housing (β) cannot be estimated from (10) then $\eta + \delta$ cannot be identified without additional information. More importantly, 2SLS estimators will not have desirable properties if dispersion functions $a_i(k)$ vary among cities.

In I.B. it is argued that the $a_i(k)$ can be treated as identical and hence that the error terms in the labor supply function are i.i.d. If the error terms are also uncorrelated with the exogenous variables, 2SLS estimators are consistent. This is equivalent to saying that city area ($\bar{k}_i$) responds with a lag to current amenity values, which determine the number of workers in the city. This is plausible in view of the time required to build new housing.

[14] In (13) Δw_i is defined to be positive if $m < 0$ and vice versa.

TABLE 3

Willingness to Pay for Reductions in SO_2, Non-Farm Managers, 1970[a]

		Arithmetic mean			Second highest value			Priority ranking
		− 1%	− 10%	− 20%	− 1%	− 10%	− 20%	Priority 1 or 2 to Priority 3
$\hat{\beta}$	0.15	$4.00	$41.8	$88.4	$2.97	$31.1	$65.8	$616
	0.10	4.23	44.3	93.6	3.15	33.0	69.7	651
	0.05	4.47	46.8	98.8	3.32	34.8	73.5	686

[a]All figures represent annual values of willingness to pay, computed for a manager earning $12,000. Estimates were computed using coefficients from Tables 1 and 2 and Eqs. (13) and (14).

Problems, however, arise if dispersion functions differ from city to city, implying that the error terms each have a different mean and variance. 2SLS estimators are still consistent, but the conventional estimator of the asymptotic covariance matrix yields biased estimates of the true covariance matrix. Statements about the asymptotic significance of the estimators cannot be made in this case.

A second difficulty concerns the estimation of β. Equation (10) implies that β can be estimated from the coefficient of employment; however, this is not true if employment acts as a proxy for urban amenities. If N_i is a proxy for scale amenities, then the coefficient of N_i in the labor supply functon is written $(\beta - \gamma)/(1 - \beta)$, where γ is the exponent of N_i in the utility function. Since the coefficient of employment cannot be used to estimate β, $\eta + \delta$ must be computed for alternate values of β.

C. *Illustrations*

To illustrate the use of (13) and (14) annual estimates of willingness to pay are presented in Table 3.

Although these estimates are only illustrations, it is interesting to compare them with results obtained using the property value approach. Perhaps the most famous application of the latter is Ridker and Henning's [9] study of air quality in St. Louis in 1960. Ridker and Henning find that a permanent 30% reduction in sulfation levels raises the value of an average home by $245.[15] Based on figures in Table 1 the present discounted value of a 30% reduction in SO_2, calculated for the median income in St. Louis in 1960, is between $418 and $489—roughly twice Ridker and Henning's

[15]Ridker and Henning estimate an hedonic price equation for housing but do not use this equation to estimate marginal willingness to pay functions for clean air. Their estimates of willingness to pay are therefore valid only at the margin.

figure. Part of this difference may represent the value of reducing pollutants which are correlated with SO_2; however, our figures should exceed Ridker and Henning's by the value of a reduction in SO_2 in the CBD. Our results may also be compared with those of Anderson and Crocker [1] who estimate an equilibrium rent function similar to (5) for St. Louis in 1960. For homeowners Anderson and Crocker's estimate of δ is 0.0542, while for renters it is 0.0223. These figures are close to our estimates of $\eta + \delta$, and suggest that our technique has produced reasonable estimates of willingness to pay.

IV. CONCLUSIONS

Regressions of property values on housing characteristics and local amenities are often used to value air quality. This paper has suggested an alternative to the property value approach based on differences in wage rates among cities. It was demonstrated that for an equal proportionate reduction in air pollution throughout a city, wage-based estimates of benefits can be used in place of property value estimates. The logical question is which method is preferable.

We emphasize that the model which justifies the wage differential approach is more restrictive than the hedonic price model underlying property value estimates. The model assumes that workers are well-informed and mobile, and makes specific assumptions about their utility functions. More importantly, the model applies only to equal proportionate changes in pollution throughout a city. When applicable, however, the wage differential approach has two advantages. It measures the benefits of clean air at work as well as at home, and it provides estimates of willingness to pay which can be applied to any city.

The property value approach might seem to offer certain econometric advantages. Hedonic price equations can be estimated consistently using OLS, whereas our labor supply functions must be estimated using 2SLS. Furthermore, the determinants of median property values by census tract seem easier to identify and measure than the factors which influence location decisions. These advantages, however, are only apparent. To estimate marginal willingness to pay functions the hedonic price of air pollution must be regressed on income, prices, and air quality. Since income and air quality are jointly determined at the census-tract level, one faces the same problems encountered in estimating (10). Also, though it may be difficult to identify factors influencing location, our labor supply functions explain a large proportion of variation in wages. Furthermore, the coefficients of most variables are insensitive to the specification of the equation. These results suggest that the wage-differential approach deserves serious consideration and provides a useful check on estimates obtained using property value data.

APPENDIX A

The purpose of this appendix is to derive labor supply functions when individuals work in different occupations and tastes differ among occupational groups.

We assume that members of each occupation are identical and solve the utility maximization problem given by (2) and (3). The indirect utility function for members of group j is

$$V_{ij}(k) = C_j w_{ij} r_i(k)^{-\beta_j} p_{1i}^{-\alpha_{1j}} p_{2i}^{-\alpha_{2j}} P_i^{-(\eta_j+\delta_j)} a(k)^{-\delta_j} k^{-\xi_j}, \tag{A.1}$$

where parameters are subscripted to allow for differences in tastes.

As above, the labor supply function for each occupation is derived from the group's location decision. In equilibrium all members of the occupation must experience the same utility regardless of where they live. Thus V_{ij} must be equal to V_j^* for all i and k. (If each city is small and open, then V_j^* can be considered exogenous to the city.) This equilibrium condition is used to determine where in each city members of group j reside. The group's labor supply function is derived by summing the number of persons in each neighborhood in which the group lives.

The crucial step is determining the spatial distribution of groups within each city. This is accomplished by solving the equilibrium condition $V_{ij} = V_j^*$ for $r_{ij}(k)$, group j's maximum willingness to pay for land at each k. Since in equilibrium land will be sold to the highest bidder, members of group j will reside at those k where

$$r_{ij}(k) = \max_j r_{ij}(k). \tag{A.2}$$

Summing the number of persons at distance k, $n(k)$, across all k at which group j resides (K_{ij}) yields group j's supply function of labor,

$$N_{ij} = M_j w_{ij}^{(1-\beta_j)/\beta_j} p_{1i}^{-\alpha_{1j}/\beta_j} p_{2i}^{-\alpha_{2j}/\beta_j} P_i^{-(\eta_j+\delta_j)/\beta_j} \times \int_{k \in K_{ij}} k^{-\xi_j/\beta_j} a(k)^{-\delta_j/\beta_j} dk. \tag{A.3}$$

The difficulty with this procedure is that the boundaries of the group j neighborhoods, which are determined by (A.2), depend on the w_{ij}'s. The integral on the right-hand side of (A.3) therefore cannot be regarded as a random error term, and omitting it from the equation will bias the coefficients of N_{ij} and P_i in (A.4)

$$(w_{ij}/\tilde{P}_{ij})^* = c_j + \frac{\beta_j}{1-\beta_j} N_{ij}^* + \frac{\eta_j + \delta_j}{1-\beta_j} P_i^* + \epsilon_{ij}. \tag{A.4}$$

How serious this problem is depends on the extent to which neighborhood boundaries depend on current wages and pollution levels. To the extent that they do not, the limits of integration in the supply function may be regarded as independent of w_{ij} and P_i, and the integral in (A.3) treated as random.

APPENDIX B SMSA'S IN SAMPLE

1. Buffalo
2. Hartford[16]
3. Philadelphia
4. Pittsburgh
5. Chicago
6. Cincinnati
7. Cleveland
8. Dayton
9. Detroit
10. Indianapolis
11. Kansas City
12. Milwaukee
13. Minneapolis–St. Paul
14. St. Louis
15. Wichita
16. Atlanta
17. Austin
18. Baltimore
19. Baton Rouge
20. Dallas
21. Houston
22. Nashville
23. Washington, D.C.
24. Denver
25. Los Angeles
26. San Diego
27. San Francisco
28. Seattle

[16]Data on net migration were not available for Hartford, hence this city is excluded from the sample for white-collar workers.

ACKNOWLEDGMENTS

We would like to thank Allen Kneese, Sherwin Rosen, and Daniel Rubinfeld for helpful comments on an earlier version of this paper, and S. James Press for econometric advice. Gary Evans and Rachel Willis provided excellent research assistance.

REFERENCES

1. R. J. Anderson and T. D. Crocker, Air pollution and residential property values, *Urban Studies*, **8**, 171–180 (1971).
2. M. Getz and Y. Huang, Consumer revealed preference for environmental goods, *Rev. Econ. Statist.*, **60**, 449–458 (1978).
3. I. Hoch with J. Drake, Wages, climate and the quality of life, *J. Environ. Econ. Manage.*, **1**, 268–295 (1974).
4. O. Izraeli, "Differentials in Nominal Wages and Prices Between Cities," unpublished Ph.D. dissertation, Univ. of Chicago (1973).
5. J. R. Meyer and R. A. Leone, The urban disamenity revisited, *in* "Public Economics and the Quality of Life" (Wingo and Evans, Eds.), Johns Hopkins Press, Baltimore (1977).
6. A. M. Polinsky and D. L. Rubinfeld, Property values and the benefits of environmental improvements, *in* "Public Economics and the Quality of Life" (Wingo and Evans, Eds.), Johns Hopkins Press, Baltimore (1977).
7. A. M. Polinsky and D. L. Rubinfeld, The long-run effects of a residential property tax and local public services, *J. Urban Econ.*, **5**, 241–262 (1978).

8. A. M. Polinsky and S. Shavell, Amenities and property values in a model of an urban area, *J. Public Econ.*, **5**, 119–129 (1976).
9. R. Ridker and J. A. Henning, The determinants of residential property values with special reference to air pollution, *Rev. Econ. Statist.*, **49**, 246–257 (1967).
10. S. Rosen, Wage-based indexes of urban quality of life, Univ. of Chicago (1977).
11. R. M. Solow, On equilibrium models of urban location, *in* "Essays in Modern Economics" (Parkin and Nobay, Eds.), Longman, London (1973).
12. U. S. Bureau of Labor Statistics, "Selected Earnings and Demographic Characteristics of Union Members, 1970," Report 417, Table 11.
13. U. S. Bureau of Labor Statistics, "Three Standards of Living for an Urban Family of Four Persons, 1969–1970," Supplement to Bulletin No. 1570-5, Table B-1.
14. U. S. Bureau of the Census, "Census of Agriculture, 1969," Vol. I, Highlights of the State's Agriculture.
15. U. S. Bureau of the Census, "Census of Governments, 1967," vol. II, Table 21.
16. U. S. Bureau of the Census, "Census of Mineral Industries, 1967," Area Statistics, Table I.
17. U. S. Bureau of the Census, "Census of Population, 1970," Vol. I, Part 1, Table 35; Parts 2-51, Tables 174–176.
18. U. S. Bureau of the Census, "Census of Transportation, 1972," Commodity Transportation Survey, Summary of Shipments: 1967 and 1972.
19. U. S. Bureau of the Census, "County and City Data Book, 1972," Table 3, Item 6; Table 6, Items 489 and 494.
20. U. S. Bureau of the Census, "Statistical Abstract, 1970," 719.
21. U. S. Bureau of Health, Education and Welfare, "Decennial Census Data for Selected Health Occupations, United States, 1970."
22. U. S. Environmental Protection Agency, "The National Air Monitoring Program: Air Quality and Emission Trends Annual Report," Vol. II, EPA-450/1-73-001-b, Appendix G-2 (1973).
23. U. S. Federal Bureau of Investigation, "Uniform Crime Reports-1970," Table 5.