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Methodology to Calculate Social Values for Air Pollution Using Discrete Choice Models

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ABSTRACT *A new methodology for the estimation of social values of urban air pollution for project appraisal is proposed. This is performed by using individual perceptions (marginal disutilities) of those who are directly affected by this externality, which are then transformed into social values using the social welfare approach developed by Gálvez and Jara-Díaz in 1998. The approach also unveils the implicit social bias behind the commonly accepted willingness-to-pay measures. The method is illustrated using individual perceptions obtained from stated preference experiments within the context of residential location including three attributes: an objective measure of air pollution by zone of the city, an index of family accessibility to work and study, and the monthly rent. Discrete residential choice models were estimated by income group, from which indirect utility functions were obtained. Marginal disutilities were used to obtain social values of air pollution for each income group by means of the calculation of a social utility of money. The methodological underpinnings and difficulties of the approach are specially highlighted. The need to establish a national programme for the estimation of social values is emphasized.*

Introduction

Air pollution is probably the worst externality in urban areas. Its presence is acquiring dramatic dimensions in cities such as Mexico City and Santiago, Chile. Its reduction is an undisputed goal in many cities around the world. The prevailing appraisal framework relies on various forms of estimating willingness-to-pay values.[1] Different approaches have been proposed, as contingent valuation (Otterbeck, 1995), calculation of direct resources saved (Maddison *et al.*, 1996) and discrete choice models (Bradley *et al.*, 1993; Ortúzar and Rodríguez, 2002; Sillano and Ortúzar, 2005). One objective of the present paper is to show that using this as a measure of social benefit hides regressive weights and does not seem appropriate

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for social project appraisal. As it is quite relevant to introduce proper social measures of the social benefits associated to the reduction of air pollution, the development of a method to obtain social values is the second objective. This is achieved by adapting the method proposed by Gálvez and Jara-Díaz (1998), which depends directly on the individual perceptions (marginal disutilities) of the attributes that one wishes to value, and on a social utility of money that transforms subjective (private) perceptions into social values.

In the second section, the approach is presented and a method to calculate a social value for air pollution is derived. The third section contains the discrete choice contexts in which this variable has been introduced in the literature, concluding with the form that was considered most appropriate to specify this variable in the case of Santiago. In the fourth section, a stated preference experiment designed to capture the perception of air pollution is described. The estimated models are presented in the fifth section; and the social values of this externality are calculated in the sixth section. The final section contains a synthesis and the main conclusions.

New Approach for the Social Valuation of Air Pollution

The social valuation approach proposed by Gálvez and Jara-Díaz (1998) is based on the idea of social preferences theoretically represented by the notion of a social utility function (W) that depends on the utility of each and every individual in society (W_q). The latter depends on the optimal amount of goods consumed by each individual q (X_{iq}), which in turn depends on individual income (I_q), market prices (P_M) and on the qualities of the goods (Q). This can be expressed as:

$$W = W(W_1, \ldots\ldots W_q, \ldots\ldots . W_n), \tag{1}$$

where:

$$W_q = W_q(X_{iq}[I_q, P_M, Q]) = V_q(I_q, P_M, Q) \tag{2}$$

is the indirect utility of individual q.

Every new project will generate variations in W_q, which in turn will affect the social utility level W. The variations in W_q can be quantified in money terms through a consumer's surplus dB_q, which measures the individual private benefit. Then the variation in social utility is (expanded from Pearce and Nash, 1981):

$$dW = \sum_q \frac{\partial W}{\partial W_q} \frac{\partial W_q}{\partial I_q} dB_q = \sum_q \Omega_q \lambda_q dB_q, \tag{3}$$

where λ_q is the marginal utility of income of individual (or socio-economic group) q. As discussed by Gálvez and Jara-Díaz (1998) and Jara-Díaz *et al.* (2000), the term $(\partial W / \partial W_q) = \Omega_q$ represents the importance that society assigns to group q.

As equation (3) is in units of W, to quantify dW in money terms (dB), it is necessary to define a conversion factor, λ_s, such that:

$$dB = \frac{dW}{\lambda_s} = \sum_q \Omega_q \frac{\lambda_q}{\lambda_s} dB_q, \tag{4}$$

where λ_s is the equivalence between social utility and money, just as λ_q is an individual utility of money. As social projects that involve the assignment of public resources that are part of the national budget are being dealing with, a good source of information for an estimate of λ_s is the tax structure, which represents the best evidence available on a collective choice between utility and money. The executive and legislative powers agree on the reduction of individual utility through the reduction in money income in order to collect a total sum to be spent according to a national plan. The marginal loss of social utility due to the marginal tax payment of each individual or group (dT_q) is given by:

$$dW_L = \sum_q \Omega_q \lambda_q dT_q. \tag{5}$$

Society is willing to accept this loss in order to obtain a marginal tax collection given by:

$$dT = \sum_q dT_q. \tag{6}$$

Therefore, the ratio between (5) and (6) is, by definition, a conversion factor implicitly revealed socially. Then, λ_s can be calculated as:

$$\lambda_s = \frac{dW_L}{\sum_q dT_q} = \frac{\sum_q \Omega_q \lambda_q dT_q}{\sum_q dT_q} = \sum_q \Omega_q \lambda_q \theta_q, \tag{7}$$

where θ_q is the marginal proportion contributed by group q to the total marginal tax collection.[2] Note that λ_s should be calculated taking into account *all* individuals in society.

Let us now see equation (4) within the context of discrete choice models, where the utility of alternative i is generally represented linearly as:

$$V_i = \sum_k \beta_k h_{ki}, \tag{8}$$

where h_{ki} is the k-th attribute of alternative i and the associated parameter β_k is its marginal utility. In this context, both λ_q and dB_q acquire particular characteristics. On the one hand, λ_q corresponds to the absolute value of the cost parameter (Viton, 1985; Jara-Díaz and Farah, 1988). On the other hand, dB_q can be approximated by a generalized version of the rule-of-a-half (Jara-Díaz, 1990), which is nothing but consumers' surplus applied to the generalized price that adds the subjective or private values of the attributes to the money value, for each alternative. This is:

$$dB_q \approx -\sum_{i\in M_q} \overline{X}_i^q \Delta c_i + \sum_k VSk^q \sum_{i\in M_q} \overline{X}_i^q \Delta h_{ki}, \tag{9}$$

where X_i^q is group q's average demand for alternative i regarding the situations with and without project; and Δc_i and Δh_{ki} are the project-induced variation on the cost and attribute k of alternative i, respectively. Lastly, VSk^q is group q's private value or willingness-to-pay for attribute k, which in this case is given by:

$$VSk^q = \frac{\beta_k^q}{\lambda_q}. \tag{10}$$

Let us concentrate only on an attribute associated with air pollution (*AP*) within a choice context. If it changes by ΔAP_i, its contribution to individual welfare measured in money terms is obtained replacing (10) in the last term of equation (9), which yields:

$$dB_q \approx \frac{|\beta_{AP}^q|}{\lambda_q} \sum_{i \in M_q} \overline{X}_i^q \Delta AP_i, \tag{11}$$

and here the absolute value appears because air pollution is a negative attribute. Replacing (11) into (4), the change in the social benefit due to variations in the attribute associated with air pollution within a choice context is given by:

$$dB = \sum_q \Omega_q \frac{|\beta_{AP}^q|}{\lambda_s} \sum_{i \in M_q} \overline{X}_i^q \Delta AP_i. \tag{12}$$

As the inner summation represents the total variation of air pollution for group q, the expression $\Omega_q |\beta_{AP}^q| / \lambda_s$ can be considered a social value of air pollution for group q.

Let us examine under which conditions the willingness-to-pay value in equation (10) could be taken as the social one and used to appraise social benefits. For this to happen, the social weight ($\partial W / \partial W_q$) has to be equal to ($\lambda_s / \lambda_q$) for all q. In other words, the social weight would have to be inversely proportional to the individual marginal utility of income; as λ_q decreases with income, this means that when the private value (willingness-to-pay) of the attribute is used as the social value, there is a hidden implicit social weight on individuals' utility that increases with individual income.

On the other hand, if an equal weight was considered for all individuals socially, Ω_q would vanish from the social value as it would appear both in the numerator and the denominator through λ_s. This unbiased social preference system would be equivalent to consider $|\beta_{AP}^q| / \lambda_s$ as the social value with λ_s given by equation (7) with $\Omega_q = 1$, which is what will be considered here. It is worth emphasizing that this approach should not be interpreted as a single equity value, as the social value depends on the marginal disutility of air pollution perceived by the different groups, which can differ or not. Therefore, whether a single value is more appropriate than group specific values becomes an empirical matter.

The challenge, then, is to calculate both β_{AP}^q and λ_s. To have an estimate of β_{AP}^q, one must identify a choice context where individuals perceive air pollution directly and, in parallel, one or more variables that have to be chosen to represent its presence. An estimate of λ_s is more difficult, though, because it requires as an input the λ_q values for *all* groups in the country. One might think that this could be obtained by means of group-specific choice models sufficiently representative of the population, because the absolute values of the corresponding cost coefficients theoretically represent the marginal utility of income. The problem, however, is that each choice model involves a potentially different scale parameter that multiplies utility. To obtain estimates of λ_q that are comparable in absolute terms, they should be estimated within the same choice model. Moreover, as the social value is constructed as a ratio, the scale parameter would vanish if λ_q and came from the same model, but this is something impossible to do for all groups in the country. In the example in the fourth section, the estimated λ_q will be used to calculate λ_s, a procedure that ensures consistency in the calculation, but is only an approximation if the sample is not representative of the whole population.

Environmental Variables and Choice Context

Within the literature, pollution has been considered within at least three choice contexts: residential location, recreational sites and mode choice. Only in the first two cases do individuals perceive the total direct effect of pollution and, therefore, its relative weight (marginal disutility) should be better captured. In the case of recreational sites, the emphasis has been on the representation of water quality. For example, Parsons and Kealy (1992) considered dissolved oxygen and water clarity. Adamowicz *et al.* (1994) used a dummy variable to represent the quality of water for each of many fishing sites; while Kaoru *et al.* (1995) considered nitrogen and the biological demand for oxygen in a similar context. Finally, Tay and McCarthy (1994) represented water quality through the concentration of different pollutants (oil, phosphorus, lead, copper, excrement, etc.).

Regarding air pollution, it has been considered mostly within the context of residential choice. Hunt *et al.* (1995) performed a ranking-based stated choice experiment to determine the relative importance of different attributes in residential location in Calgary, Canada. Three of these attributes were related with the environment: the frequency of low air quality (as measured by a state entity), the proximity to river valleys or to other environmentally important areas, and the presence of facilities (i.e. highways) that cause damage to environmentally attractive elements.

Wardman and Bristow (2004) tried to obtain money values of both air quality and accessibility using stated preference information obtained from families. Objective measures of air pollution were considered, as the presence (concentration) of nitrogen dioxide (NO_2; $\mu g/m^3$). This environmental attribute was specified using two approaches: the absolute level associated with each location, and percentage changes. In the first approach, each family head was presented five locations with very bad air quality and five with a very good one. They had to select one location from each group, denoted best and worst. Then the location choice game was constructed using pairs including the present location and each of the previously identified alternatives. In the second approach, each pair was built presenting percentage variations with respect to the present situation of each family for each attribute.

One should mention that Bradley *et al.* (1993) developed an approach to capture the perception of air pollution through vehicle choice. However, the authors themselves warn that the interpretation of their results should be done cautiously, because the individual consumer cannot perceive directly the benefit of acquiring an environmentally cleaner vehicle. Such a choice could be the result of an altruistic attitude, whose benefits would be realized only if many individuals act similarly.

Based on the limited international experience, it was decided to obtain the (subjective) perception of air pollution within the context of the choice of residential location, as this is the type of decision where the individuals (families) fully perceive this externality and trade-offs are present between money paid (rent) and environmental quality and other location specific variables. A choice model including the relevant aspects would yield the desired coefficients, particularly the marginal utilities of air pollution and the (individual or group-specific) marginal utilities of income, which coupled with tax information would allow for the calculation of the social utility of money and the social value of air pollution. In what follows we report the approach used and the data collected to estimate

Table 1. Classification of air quality in Santiago, Chile

Index	Category	Comment
0–100	Good	within the Chilean standards of air quality
101–200	Average	air quality diminishes; moderate discomfort
201–300	Bad	environmental warning; possible health damages
301–400	Critical	environmental pre-emergency; health effects on risk groups
401–500	Dangerous	environmental pre-emergency
> 500	Very dangerous	environmental emergency

Source: SESMA (1998).

choice models as that just described. This task was originally accomplished by a team composed by S. Jara-Díaz, J. de D. Ortúzar, G. Rodríguez and C. Vergara. Subjective (private) values have been reported by Ortúzar and Rodríguez (2002) using multinomial logit models and by Sillano and Ortúzar (2005) using mixed-logit (ML) specifications. Data and the new models that feed the calculation of social values are presented in the following section.

Regarding the definition of a variable to represent air pollution, the best source of information was the classification and the data collected by the Environmental Metropolitan Health Service (SESMA). Air quality was measured daily at each of eight monitoring stations within the Santiago Metropolitan region, and was known daily by the population through different media channels (television, radio, newspapers). This means that the population was familiar with the qualitative meaning of each category. The SESMA classification is shown in Table 1.

At each monitoring station the concentration of different pollutants is measured daily, as carbon monoxide (CO), NO_2, particulate material below 10 microns (PM_{10}), ozone (O_3) and sulphur dioxide (SO_2). During the period of the study, the only pollutant that varied significantly causing up to environmental emergency levels was PM_{10}. The rest remained below the acceptable range.

The spatial distribution of the monitoring stations is shown in Figure 1, where the Santiago urban sprawl and the main road links appear. Stations are quite spaced, covering different zones of the city (Centre, Northeast, Northwest, Southeast, Southwest). This allows one to find differences regarding air pollution across zones.

As the concentrations of PM_{10} ($\mu g/m^3$) are measured on a daily basis, the number of days per year within each category in Table 1 can be obtained, providing an easily understandable figure that reflects the environmental quality of different zones. Note that figures larger than 200 were obtained only during fall and winter, which are the most critical periods regarding air pollution in Santiago.

Stated Preference Experiment

To capture the individual perception of air pollution, a stated preference experiment (SP) on residential location choice was conducted. Previous pilot surveys and personal interviews helped the authors determine the specific variables to be incorporated into the SP along with their level of variation. These variables were travel time to work (T_w) and/or to study (T_e) for each family member, as appropriate, rent (*Arr*) and air quality at that location (*AP*). It was also concluded that families renting their residence consider the experiment more realistic than families owning it.

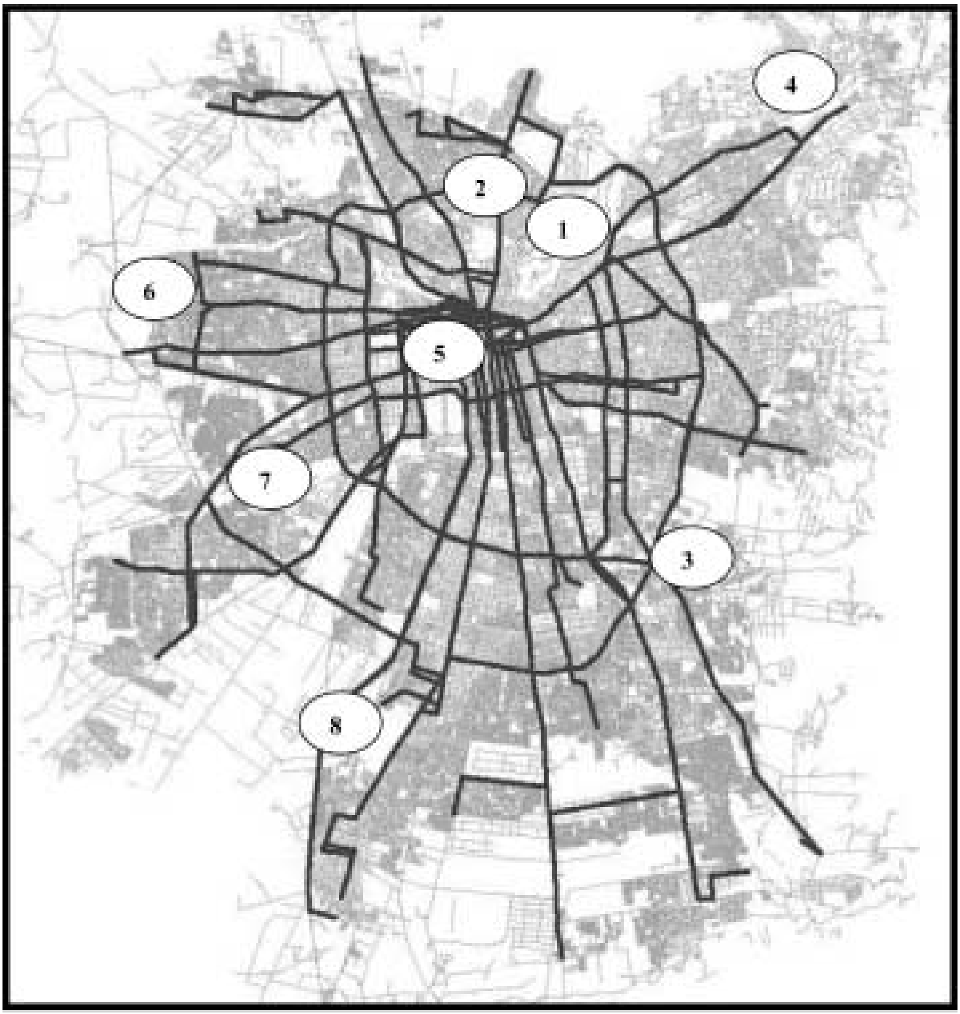

Figure 1. Spatial distribution of the monitoring stations. *Source:* Authors' own elaboration using information from SESMA (1998).

The SP experiment mainly followed the methodology described by Ortúzar *et al.* (2000), which included two stages. First, information was collected regarding the geographical location of the residence in Santiago, i.e. the actual values for T_w, T_e and Arr, and the perception of air quality by each family in that location. The second stage was the SP experiment on residential location applied to each family, with the values for the variables generated from the objective information gathered in the first stage.

It was decided to represent air quality through the number of days/year with an environmental index above 200, as the families make a direct relation between air pollution and the number of days with some environmental warning. The actual number for the station closest to the actual residential location and the actual number for Santiago were made known to each family before the experiment.

A fractional factorial design was used considering the main effects only and three levels for each variable; this gave rise to a design with nine alternatives.

Table 2. Variation of each attribute

	0	1	2
Travel time to work (min)	–25%	20%	40%
Travel time to study (min)	25%	–20%	–40%
Rent (Ch$/month)	–10%	15%	20%
Environmental emergency (days)	0	–3	–5

Each alternative corresponded to a given per cent variation on each variable considered with respect to its observed values for each family (Table 2). The actual situation was included as well as an alternative in order to increase a familiarity with the values given and to make it clear that the remaining attributes (those not considered in the experiment) were kept unchanged. The families were asked to rank the ten alternatives generated, from the most attractive to the less preferred one. The alternatives were randomized before being shown to the household members. Thus, the data are group rank-based and the design was customized. The ranking was exploded using Chapman and Staelin (1982) suggestions to yield nine equivalent choices per household.

The final sample included 134 households (Ortúzar and Rodríguez, 2002). Table 3 shows the distribution of families according to monthly per-capita income.

With this segmentation, two income groups were defined: those with a family income below Ch$397 222/month (*L*, strata 1–4), who paid an average monthly rent of Ch$138 778 (35% of their income), and those (*H*, strata 5–8) with an average family income of Ch$1 116 440 monthly, paying an average rent of Ch$219 540 (20% of their income). Most of the families lived in urban zones that can be described as high income on average (eastern Santiago).[3]

Before estimating models, the surveys were filtered in order to obtain unbiased parameter estimates. The ranked choices made by the families were analysed and lexicographic preferences eliminated, i.e. those that were based only upon one attribute (Saelesminde, 2002), as well as those that reflected inconsistent choices. Families whose rent was paid by third parties were eliminated as well. The sample for model estimation was reduced to 648 valid observations.

The choice process was modelled following the approach proposed by Jara-Díaz and Martínez (1999), who derived a conditional indirect utility function associated to location *s* that in this case is given by:

Table 3. Number of families on each per-capita income strata

Strata	1999 Ch$/month	Number of families
1	0–37 879	2
2	37 880–75 758	4
3	75 759–106 061	3
4	106 062–166 667	18
5	166 668–257 576	31
6	257 577–378 788	31
7	378 789–757 576	21
8	> 757 577	9
9	No reply	15

$$V_s = \beta_{Arr} p_s + \beta_{AP} AP_s + acc_s, \tag{13}$$

where p_s is the rent and AP_s is the number of emergency days that occurred at location s. The variable acc_s corresponds to the accessibility of location s. In this case, accessibility was measured as the sum of two terms associated with location relative to work and study, measured by the corresponding travel times T_w and T_e of each family member. This is represented in equation (14) regarding travel times within a week:

$$acc_s = \beta_{Tw}\left(\sum_{j \in W} f_j t_j\right) + \beta_{Te}\left(\sum_{j \in E} f_j t_j\right), \tag{14}$$

where W is the set of individuals that travel to work in the family, E is set of individuals in the family that travel to study, t_j is the travel time spent by individual j from/to the work or study place (min), and f_j is the weekly frequency of trips to/from work or study by individual j.

Equations (13) and (14) generate four parameters for each income segment. The parameters were estimated using a variety of logit models, including an income-segmented MNL, a restricted MNL (letting only the rent parameter to differ across segments), an MNL with correlation for family choices and an ML model considering taste variations (Bierlaire *et al.*, 2004).[4] The parameter estimates for the multinomial logit model including family correlation, which was considered the best and most appropriate, are shown in Table 4.

All marginal utilities (mean) are statistically significant and intuitively reasonable in terms of relative value and sign. Those parameters associated with work travel time and air pollution are larger in absolute value for the high-income segment of the sample, revealing a larger marginal disutility for each attribute. The contrary happens with the parameters associated with rent, as lower income families assign more importance to rent than rich ones.

Table 5 shows the subjective or private values for each attribute and group, calculated as in equation (10) using the results given in Table 4. To obtain travel times (Ch$/min), the ratios calculated directly from Table 4 were divided by the number of weeks per month. In the case of air pollution, the ratios were multiplied by the number of months in a year in order to obtain the results in Ch$/emergency day. Lastly, all ratios had to be multiplied by 1000 as the rent was described in thousands of Ch$. These values are the willingness to pay to reduce travel times or air pollution.

As stated above, the differences between segments are due to the difference in the marginal utility of income ($-\beta^H_{Arr}$), which is larger for the lower-income group, as well as to the difference in the marginal utilities of travel time and pollution. The willingness to pay to diminish one emergency day per year is 4.8 and 4.7% of the average annual rent paid by the low- and high-income segment households, respectively. Thus, the subjective valuation of air pollution is a modest (but not negligible) proportion of the rent for both groups. The absolute values obtained, Ch$79 810 and Ch$124 235, are comparable with the Ch$93 000 and Ch$169 000 obtained by Ortúzar and Rodríguez (2002) using a variety of multinomial logit models applied to the same sample, and with the Ch$98 000 obtained by Sillano and Ortúzar (2005) in one (of many) of their ML models.

Note that the values obtained for both work and study travel times are within the range of values obtained in other studies in Santiago (e.g. Ortúzar *et al.*, 2000;

Table 4. Parameter estimates (t-statistics)

(Utility units/(minute/week))				(Utility units/(emergency day/year))		(Utility units/(1000 Ch$/month))	
β^{L}_{Tw}	β^{H}_{Tw}	β^{L}_{Te}	β^{H}_{Te}	β^{L}_{AP}	β^{H}_{AP}	β^{L}_{Arr}	β^{H}_{Arr}
–0.00265 (–4.3)	–0.00356 (–9.1)	–0.00255 (–4.4)	–0.00161 (–3.2)	–0.19047 (–4.1)	–0.26477 (–8.7)	–0.02864 (–5.1)	–0.02556 (–9.8)
$L = -822.058$							
$\rho^2 = 0.18$							
$N = 648$							

Table 5. Subjective values by income segment (*t*-statistics)

Travel time to work (Ch$/min)		Travel time to study (Ch$/min)		Air pollution (Ch$/annual emergency day)	
L	H	L	H	L	H
23	35	22	16	79 810	124 235
(3.5)	(7.1)	(3.6)	(3.2)	(3.2)	(6.5)

Jara-Díaz *et al.*, 1988; Guevara, 2000), who estimated values between Ch$8/min and Ch$69/min for travel to work and between Ch$10/min and Ch$50/min for travel to study.

Application of the Social Valuation Method

As explained above, to obtain a social value for air pollution, it is necessary to calculate a social utility of money λ_s, which depends on the marginal utilities of income and on the marginal tax proportions paid by each segment, as shown in equation (7). However, proper calculation of λ_s requires estimates of values for the marginal utilities of income for all the population. This is a major task that would require a national concerted effort from researchers and planners; the specific way to obtain such values is presently under design. However, note that income distribution is quite skewed in Chile, as the income ratio between the richest 20% and the poorest 20% is about 15:1. This should make λ_s closer to the λ of the high-income segments. The present paper will use the estimated values of the marginal utilities of income obtained above in order to make the calculations, which unfortunately are not that different. Note that this estimate of λ_s can only be used in conjunction with the air pollution parameters obtained from the same models, because they involve the same scale parameters; this is exactly what generates the need to design and establish a procedure to obtain a better representation of the social utility of money.

One has to estimate the marginal tax proportions. To do this, Table 6 shows a synthesis of income and tax distribution in Chile by decile (Engel *et al.*, 1998). Note, though, that the tax proportions represent the sum from taxes applied to rent, value added tax (VAT) and property. Tax on income is progressive (increases with income), and the VAT is the same across income groups. However, those with lower income spend all their money buying goods, which implies a marginal contribution approximately equal to the VAT rate. As income increases, the proportion of money spent on services that do not pay VAT increases, such as travel or home personnel. This explains the lower rate for the high-income segments, in spite of their larger income tax on rent.

From the data on average income and the information contained in Table 3 regarding income distribution in the sample, one can associate strata 1–4 (the low income segment, *L*) to deciles 1–8, while strata 5–8 (the high income segment, *H*) are completely contained in deciles 9 and 10:

$$\theta_L = \frac{\mathrm{d}T_L}{\sum_{q\in P} \mathrm{d}T_q} \approx \frac{\sum_{i=1}^{8} \varepsilon_i \phi_i}{\sum_{i=1}^{10} \varepsilon_i \phi_i} \approx 0.484 \quad \textit{and} \; \theta_H = \frac{\mathrm{d}T_H}{\sum_{q\in P} \mathrm{d}T_q} \approx \frac{\sum_{i=9}^{10} \varepsilon_i \phi_i}{\sum_{i=1}^{10} \varepsilon_i \phi_i} \approx 0.516, \tag{16}$$

Table 6. Income and tax distribution in Chile

Decile	Average monthly income (Ch$)*$10^3$	Income as percentage of gross national product (ϕ_i)	Tax as a percentage of income (ε_i)
1	16.5	1.45	14.4
2	32.5	2.74	16.0
3	45.5	3.77	15.8
4	59.5	4.73	15.2
5	75.5	5.57	15.0
6	96.5	6.76	14.3
7	124.5	8.22	13.8
8	170.5	10.60	13.1
9	256.0	15.42	12.2
10	728.5	40.75	11.8

Source: elaborated from Engel *et al.* (1998).

such that λ_s can be calculated as:

$$\lambda_s = 0.484\beta_{Arr}^{L} + 0.516\beta_{Arr}^{H}. \tag{17}$$

This yields λ_s = 0.0271. From this and the quality parameters in Table 5, the social values for all attributes can be calculated. These are presented in Table 7.

Note that the social values obtained for air pollution come from models that yield subjective values that are intuitively reasonable for all attributes. The subjective values for air pollution can be compared with those obtained by Wardman and Bristow (2004) and Hunt *et al.* (1995). If one uses the statistically significant parameters in the first paper, one obtains figures that range from Ch$121/(μg/m^3) to Ch$188/(μg/m^3) per week. To compare these values with those from Table 6, note that an emergency day means roughly 200 μg/m^3 and that a year has 52 weeks, which yields 7.7–11.9 Ch$/(μg/m^3) per week, which is much smaller than Wardman and Bristow's estimate. This could be due to a larger marginal utility of income and/or a smaller perception of the environmental pollution measure. However, from the information provided by Hunt *et al.* (1995), their estimated willingness to pay for the reduction of a day with bad air quality in the context of residential location was roughly Ch$30 555, which is between 25 and 38% of the values found herein. Thus, the subjective values that feed the social value obtained here are contained within the very wide range of previously obtained values in the literature. Furthermore, the social values of travel times are comparable with the social value for interurban travel obtained by Jara-Díaz *et al.* (2000): 25 Ch$/min.

Table 7. Social values

			Air pollution (Ch$/ emergency day)		Travel time to work (Ch$/min)		Travel time to study (Ch$/min)	
θ_L	θ_H	λ_s	L	H	L	H	L	H
0.484	0.516	0.02705	84 485 (3.7)	117 409 (6.5)	25 (4.1)	35 (6.8)	21 (4.2)	22 (3.1)

The social values for air pollution are different, but not substantially so, from the private values. The reason is the relatively low difference in the marginal utilities of income in the sample, which were used to feed the calculation of λ_s. Note, however, that the marginal utilities do differ between income segments. Therefore, once the social utility of money can be calculated more rigorously, differences will show up neatly. Nevertheless, the approach is different and helps advance the discussion on which is the right direction to continue this research.

Synthesis and Final Comments

The paper has presented and applied an approach to calculate social values for the reduction of air pollution. The approach is based upon two main elements: first, the formulation of the variation of social utility, expressed as a weighted sum of individual benefits; and second, the transformation of social utility into money units by means of a social utility of money. With these elements, it has been argued that the ratio between the marginal (dis)utility of air pollution and the social utility of money can be defined as a social value of this externality. This pioneering result is particularly attractive as it combines individual perceptions with a collective welfare framework, and potentially yields different values if different groups have different marginal disutilities, as is the case here. The approach also shows that using willingness-to-pay (private or subjective values) for social appraisal of projects involving changes in air pollution hides implicit social weights that favour high-income individuals. Nevertheless, all the methodological advances in the estimation of models that permit the calculation of these private values are quite useful to provide the inputs needed to calculate the social values.

To evaluate the marginal disutilities of air pollution in Santiago, a SP exercise was conducted within the context of a residential location choice, where individuals perceive directly the effects of air pollution as it affects quality of life. Following previous experiences reported in the literature, the frequency of low air quality was used as the attribute to represent this externality, as the inhabitants of Santiago know well the meaning of the measures used by the environmental agency to describe a day with bad air quality. Rent and travel times to work and study were used as well in the SP experiment.

Both the social and private values obtained are statistically significant, and the subjective values for travel to work and study fall within the range of values previously obtained. Two social values for air pollution were obtained as the marginal utilities happened to be quite different between low- and high-income groups. These figures are equivalent to Ch$159 and 232 per emergency day in a year for the low- and high-income groups, respectively. As this is a novel approach to define social values, it is inappropriate to make comparisons with previous figures. However, the subjective values that feed this result fall within the very wide range of measures obtained from the scarce literature on the subject. It would be interesting to determine if these figures represent only the value of avoiding health damage, or if they also include the perception of a nicer environment. This could be done in the future if the appropriate variables are identified within a given context.

One of the main challenges that lie ahead is to design and apply a procedure to estimate what has been called here the social utility of money, which is an essential component for the calculation of unbiased social values of air pollution. This will require the close collaboration of research and planning institutions, and the interaction of researchers coming from different backgrounds.

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Notes

1. Other forms are present in the literature, though, as the Life Quality Index (Pandey and Nathwany, 2003) or cost-effective approaches (Farrow *et al.*, 2005).
2. Note that this approach can also be applied to a privately financed project, where each individual contributes with a payment equal to his/her money gains dB_q. In this case, replacing dT_q by dB_q in equation (7) and plugging the result in equation (4) yields $dB = \Sigma dB_q$. This confirms that the approach is general and the social nature of equation (4) rests upon the way in which λ_s reflects a socially funded project.
3. US$1 = 506 Chilean pesos (Ch$) at the time of the survey.
4. Although taste variation is presumably captured through the estimation of the mean and variance of each parameter in utility, a large value of the latter implies that many individuals can present 'wrong' signs, e.g. negative values for the marginal utility of income, which is what happened in the present case. However, see Sillano and Ortúzar (2005), who also discuss this point using these data. Thus, statistical fit would sacrifice the underlying theory. Although imposing specific distributions might solve this problem, other shortcomings make this a still unresolved issue (Hensher and Greene, 2003). This is why these results were not used.

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