Chapter 7

VALUING A PUBLIC GOOD: DIRECT AND INDIRECT VALUATION APPROACHES TO THE MEASUREMENT OF THE BENEFITS FROM POLLUTION ABATEMENT*

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1 INTRODUCTION

Air pollution is known to cause damages to health and environment. Pollutants in the air increase mortality and morbidity; they also affect agricultural productivity, damage materials (mainly by corrosion), have negative ecological impacts, and cause aesthetic damage (mainly through reduced visibility). Converting these damages into money values, an analysis of U.S. data has recently shown that the effects on health are dominant, contributing perhaps 90% of total damages (Freeman, 1982). This paper deals specifically with estimating the economic benefits of reducing air pollution-induced morbidity.

The public good attribute of environmental quality requires that different approaches to those customarily employed in market-goods studies be adopted. Two basic approaches have been usually employed. The first encompasses indirect methods such as hedonic price models. In principle these infer the implicit value of a public good from the observable demand for some private good associated with it (e.g., air quality and housing values). The second approach is based on direct methods, principally the contingent valuation method (CVM). These elicit directly from individuals the value they would attribute to the public good in a market-like environment (on the state-of-the-art of CVM, see Cummings, et al., 1986).

In this paper both approaches are applied to the valuation of benefits from the reduction of morbidity associated with air pollution and the results are compared. The empirical analysis is based on individual household data, obtained through a large-scale household survey conducted in Israel during 1986. Unlike most treatments of the subject using the indirect approach, the present study employed primary, individual household data. This enabled us to apply both approaches to the same data base, and compare them. The results indicate that both approaches yield reasonably close estimates of the welfare changes associated with improved air quality and improved health.

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2 AN INDIRECT APPROACH TO PUBLIC GOOD VALUATION

2.1 Market good - public good relationship

Two basic methods, each using an indirect approach, are usually invoked to derive measures of welfare change. The first begins by estimating an observed market demand function for a market good, specifying some type of demand interdependence between the public good and the market good. This interrelationship is reflected in the change in market good demand due to observed variations in the quantity of the public good. The consumer surplus associated with these variations measures the corresponding welfare change. However, as is well known (cf. Just, et al. 1982), this yields an *approximate* value of the potential welfare change.

The second method specifies a demand system in terms of the parameters of an underlying direct or indirect utility function. The corresponding expenditure function, or money metric utility, is then used to calculate the monetary value of welfare changes. In this case, a theoretically *exact* measure of the welfare change involved is obtained -- the compensating and equivalent variations.

In the study presented here we began with a translog approximation to any arbitrary indirect utility function, and then proceeded to derive the implied demand system in the form of budget share equations. Here we deal with two market goods, housing services and medical services, both of which are related to the public good, air quality. Clearly, air quality affects housing prices, as well as expenditures on preventive and medical care associated with the effect of pollution on health.[1]

2.2 Indirect valuation: Exact welfare measures

Assume individual preferences are defined over a vector of market goods $\underline{X}$ and a public good y, by $U(\underline{X},y)$, where U is a well defined utility function. Dual to $U(\cdot)$ there exists an indirect utility function, $V(\underline{P},M,y)$, which solves $\mathrm{Max}[U(\cdot)|\underline{P}\cdot\underline{X}\leq m]$ where $\underline{P}$ is the vector of prices of the market goods, M denotes expenditures on $\underline{X}$, and m is money income. The indirect utility function defined on prices and the level of a public good has also been termed *conditional* indirect utility. The function can also be defined in terms of *normalized* prices, $P^*=P/M$. The conditional indirect utility function is non-negative, non-increasing, and convex in P^* for fixed y, and non-decreasing and concave in y for fixed P^*. It is also positively linearly homogenous in P^* for given y.

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1 This is related to Mäler's (1974) weak complementary condition, or Bradford and Hildebrandt's (1977) demand interdependence condition, which are required in order to solve the public good demand in terms of the underlying utility function.

The expenditure function, μ, which relates income and utility (strictly, the inverse of the indirect utility function), is defined as the minimum sum necessary to maintain a given level of utility, U^0, at a given price P^0:

$$\mu(P^0, U^0) = \underset{X}{\mathrm{Min}}\ [P^0X: \ U(X) = U(X^0)] \tag{1}$$

where $\frac{\partial\mu}{\partial P}$ is the Hicksian compensated demand function. For a given set of reference prices, the function serves as a money index of utility –– a money metric utility (see, Varian, 1984, ch. 3; McKenzie and Pearce, 1982).

If the *quantity* of a public good, y, is now included in the indirect utility function, a corresponding expenditure function can be defined (Bradford and Hildebrandt, 1977). Its derivative with respect to the public good ($\partial\mu/\partial y<0$) yields a marginal willingness to pay schedule, or the compensated demand function, for the public good, from which exact welfare measures – compensating and equivalent variations associated with the change in y – may be calculated. In this case, compensating variation (CV) is defined as the income change which offsets the change in utility induced by a change in the level of y, holding utility (U) constant at its *original* level. CV can therefore be defined in terms of the expenditure function as:[2]

$$CV = \mu(P_X^0, y^0, V^0) - \mu(P_X^0, y^1, V^0), \tag{2}$$

Analogous to this,the equivalent variation (EV) for the non-market good is the change in income equivalent to the utility gain induced by a change in the non-market good, holding utility at its *subsequent* level.

$$EV = \mu(P_X^0, y^0, V^1) - \mu(P_X^0, y^1, V^1) \tag{3}$$

If $y^1>y^0$, the CV measure is interpreted as the the maximum amount of money a consumer would pay as a lump sum to obtain the specified increase, Δy (following Randall and Stoll, 1980). It is a measure of a willingness to *pay* rather than a willingness to *accept*, and it is denoted here as WTP^c. If $y^1<y^0$, the EV measure is similarly interpreted as the maximum payment to prevent a decrease in y (denoted WTP^e).

Our analysis, however, involves only a subset of commodities from the consumer's total consumption space. As noted by Hanemann and Morey (1987), the CV and EV measures calculated from a partial demand system are not identical to those calculated from a full system. The CV is a lower bound on the conventional CV, and the EV can be greater than, less than, or equal to the

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2 Strictly, it is defined in terms of the *compensation function*, or the *money metric utility*, which is identical to the expenditure function for fixed y (cf. Varian, 1984, pp. 123–125).

conventional EV.[3]

3 APPLICATION

3.1 The survey

The household survey was based on a stratified, cluster area probability sample of about 2,000 household in the metropolitan area of Haifa in northern Israel.[4] The sample was drawn from 137 Census Statistical Areas which were classified into four socioeconomic groups on the basis of data from the latest (1983) Census. They were further classified into three levels of ambient pollution. Seventeen statistical areas (each approximating a different urban neighborhood) were chosen to represent the 12 (3x4) sampling strata. City blocks were randomly sampled within each stratum, with approximately equal sampling ratios in each of the strata. Heads of household (either spouse) within each block were interviewed. The survey was carried out over a period of six months, from April 1986 through August 1987. Each neighborhood was repetitively sampled over the entire period, so that every household in each neighborhood had an approximately equal chance of being sampled at any time. This was in order to capture the seasonality effect of air pollution in the Haifa area. The data were collected during the course of a structured interview, lasting about 30 minutes. The overall response rate was 81%, 9% refused to be interviewed, and another 10% could not be reached even after a second visit. Descriptive statistics of the relevant variables of interest appear in Appendix A.

3.2 Model specification and estimation

The translog form was chosen to represent the indirect utility function (Christensen et.al., 1975). The translog function is a general, flexible form of a second-order local approximation to any twice-differentiable indirect utility function (Just, et al., 1982, Appendix B). Given the properties of the indirect utility function, we have specified the following function for the empirical application:

$$V = \dot{V}(P^*,y,h) \qquad (4)$$

where h represents a vector of individual household characteristics employed

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[3] In order for the partial system to represent preferences satisfactorily, it must be assumed that the group of commodities for which data exist is separable in consumption from the group of all other commodities (see Hanemann and Morey, 1987).

[4] The Haifa Bay area is considered to be one of the most polluted regions in the country. Its topography, meteorological conditions, and concentration of heavy industry create conditions which are often conducive to high ambient pollution levels, especially high SO_2 and TSP concentrations, in residential areas.

here as control variables. An approximation to an arbitrary, twice differentiable, conditional indirect utility function specified by (4), can be obtained by utilizing the translog specification (Christensen, et al., 1975). For the three-good, partial demand system, the translog approximation takes the following form:

$$\ell n V = \alpha_0 + (1 + \ell n y) + (\alpha_1 + \gamma_1 \ell n y)\ \ell n\ P_1^* + (\alpha_2 + \gamma_2 \ell n y)\ \ell n\ P_2^* +$$
$$+ \frac{1}{2}\Big[(\beta_{11} + \delta_{11}\ \ell n y)[\ell n\ P_1^*]^2 + (\beta_{12} + \delta_{12}\ \ell n y)\ell n P_1^*\ \ell n P_2^* +$$
$$+ (\beta_{21} + \delta_{21}\ \ell n y)\ell n P_1^*\ \ell n P_2^* + (\beta_{22} + \delta_{22}\ \ell n y)[\ell n P_2^*]^2\Big] +$$
$$+ (\ell n\ P_1^*)\ [\phi_{11}h_1 + \phi_{12}h_2 + \phi_{13}h_3 + \phi_{14}h_4 + \phi_{15}h_5 + \phi_{16}h_6] +$$
$$+ (\ell n\ P_2^*)\ [\phi_{21}h_1 + \phi_{22}h_2 + \phi_{23}h_3 + \phi_{24}h_4 + \phi_{25}h_5 + \phi_{26}h_6] \quad (5)$$

where

P_1 – housing prices;

P_2 – index of medical services price;

M – annual household expenditure on both goods;

$P_1^* = \frac{P_1}{M}$

$P_2^* = \frac{P_2}{M}$

h_1 – smoking habits (head of household);

h_2 – respiratory illness symptoms (head of household);

h_3 – respiratory illness symptoms (other household members);

h_4 – respiratory diseases (head of household);

h_5 – respiratory diseases (other household members);

h_6 – net household income from all sources.

Housing prices were represented by annual municipal tax assessements, the rates of which generally reflect the socio-economic status of the neighborhood and the quality and size of the dwelling. This variable was used instead of imputed rental values because there are no reliable, published statistics on housing prices by neighborhood and housing quality. The index of medical service prices is based on reported national average estimates of visits to clinics and hospitalization costs. As no better statistics were available, these are merely rough figures for all illnesses combined. However, we also obtained out-of-pocket doctor and medication expenditure from the survey.[5] The survey also provided information on implied and reported consumption levels of housing (dwelling size and locational quality are the two parameters affecting local property tax assessments), and the consumption of medical services. Air quality, y, indicates the *perceived* level of neighborhood pollution[6]. This information was obtained from the respondents who were asked how *they* perceived the pollution level in their neighborhood. They were requested to indicate this on a severity scale of 1 to 6. The h_ks are the health attributes of the respondents (head of household), or the other household members, that are associated with air pollution (with the except of smoking which, in and by itself, induces similar illnesses). The illness symptoms include coughing, wheezing, sputum emission, and shortness of breath; diseases refer to asthma, bronchitis, pneumonia, and other lower respiratory tract diseases. The sixth attribute, h_6, is a proxy for socioeconomic status.

Two distinguishing features of specification in eq. (5) should be pointed out. One is the introduction of a public good as a quality parameter in the translog function, and the inclusion of relevant individual characteristics pollution related symptoms and illnesses.[7] Applying Roy's identity (cf. Varian, 1984, p. 126–7) to (5), and transforming the resulting demand equations into expenditure share equations for the *market* goods, the logarithmic form of share equations to be estimated is obtained. Symmetry constraints were imposed in eq. (6) below, equivalent to ensuring the integrability of the posited demand system (cf. Christensen, et al, 1975), namely: $\beta_{ij}=\beta_{ji}$ $\delta_{ij}=\delta_{ji}$ and $\phi_{1k}=-\phi_{2k}$ for all k. This causes the characteristics variables (the h_ks) to drop out of D, as is shown below:

$$\frac{\partial \ell n V}{\partial \ell n P_i} \Big/ \frac{\partial \ell n V}{\partial \ell n M} = S_i = \frac{P_i X_i}{M} = \tag{6}$$

$$= \Big\{(\alpha_i + \gamma_i \ell n y) + (\beta_{ii} + \delta_{ii} \ell n y) \ell n P_i^* + \frac{1}{2}(\beta_{ij} + \delta_{ij} \ell n y) \ell n P_j^* +$$

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5 It should be noted that most of the population subscribes to one of several public health insurance schemes, and do not pay directly for medical services except for a monthly insurance premium. However, paying for private medical visits and medications in order to receive faster, and often better quality, treatment is rather common. Thus, the opportunity cost of time involved in obtaining medical treatment cannot be overlooked, too.

6 On the appropriateness of using perceived rather than measured pollution level in such circumstances, see Zeidner and Shechter(1988).

7 The inclusion of characteristics in a translog utility function was first introduced by Woodbury (1983), in connection with a model describing labor compensation by either wage or fringe benefits. The characteristics were variables describing the worker or the workplace. Morey (1985) incorporated personal and site characteristics into a demand system for ski resorts.

$$+ \frac{1}{2} (\beta_{ji}+\delta_{ji}\ell ny)\ \ell n P^*_j + \sum_{k=1}^{6} \phi_{1k} h_k \Big\} \Big/ D$$

where

$$D = (\alpha_i+\gamma_i \ell ny)+(\alpha_j+\gamma_j \ell ny) + (\beta_{ii}+\delta_{ii}\ell ny)\ell nP^*_i + (\beta_{jj}+\delta_{jj}\ell ny)\ell nP^*_j +$$

$$+ \frac{1}{2} (\beta_{ij}+\delta_{ij}\ell ny)(\ell nP^*_i + \ell nP^*_j)+\frac{1}{2}(\beta_{ji}+\delta_{ji}\ell ny)(\ell nP^*_i + \ell nP^*_j)$$

From consumer theory it is known that the budget share equations should be homogenous of degree zero. A customary normalization which imposes this constraint on the demand system is $\sum_i \alpha_i = -1$ (cf., e.g., Christensen and Manser, 1977). The system should also satisfy the "adding up" restriction of consumer theory, $\sum_i S_i = 1$, implying that the parameter of the m–th equation (our second equation) can be determined from the m–1 budget shares equations (our first equation). To estimate the share equation (6) we employed the SAS SYSNLIN procedure (SAS, 1985) which combines iterative minimization methods for non–linear regression with OLS estimation technique. Table 1 displays the parameter estimates.[8]

It is instructive to check the properties of the estimated indirect utility function. For example, differentiating it with respect to prices, income and the public good, and evaluating at the point of means of P^*_1, P^*_2, and y, the following is obtained:

$\frac{\partial \ell nV}{\partial \ell nP^*}$ < 0 $(=-0.058)$ — for i=1 (housing)

< 0 $(=-0.303)$ — for i=2 (medical care)

$\frac{\partial \ell nV}{\partial \ell nM}$ > 0 $(=0.36)$

$\frac{\partial \ell nV}{\partial \ell ny}$ > 0 $(=5.06)$

Thus, the estimated (indirect) utility function exhibits the correct signs. It decreases with a rise in the (normalized) prices of housing and medical care services, and rises with the level of money expenditures, and with the level of the public good — air quality. It can also be shown that the estimated function is concave. Moreover, the estimated share equation yields the corresponding share elasticites, which are closely related to income

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8 Respondents' perceived air quality levels were used for y. Specifically, for observation i the independent variable is $y_i/\bar{y}$, where $\bar{y}$ is the sample mean.

TABLE 1

Parameter estimates of the budget share equation*.

Parameter	Estimate	Parameter	Estimate
α_1	−0.155 (−16.28)	ϕ_{11}	−0.0038 (−5.20)
γ_1	0.258 (−22.44)	ϕ_{12}	0.0036 (5.53)
γ_2	−1.346 (−35.71)	ϕ_{13}	0.0055 (7.49)
β_{11}	−0.029 −(11.73)	ϕ_{14}	0.005 (7.49)
β_{12}	0.0147 (3.61)	ϕ_{15}	0.0055 (7.68)
β_{22}	−0.153 (−27.91)	ϕ_{16}	$8.4\text{x}10^{-6}$ (3.83)
δ_{11}	−0.0269 (−11.92)	R^2 = 0.31	
δ_{12}	−0.0197 (−9.25)	N = 2234	
δ_{22}	−0.243 (−33.83)		

* Asymptotic t statistics in parentheses.

elasticities (cf., for example, Christensen and Manser, 1977). Of special interest in the present context is the elasticity with respect to variations in the level of air quality:

$$\eta_{iy} = \frac{\partial \ell n S_i}{\partial \ell n\ y} = 0.113 \text{ (for i=1, the housing share)}$$

$$= -0.023 \text{ (for i=2, the medical care share)}$$

Thus, these elasticities bear the sign expected. On average, individuals would spend 1.3% more on housing and 0.2% less on medical care given a 10% improvement in air quality levels from levels currently *perceived* in their respective neighborhoods. Such results may clearly have significant policy implications for setting ambient air quality standards.

3.3 Computing welfare change measures

The expenditure function corresponding to (5) is given in Appendix B. In the survey respondents were asked to state their WTP for a ±50% change in currently perceived air quality levels. Accordingly, the calculations of CV and EV associated with a such a change are presented. WTP^c and WTP^e as functions of y – the Bradford (1970) bid curves – are computed from eq. (B1) in Appendix B, as shown in eqs. (2) and (3). These calculations yielded values of 30.1 and 130.6 New Israeli Shekels (NIS)[9], respectively, per household, per year.

4 A DIRECT APPROACH TO PUBLIC GOOD VALUATION

In this section several salient results from the survey are presented. These deal with the direct valuation of the environmental good, through the use of CVM. In the household survey respondents were asked to state their preferences regarding changes in air quality in a contingent valuation framework. The questionnaire included one question eliciting a willingness to pay in order to prevent a worsening of present air quality levels (specifically, a 50% increase in ambient pollution levels) – WTP^e. There was also a question relating to the respondent's willingness to pay in order to achieve a 50% improvement through a reduction of present pollution levels – WTP^c.[10] The payment vehicle was the municipal tax, and the interviewee was asked to indicate WTP in terms of a percentage increase in his or her currrent tax payment (the percentage change categories were listed on a card shown to the respondent by the interviewer). Respondents were also asked about the reasons for refusing to pay any sum at all.

Mean sample values of WTP^c and WTP^e for air quality changes are presented in Table 2. For the purpose of the analysis, neighborhoods were divided into the three pollution levels. With regard to WTP^c, it was assumed that a 50% improvement roughly implies that a neighborhood with moderate air quality would be upgraded into one with good air quality, i.e., a (relatively) clean one, and that a "bad" neighborhood would move into the "moderate" category. Similarly, with respect to WTP^e, a 50% deterioration in pollution levels would imply a downgrading of a relatively clean neighborhood to one with moderate levels, and so on.[11] Thus, on average, an individual living in a moderately polluted neighborhood (according to his or her perception) would be willing to contribute a yearly sum of NIS 37.9 towards improving air quality, and a sum of NIS 40 in order to prevent a worsening of present levels. Both WTP^c and WTP^e increase with pollution levels, and the between-group differences are significant (non parametric median test). The two-sample mean tests indicate that although WTP^e and WTP^c differ significantly, $WTP^c > WTP^e$ in one case (poor neighborhood respondents), but the reverse holds for moderate neighborhoods.

The variables found to be significant in explaining the variation in WTP^c

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9 The exchange rate of the NIS during the survey period was 1.5 NIS to $1 (USA), approximately.

10 A visual stimulus, presenting respondents with photographs depicting a polluted and a clear day in the Haifa area, was provided.

11 Note that the neighborhood marked "Very poor" in Table 2 is a fictitious neighborhood, created by hypothetically downgrading the "poor" neighborhood category.

TABLE 2

Direct (CVM) valuations of *perceived* air quality changes*.

Present pollution level	Pollution level *after* change			
	Good	Moderate	Poor	Very poor
Good		(a) WTP^e Mean = 26 Median = 15 N =847		
Moderate	(b) WTP^c Mean = 37.9 Median = 28 N =750		(c) WTP^e Mean = 40 Median = 28 N =749	
Poor		(d) WTP^c Mean = 47.2 Median = 40 N =192		(e) WTP^e Mean = 42.7 Median = 32 N =192

* Values in table refer to means and medians of the indicated sample air quality stratum, and stated in NIS per household per year.

Significance Levels:

Nonparametric median test for 2 samples:

H_0: WTP^c (cell b) = WTP^c (cell d)	0.015
H_0: WTP^e (cell a) = WTP^e (cell c) = WTP^e (cell e)	0.001

Paired t-test for means (2 tailed):

H_0: WTP^c (cell b) = WTP^e (cell c)	0.001
H_0: WTP^c (cell d) = WTP^e (cell e)	0.049

and WTP^e (using a stepwise OLS procedure) are presented in Table 3. The multiple regressions support the finding in Table 2 that air pollution significantly affects both WTP variables. It should be noted that health status-related variables did not enter the regressions, whereas they did enter the share equations. However, it was found that these variables did explain some of the variation in WTP when "untrue" zero answers were excluded from the analysis[12].

[12] These refer to zero payments, while the reasons given for it indicate that the respondent does value the public good but either objects to the vehicle (tax) or believes that the "authorities" or the "polluter" should pay. Also note the importance of question order on WTP. This result supports earlier arguments by Tversky and Kahenman (1981) and others, concerning the influence of framing and sequence of questions on decision.

TABLE 3

Willingness to pay regression coefficients.

Explanatory variable	Regression coefficients WTP[c]	WTP[e]
Demographic and socioeconomic variables:		
Age of respondent	−0.39[a]	−0.34[a]
Education	0.43[d]	
Self-employed*	2.87[d]	
Blue collar worker*	−7.4[b]	−7.37[b]
Number of children	−4.1[a]	−1.77[b]
Size of apartment	0.22[b]	0.5[a]
Apartment size squared	−0.002[a]	−0.002[a]
Net household income		0.009[a]
Age x income	0.0002[a]	
Number of children x income	0.002[c]	
Annual municipal taxes	0.05[a]	0.045[a]
Attitudional variables:		
Perceived exposure to pollution at work*	4.58[c]	4.53[c]
Perceived neighborhood pollution (log)**	8.78[a]	18.48[a]
Believes budget share allocated to pollution abatement too high*	−7.66[a]	−8.76[a]
Pollution induces defensive actions by respondent*	6.77[b]	
Questionnaire structure:		
Health questions before WTP questions*	−3.75[c]	−5.67[b]
Intercept	12.51	−1.35
R^2	0.25	0.23
F	40.14[a]	36.88[a]
d.f.	(14, 1770)	(13, 1770)

* A binary variable
** On an ordinal severity scale (1 to 6)
a Significance level = 0.0001
b Significance level = 0.001
c Significance level = 0.01
d Significance level = 0.1

5 CONCLUDING REMARKS

A uniform primary data set - household survey data - was employed in this study to obtain implicit and explicit valuations of an environmental good - air quality. Two approaches were applied, an indirect, market good related approach, and a direct, nonmarket good valuation approach. On the one hand, direct valuation relies exclusively on direct question techniques. Primary survey data composed of individual responses are therefore essential for its application. Market demand systems, on the other hand, are normally estimated from aggregate, secondary market data.

However, the information gathered in the present study made it possible to apply these two different approaches to the *same* data, and thus obtain comparable valuations pertaining to exactly the same set of data. Since both approaches are supposed to measure the same thing – the implicit demand for a public good, they could be expected, *a priori*, to yield similar results. In this paper we have attempted to test this proposition. The welfare change measures obtained under these two approaches are presented in Table 4.

TABLE 4
Direct and indirect valuations (NIS per household per year).

	Indirect approach	Direct approach
WTP^c	30.1	32.6
WTP^e	130.6	33.4

These results could be viewed as a modest addition to the efforts of environmental economists to establish CVM as an appropriate valuation tool. It should be noted that the comparisons essentially are made between *ex post* and *ex ante* measures. The closeness of the two WTP^c values, however, must hearten CVM practitioners. They are encouraging and seem, at least to us, to add support to and increase the profession's confidence in the use of the contingent valuation method.[13]

[13] In investigating further the "robustness" of CVM, we have recently analysed results from closed-ended questions (referendum-style), binary response questions . These questions demand "yes" or "no" responses to a given, randomly assigned payment level. This form of eliciting WTP response has been recently advocated by several CVM practitioners (e.g. Loehman and De, 1982; Hanemann, 1984, Cameron and James, 1987). Preliminary results indicate that this variant of the direct approach yields values comparable to those given in Table 4.

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APPENDIX A: Descriptive Statistics.

Variable	Mean	Standard Deviation
Apartment area (m^2)	81.5	25.4
Physician visits per year	7.69	8.76
Annual tax rate (NIS*per m^2)	6.01	2.54
Annual rent proxy (NIS)	464	253
Annual medical outlay (NIS)	938	400
Total annual expenditure, M (NIS)	1402	518
Cigarette smoking, h_1**	0.29	0.45
Respiratory illness symptoms of head of household, h_2	0.65	0.47
Respiratory illness symptoms of all other members of household, h_3	0.54	0.49
Respiratory illness of head of household, h_4	0.19	0.39
Respiratory illness of all other members of household, h_5	0.28	0.45
Net household monthly income from all sources, in NIS, h_6	1174	589
Perceived air quality level [Scale: 1 - (bad) - 6 (good)]	4.06	1.5
N = 2277		

* NIS = New Israeli Shekel. The average exchange rate of the NIS during the survey period was 1.5 NIS to $1 (USA).

** Variables h_1 through h_5 are binary.

APPENDIX B: The expenditure function and bid curve.

The expenditure function corresponding to indirect utility function (5) has the following form (in terms of the *log* of M):

$$\mu = \Bigg\{ \left[a_1+a_2+(\ell nP_1)(b_1+b_2)+(\ell nP_2)(b_2+b_3)\right] \pm$$
$$\pm . \Bigg\{ \left[a_1+a_2+(\ell nP_1)(b_1+b_2)+(\ell nP_2)(b_2+b_3)\right]^2 -$$
$$- (2b_1+4b_2+2b_3) \times \Big[\alpha+(\ell nP_1)(a_1+d_1)+(\ell nP_2)(a_2+d_2)+\tfrac{1}{2}b_1(\ell nP_1)^2 +$$
$$+ b_2 \ell nP_1 \ell nP_2 + \tfrac{1}{2}b_3(\ell nP_2)^2 - \ell nV^0\Big]^{\frac{1}{2}} \Bigg\} \times \left[\frac{1}{(b_1+2b_2+b_3)}\right] \tag{B.1}$$

where

$$\mu = \ln M$$

$$\alpha = \alpha_0 + 1 + \ell n y$$

$$a_1 = \alpha_1 + \gamma_1 \ell n y$$

$$a_2 = \alpha_2 + \gamma_2 \ell n y$$

$$b_1 = \beta_{11} + \delta_{11} \ell n y$$

$$b_2 = \beta_{12} + \delta_{12} \ell n y$$

$$b_3 = \beta_{22} + \delta_{22} \ell n y$$

$$d_1 = \sum_{k=1}^{6} \phi_{1k} h_k$$

$$d_2 = \sum_{k=1}^{6} \phi_{2k} h_k$$

The expenditure function is derived by solving for M from the indirect utility function (5), in terms of given (initial) prices of the two market goods, quantity of the public good (perceived neighborhood air quality), and a given level of utility. Ln V^0 was computed by inser ting the sample mean values of y^0, P^0, and h_ks in eq. (5).

Differentiation of the expenditure function (B.1) with respect to the public good, y, yields the marginal bid function, or the (compensated) demand price function for air quality, $-\partial\mu(y,P^0,U^0)/\partial y$. It can be shown that for our parameter estimates (Table 1), $-\partial\mu/\partial y>0$ (cf. Loehman, 1986), and it decreases with y.