Valuing Environmental Factors in Cost-Benefit Analysis Using Data Envelopment Analysis

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Summary

Environmental cost-benefit analysis (ECBA) refers to social evaluation of investment projects and policies that involve significant environmental impacts. Valuation of the environmental impacts in monetary terms forms one of the critical steps in ECBA. We propose a new approach for environmental valuation within ECBA framework that is based on data envelopment analysis (DEA) and does not demand any price estimation for environmental impacts using traditional revealed or stated preference methods. We show that DEA can be modified to the context of CBA by using absolute shadow prices instead of traditionally used relative prices. We also discuss how the approach can be used for sensitive analysis which is an important part of ECBA. We illustrate the application of the DEA approach to ECBA by means of a hypothetical numerical example where a household considers investment to a new sport utility vehicle.

Keywords: Cost-Benefit Analysis, Data Envelopment Analysis, Eco-Efficiency, Environmental Valuation, Environmental Performance, Performance Measurement

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1. Introduction

While goods and services exchanged in the market place have readily observable measures of their value, the market price, many environmental goods and services such as clean air and water resources are generally not valued at all. The absence of markets for environmental services is one of the prime examples of the market failure. It is well known that the lack of economic value for environmental goods generally leads to over-exploitation and degradation of these resources. Therefore, economic valuation of the environment and its services is one of the most fundamental topics in ecological and environmental economics (e.g. Cropper and Oates, 1992; Bingham et al., 1995, Costanza et al., 1997).

Standard valuation methods of environmental economics can be classified into two main categories: the *stated preference* (SP) methods and the *revealed preference* (RP) methods.[1] The first category includes techniques such as Contingent Valuation Method (CVM) that inquires people directly about their willingness to pay for environmental goods or willingness to accept compensation for reduction in environmental quality, asking the respondents to describe their behavior in a hypothetical situation. While there are many different strategies to encourage the respondents to state their preferences, all approaches of this category rely on their subjective valuation of the environmental issue at hand.[2] The second category rejects the idea of asking individuals' opinions, and instead, tries to infer their willingness to pay indirectly based on the observed behavior. Notable examples of the revealed preference approaches include Travel Cost Method (TVM) and the hedonic pricing method. While the revealed preference techniques stand on a more objective ground, their scope of environmental valuation tends to be more limited. The

[1] For a textbook presentation of these methods in environmental valuation, see e.g. Freeman (1993) and Perman et al. (2003).

[2] Other stated preference methods include conjoint analysis and contingent behavior. For empirical comparison of different stated preferences methods, see e.g. Mackenzie (1993) and Boxall et al. (1996).

revealed preference approaches can be applied in situations where people already pay for an environmental good or service in one way or another, and this payment can be directly observed and associated with the use of that particular good or service.

Environmental Cost-Benefit Analysis (ECBA) is one important area where valuation techniques have been used. ECBA refers to social evaluation of investment projects and policies that involve significant environmental impacts. ECBA is widely applied by national environmental protection agencies and in many countries the legislation requires ECBA to be implemented for all public projects and policies that have significant environmental impacts.[3] Yet, many economists and ecologists have pointed out numerous problems, challenges and concerns associated with ECBA (see e.g. Dorfman, 1996; Heinzerling and Ackerman, 2002; Ackerman and Heinzerling, 2004).

The economic valuation of the environmental impacts is clearly one of the most heavily debated stage of ECBA due to the deficiencies and problems of different valuation techniques.[4] First of all, as RP techniques are based on observed data from past individual behavior and cannot be employed for evaluating environmental non-use (or existence) values such as preserving an endangered species, their potential in ECBA has been more limited. Indeed, SP methods have been more typically used for environmental valuation in ECBA. On the other hand, the SP methods have also been heavily criticized because of their hypothetical character; according to many critics, the price estimates given by these methods are just hypothetical and do not represent actual willingness to pay (see e.g. Kahneman and Knetsch, 1992; Rosenthal and Nelson, 1992; Hausman, 1993; Diamond and Hausman, 1994; Cummings et al., 1995). Many critics reject CVM

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[3] For example, in U.S. Executive Order 13258 requires mandatory environmental cost-benefit analysis for large-scale government projects.
[4] See e.g. the lively debate by Frank Ackermann, Kerry Smith and Lisa Heinzerling in *American Prospect* (May 12, 2004), http://www.prospect.org/web/page.ww?section=root&name=ViewWeb&articleId=7696.

as a valuation method because in their view the results of CVM studies are inconsistent with the economic theory and do not measure individual's underlying preferences (see e.g. Hausman, 1993). Despite this important critique presented by both economists and ecologists, CVM and other SP methods are extensively used in ECBA, because in many applications there are no alternative methods (see Whitehead and Blomquist, 2006).

This paper proposes a new alternative approach for environmental valuation within ECBA framework that is based on Data Envelopment Analysis (DEA). In addition to its traditional confinements in productivity and efficiency analysis, DEA is frequently applied in many other areas of applied economic sciences, including agricultural economics, development economics, financial economics, public economics, and macroeconomic policy, among others. In the fields of ecological and environmental economics, DEA has been earlier used for environmental performance and eco-efficiency analysis (see e.g. Färe et al., 1996; Kortelainen and Kuosmanen, 2005; Kuosmanen and Kortelainen, 2005). This paper intends to show that DEA can also be a very useful tool for ECBA.

In its purest form the unique valuation principle of DEA does not depend on either stated or revealed preferences. Rather, it turns the value problem other way around, and asks what kind of prices would favor this or that particular project or policy alternative. In some situations, DEA can provide a clear-cut solution for the ECBA valuation problem without a need to invest in costly RP or SP studies. Even if such clear-cut solution does not arise, a preliminary DEA assessment can help to structure the problem as well as identify the critical parameters that need to be estimated by other methods, which can save a considerable amount of time and money when the more demanding RP or SP evaluation studies are implemented.

Relying on the implicit preferences of the project proponents revealed by the observed environmental profiles of the projects, DEA does share some common intellectual roots with the revealed preference valuation approaches. Thus, the basic DEA approach is likely to appeal those who generally prefer the RP approach to SP methods. However, in contrast to the traditional RP techniques, the DEA approach proposed in the paper does not require historical, observed data, but can equally well be used for evaluating future projects, policies or investments. On the other hand, the DEA framework is technically closely related with the Multi-Criteria Analysis (MCA), which is often mentioned as a "softer" alternative for the more traditional economic techniques. Like MCA, DEA approaches the valuation problem from a multi-dimensional perspective, and can be applied in combination of MCA or other valuation techniques that incorporate subjective judgments and stated preference information to the objective DEA assessment. Thus, DEA offers a flexible and general framework that can easily be adapted to the specific features and purposes of the ECBA study.

The practical application of DEA in the ECBA framework presents two major challenges.[5] First, the purposes of the traditional DEA and ECBA are very different. The traditional DEA is geared towards comparative performance assessment of comparable production units performing similar tasks or function. By contrast, the purpose of environmental CBA is to identify one socially optimal project (or a basket of projects) to be implemented from a set of available alternatives. Second, the concept of price is different in DEA and ECBA. The traditional DEA applies shadow price multipliers that have only a meaning as a relative price, and thus cannot be anchored in some currency unit (such as dollar or euro). By contrast, the absolute prices expressed in a given currency are necessary for ECBA in order to determine whether any of the alternative projects is profitable enough to be implemented.

[5] Färe and Primont (1995) and Womer et al. (2006) have earlier suggested the use of DEA in the cost-benefit analysis. These studies focused on other aspects of CBA and did not pay particular attention on the valuation of the environmental impacts, which forms the main topic of this paper. The adjustments we propose to the standard DEA are novel contributions of our paper.

The main contribution of this paper is to show that these two rather fundamental differences can be reconciled by adjusting DEA for the use as a valuation tool for the ECBA framework. Further, because sensitivity analysis is also an important part of ECBA, we describe how DEA approach can provide useful information for that purpose. We also illustrate the application of the DEA approach to ECBA by means of a hypothetical numerical example related to a household's investment to a new sport utility vehicle (SUV).

The rest of the paper is organized as follows. In Section 2 we present shortly different stages of environmental cost-benefit analysis (ECBA). Section 3 outlines our methodology for using DEA to ECBA. Section 4 provides further insight by presenting the dual interpretation for our model. Section 5 discusses how DEA approach can be extended to sensitivity analysis. In Section 6 we illustrate the proposed methodology by means of numerical example concerning investment to a new sport utility vehicle. Finally, Section 6 presents some concluding remarks.

2. Environmental Cost Benefit Analysis (ECBA)

Environmental Cost-Benefit Analysis (ECBA) typically concerns social evaluation of investment projects or policies that involve significant environmental impacts, for example, construction of a new highway. Depending on the timing of the analysis relative to implementation of project or policy, two different types of studies can be separated (Whitehead and Blomquist, 2006). *Ex ante* cost-benefit analysis is conducted before any project or policy is implemented to find optimal alternative, whereas *ex post* cost-benefit analysis is conducted after the implementation of the project or policy to examine realized net benefits. In this paper, we focus on the more common *ex ante* analysis, where the purpose is to find the optimal project to be implemented in the future.

Typical ECBA consists of multiple stages, which usually include:

1) *Problem definition* (i.e., what are the objectives, what are the alternatives, whose welfare is considered, and over what time period),

2) *Identification of the physical impacts of each project* (i.e., environmental impact analysis),

3) *Valuation of the impacts*,

4) *Discounting of cost and benefit flows*,

5) *Selection of the project to be implemented based on the net present value test*, and

6) *Sensitivity analysis* (i.e., is the result robust to small changes in parameter values).

Typically, the policy or decision makers are responsible for the first stage of the analysis, whereas second stage is conducted by experts in ecology, geology, medicine, and other relevant sciences (Whitehead and Blomquist, 2006). Although economists can assist in these first two stages, their primary function is usually in stages 3)-6). As discussed in the introduction, especially the monetary valuation of environmental impacts in stage 3) is critical for the reliability and success of the whole ECBA study. However, also sensitivity analysis (i.e. stage 6)) should have very important role in any empirical cost-benefit analysis study, as in that phase one can typically account for the effect of changing certain assumptions.

The main focus of this paper will be on the valuation stage 3), which is usually seen as the most critical and difficult part of the analysis. We also consider stages 4)-6) as they are closely connected with the valuation stage, but to keep the presentation compact, we abstract from the first two stages. For general and detailed presentations of different stages and underlying economic theory behind cost-benefit analysis, we refer to the excellent books by Dasgupta and Pearce (1985), Johansson (1993) and Boardman et al. (2001).

3. DEA Approach to ECBA

Assume the stages 1) and 2) have been completed: the problem has been clearly defined and the economic costs and benefits of each project have been estimated. Let the net economic benefit of project n in time period t be denoted by B_{nt}. The net benefit is the difference of economic revenues and costs; it has a positive value in the periods where the total revenue exceeds the total cost, and a negative value when the costs exceed revenues. Suppose further that there are M relevant environmental impacts that need to be considered. We will assume that the physical environmental impacts can be unambiguously quantified and the impacts of project n in period t can be numerically represented by vector $\mathbf{Z}_{nt} = (Z_{1nt} \ldots Z_{Mnt})'$.

Before proceeding, the meaning of "environmental impact" is worth elaborating. By impact we here refer both to direct impacts do to the project (for example, loss of forest land due to highway, extinction of certain species) as well as pressures that contribute indirectly and over longer time scale to environmental problems (for example, emission of green house gases, depletion of natural resources). By impact we also refer to broader environmental themes such as acidification, not to specific substances that cause it. In the case of acidification, for example, the different emissions (e.g. nitrogen oxides, sulphur dioxide) should be first converted to acid equivalents and then summed together to get an overall measure for the acidification pressure due to the project. Some harmful substances may contribute to several impacts, for example, carbon monoxide from traffic has direct health effects in humans and it also contributes to the climate change in the atmosphere.

We denote the unknown prices for the environmental impacts by $\mathbf{p} = (p_1 \ldots p_M)$. How to estimate these prices has been one of the key issues in environmental economics, and constitutes the stage 3) of the usual CBA routine. We here deviate from the conventional approaches in that we do not try to "parameterize" the prices based on stated or revealed preference information, but rather treat the prices as unknown model variables. Therefore, we next proceed to stage 4) and postpone the determination of prices **p** after that stage. That is, in our approach the order of stages 3) and 4) is reversed compared to the traditional ECBA.

Usually the economic benefits and environmental impacts vary over time. Discounting the costs and benefits that occur over time, to express them in net present value terms, is important because most project have considerable economic set-up costs while the benefits and the environmental impacts accumulate over a longer period. For example, a lump sum payment of one million dollar today is worth more than a million dollars of benefits accumulating over the next ten years due to the opportunity cost of the foregone interest revenue. Discounting forms the step 4) of the usual CBA routine.

Denoting the discount rate by *r*, the net present value of the economic benefits of project *n* can be expressed as

$$NPV(B_n) = \sum_{t=0}^{\infty} (1+r)^{-t} B_{nt} \ . \tag{1}$$

Similarly, the net present value of the environmental costs of project *n* can be calculated as

$$NPV(C_n) = \sum_{t=0}^{\infty} \sum_{m=1}^{M} (1+r)^{-t} p_m Z_{nmt} \ . \tag{2}$$

If the prices of the environmental impacts (**p**) are constant over time (as we assume here), then we may first discount the impacts and make the conversion to economic costs later. Observe that we can write the identity (2) as

$$NPV(C_n) = \sum_{m=1}^{M} p_m \left(\sum_{t=0}^{\infty} (1+r)^{-t} Z_{nmt} \right). \tag{3}$$

The sum expressed in the parentheses is the discounted total environmental impact *m* for project *n*. Although we discount the physical impacts, the environmental impacts of the future are considered to be equally valuable as environmental impacts of today: we do not assume any time preference for the environmental impacts. The rationale for the discounting lies in the necessity to discount the monetary costs due to the opportunity cost of the foregone interest. As equation (3) shows, discounting costs or impacts yields the same net present value when the price vector **p** is constant over time. For consistency, the same discount rate r should be applied in discounting of both economic benefits and environmental impacts.

The discounting stage 4) provides us with the discounted total environmental impacts denoted by Z_{nm} (the time index t is eliminated). Similarly, we use B_n for the total (discounted) net present value of the net economic benefits. If B_n has a negative value, then project n does not make economic sense even if we disregard the environmental impacts. Such projects can be safely discarded at this stage. All remaining candidate projects are assumed to yield a strictly positive net economic benefit.

The net social benefit of project n (SB_n) is the monetary benefit that is left after subtracting the cost of environmental impacts from the net economic benefits (both expressed in terms of the net present value). Formally, SB_n can be expressed as

$$SB_n = B_n - \sum_{m=1}^{M} p_m Z_{nm} \,. \tag{4}$$

In stage 5) we need to identify the project that offers the highest net social benefit. Now the price variables **p** must be determined. In the present context it is illustrative to view the DEA method from the game-theoretic perspective. Suppose we evaluate project k, whose proponents exhibit strongly opportunistic, strategic behavior. Suppose further that the project proponents can order a bogus valuation study where they can manipulate the price estimates $\hat{\mathbf{p}}$ (which may differ from the true prices **p**) to show the project k in the best possible light (e.g. by paying bribes for the respondents). How would such aggressively opportunistic project proponents valuate the environmental impacts? What is the maximum competitive advantage that the proponents of project k can demonstrate over competing projects if they could choose the prices $\hat{\mathbf{p}}$ at will?

These questions are worth asking even though the may appear cynical. The answers to these questions can guide us to more objective policy recommendations in the sense that subjective valuation of prices $\hat{\mathbf{p}}$ is not required. After all, if the most aggressively opportunistic project proponents cannot demonstrate their project to offer the social optimum, then nobody can. If the proponents successfully demonstrate the benefits, we can objectively identify a range of prices under which project k could be the socially optimal choice.

The problem of the opportunistic project proponent can be addressed in a DEA-type framework. Specifically, we calculate the maximum *competitive advantage* of project k (CA_k) that the proponents of this project can demonstrate over the competing projects if they can choose non-negative prices $\hat{\mathbf{p}}$ subject to the condition that project k must be socially beneficial. Formally, the optimal CA_k^* are obtained as the optimal solution to the following linear programming problem:

$$\begin{aligned}
&\max_{\hat{\mathbf{p}}} CA_k \\
&CA_k \leq \left[B_k - \sum_{m=1}^{M} \hat{p}_m Z_{km} \right] - \left[B_i - \sum_{m=1}^{M} \hat{p}_m Z_{im} \right] \; \forall i = 1,\dots,N \\
&B_k - \sum_{m=1}^{M} \hat{p}_m Z_{km} \geq 0 \\
&\hat{\mathbf{p}} \geq \mathbf{0}
\end{aligned} \tag{5}$$

The “estimated” prices $\hat{\mathbf{p}}$ are the unknown variables and the net economic benefit B and the environmental impacts $\mathbf{Z}$ are known parameters of the linear programming problem (5). The first constraint compares in the pair-wise fashion the net benefits of project k relative to all competing projects. Because only one of the competing projects is chosen, the competitive advantage CA that is maximized in the objective function depends on how well project *k* performs relative to its best competitor. Thus, only the smallest value of the net benefit differences counts. To qualify as the socially optimal choice, the net benefit of project *k* must be greater than (or equal to) zero. The second constraint ensures that net benefit is non-negative at the estimated prices. Since the project that yield a negative economic net benefit (i.e., B_n <0) were already discarded after stage 4), problem (5) is feasible and has a finite maximum.

The optimal solution CA_k^* to problem (5) can be a negative number or zero. This implies that there *does not exist* any non-negative prices $\hat{\mathbf{p}}$ at which project *k* could yield the highest social net benefit. Whatever prices one uses for the environmental impacts, there is another project that yields a higher social net benefit. Therefore, projects with negative score in (5) can be discarded as "inefficient" alternatives.

If the optimal solution CA_k^* is a positive number, then there *does exist* a vector of non-negative prices $\hat{\mathbf{p}}$ at which project *k* proves to be socially optimal. In this case, project *k* is potentially an attractive investment project, so we diagnose it as "efficient". The optimal solution CA_k^* indicates the maximum monetary net benefit that this project can offer over the second best candidate (prices $\hat{\mathbf{p}}^*$ maximize this competitive advantage). If CA_k^* is large, then project *k* can present itself as a superior candidate at least at some prices. If CA_k^* is small, then project *k* can provide, even at best, only a modest advantage over the competing candidates.

In conclusion, the competitive advantage score CA_k^* provides an objective benchmark that can be used for eliminating inefficient alternatives ($CA_k^* < 0$) without assigning any a priori weights or prices for the environmental impacts. Among the efficient alternatives ($CA_k^* > 0$), the CA_k^* score measures the maximum benefit the evaluated project can yield relative to the second best alternative.

However, the *CA* scores are not the only information to consider in the ranking the projects. In general, it is more important to assess if the prices **p** are realistic or not. This forms the topic of the next section.

4. Dual interpretation

Above we noted that problem (5) resembles the usual DEA models, but presents some novel features. The purpose of this section is to elaborate on the similarities and differences between our ECBA model and the standard DEA. This section is intended for readers who are familiar with the conventional DEA; others may skip or browse through this section.

Duality theory of linear programming implies that every maximization problem can be equivalently expressed as a minimization problem. Hence, it is illustrative to derive the dual problem for (5). The dual problem can be expressed as

$$
\begin{aligned}
&\min_{\lambda,\alpha,\theta} CA_k \\
&\alpha B_k - CA_k \le \sum_{i=1}^{N} \lambda_i B_i \\
&\alpha Z_{km} \ge \sum_{i=1}^{N} \lambda_i Z_{im} \;\; \forall m = 1,\ldots,M \\
&\sum_{i=1}^{N} \lambda_i = 1 \\
&\lambda_i \ge 0 \;\; \forall i = 1,\ldots,N \\
&\alpha \ge 1
\end{aligned}
\tag{6}
$$

where variables λ_i represents the intensity weight assigned for project *i*, and $\alpha \ge 1$ is a scaling factor assigned for the evaluated project. One can prove that problems (5) and (6) always yield the same solution.

It is illustrative to compare the dual formulation (6) with the standard envelopment side formulation of the output-oriented variable returns to scale DEA model (Banker et al., 1984). The similarities become apparent if we interpret the economic net benefit (*B*) as an output and the environmental impacts (*Z*) as inputs. Technically, problem (6) differs from the standard DEA formulations in two notable respects. First, the efficiency score is expressed in absolute terms as an additive measure, while the classic DEA models resort to relative, multiplicative measures.[6] Second, the data of the evaluated project are multiplied by the scaling factor α, which enables upward scaling of the evaluated project. This scaling factor emerges as the shadow price of the non-negativity constraint for the NPV of the evaluated project introduced in problem (5). As far as the reference technology is concerned, an upward scaling of the evaluated project is equivalent to a downward scaling of the intensity weights $\boldsymbol{\lambda}$. Therefore, an efficient project must lie on the boundary of the non-increasing returns to scale (NIRS) reference frontier. However, the scaling also influences the efficiency measure. Thus, problem (6) is not a special case of the output-oriented NIRS DEA model.

It is also worth noting that the present ECBA formulations are technically similar to the eco-efficiency measures proposed by Kortelainen and Kuosmanen (2005), which also utilize a similar absolute scale efficiency measures. The key differences to that paper is that we here assess efficiency of projects in terms of the discounted NPV of economic benefits over the entire use life, whereas Kortelainen and Kuosmanen (2005) measure eco-efficiency of consumer durables in terms of economic cost per single use or performance.

5. DEA as a Tool for Sensitivity Analysis

In practice, there may exist several candidate projects that can demonstrate a positive *CA* score. In any case, all projects become unprofitable at some point when prices $\hat{\mathbf{p}}$ are set sufficiently high.

[6] Of course, additive efficiency measures have been extensively used in the DEA literature before (e.g. the slack based Pareto-Koopmans measures and the directional distance functions), but the present interpretation of the efficiency index as an absolute inefficiency loss with the units of measurement (currency) is new.

To make the final choice of which project –if any- will be implemented, our DEA framework offers a platform for a number of alternative approaches.

The first approach is to impose domain restrictions on the admissible prices $\hat{\mathbf{p}}$, as in the weigh-restricted DEA approaches (see e.g. Allen et al., 1997; Pedraja-Chaparro et al., 1997, for reviews). In problem (5) we only postulated that prices should be somewhere between zero and plus infinity. It is often possible to narrow down this interval to a more specific range on objective or subjective grounds. Typically, specifying a certain range for the admissible price is considerably easier than finding a specific point estimate. If the lower bound for the price of impact m is L_m and the upper bound is U_m, we can simply insert in (5) an additional linear constraint:

$$L_m \leq \hat{p}_m \leq U_m. \qquad (7)$$

As these price constraints can account for either individuals' or decision maker's subjective valuation, this approach can be called *value judgement sensitivity analysis* (e.g. Nash et al., 1975). To determine price ranges, we could, for example, use stated-preference techniques such as CVM to get a distribution of subjective price estimates, and restrict shadow prices to lie within a certain confidence interval (e.g., 95% or 99%) obtained from the subjective valuations. Alternatively, we could estimate lower and upper bounds by utilizing stated opinions of expert group in the same way as in Cherchye et al. (2006). Regardless of how price constraints have been estimated or determined, they can be very useful in finding the optimal project to be implemented. Note that when the price ranges are gradually narrowed down, at some point one of the projects will emerge as the only project that can show a positive *CA* score.

The second approach is to directly present the decision-makers the entire range of prices at which a given project is the socially optimal choice. Presenting such objective price ranges would enable the decision-makers to weigh the potential competitive advantages of the projects against the robustness regarding the choice of prices (see Kuosmanen and Kortelainen, 2004, for more details). However, identifying and presenting the supporting price domains can become technically demanding especially when there are multiple environmental impacts.

The third approach is to combine the DEA evaluation with the more traditional valuation techniques. We can check which of the objective price ranges the prices estimated by some other technique(s) fall into. In this sense, DEA can be a supportive tool for sensitivity analysis in the traditional valuation approaches: we can see if a small change in the estimated prices changes the policy recommendation. DEA could also save the costs of the traditional valuation studies. If the DEA analysis is conducted prior to the valuation study, we can differentiate between those environmental impacts that are critically important for the decision and should be evaluated using ore expensive valuation techniques (such as CVM), and those impacts which are unimportant for the decision.

6. Numerical example

This section illustrates the application of the DEA based CBA by means of a hypothetical numerical example that relates to a household's car investment. Although ECBA has been mainly used in the domain of the public sector, it applies equally well to private-sector investments (see e.g. Pearce, 1983). In our view, this example is a useful illustration as it pertains to a familiar situation and does not require much prior knowledge or expertise about the problem at hand.

Consider an environmentally conscious four-person family living in Helsinki, Finland, who is planning to invest to a new sport utility vehicle (SUV). Alternatively, the family can continue using the public transportation and occasionally rent a car for convenience. Thus, we measure the benefits of the SUV by means of the opportunity cost of the transportation functions it provides.[7] For example, instead of using public transportation, one person can drive to work every day, which saves the monthly ticket of value €40.90 every month. Thus, this saved ticket price is calculated as an economic benefit of the SUV. Similarly, instead of using taxi, train and rental cars for going to hobbies and weekend shopping and for holiday trips, the family can drive in their new SUV. The expenses thus saved are counted as the benefits of the car. We also explicitly accounted for the prestige value of owning a SUV. The larger vehicles look generally more impressive, and are considered safer than the smaller ones. Thus, we estimated the prestige value of a vehicle based on the car weight, using the monetary value of €7 per kg. Finally, the used car can be sold at second-hand market in the end of the usage period (8 years assumed).[8]

Table 1 describes the economic benefits and costs as well as the environmental impacts considered in the example. All benefits and costs are calculated on monthly basis, and discounted using the discount rate of five percent. Regarding the economic costs, the purchase prices are obtained from the database of the Finnish vehicle administration (AKE). The fuel expenses are calculated monthly based on the mileage and vehicle-specific consumption data, assuming the fuel prices 1.35 Euro per liter for gasoline and 1.04 Euro per liter for diesel (the prevailing price level in Finland at the time of analysis). Insurance fees are based on the database of If Ltd. (www.if.fi), a major Nordic insurance company, assuming the driver has no prior bonuses based on driving history. The annual vehicle taxes are the same for all gasoline vehicles, but vary according to the mass for the diesel vehicles. The mandatory annual inspection costs €55 for gasoline vehicles and €66 for the diesel vehicles. The annual service expenses are assumed as

[7] For (theoretical) reasons to use opportunity costs as benefits, see e.g. Boardman et al. (2001).
[8] Owning a car can also save time compared to public transportation, which should be accounted for in the benefits. However, in the urban environment of Helsinki, the time spent in traffic congestion can offset the waiting time of the bus, metro, train, or tram. Moreover, refueling, maintenance, changing tires, and the administrative work related to owning a car also require considerable amount of time. Therefore, in this example the time-saving of owning a car has been considered to be negligible. In any case, the time-saving would bring equal benefits to all models, and thus would not influence the competitive advantage of any model.

€200 per year for all vehicles. New tires are purchased after four years of use, and the cost of changing winter/summer tires every May and October is also included. Finally, a parking fee of €20 per month is assumed for all vehicles.

Table 1: Benefits, costs, and environmental pressures

Economic benefits	**price or opportunity cost**
daily drive to work (20 km)	bus ticket, 1 person (€40.90 per month)
weekend shopping and hobbies	taxi / car rental (€500 per month)
holiday trips (4 per year)	train+taxi, 4 persons (€200 per quartal)
prestige value of owning a SUV	€7 per kg of weight
resale value of the used car (assumed to be 15% of the purchase price)	(varies by model)
Economic costs	**Notes**
purchase price of the vehicle	varies by model
fuel expenses	varies by model
insurance fees	varies by model
taxes	same for gasoline vehicles, for diesel vehicles varies according to the mass
annual inspection fee	same for gasoline/diesel models
annual service	same for all models
tyres	same for all models
parking €20 per month	same for all models
Environmental impacts	**Based on data of**
Climate change	CO_2, CO
Acidification	NO_x
Smog formation	HC
Dispersion of particles	TPM
Noise	measured in the speed of 50 km/h

The environmental impacts are based on the earlier study Kortelainen and Kuosmanen (2005), which included five different environmental pressure categories: climate change, acidification, smog formation, dispersion of particles and noise. The climate change impact is estimated based on the carbon monoxide (CO) and carbon dioxide (CO_2) emissions (grams of CO_2 equivalent), the acidification impact is based on the nitrogen oxides (NO_x) emissions (grams), smog formation is based on the hydrocarbons (HC) (grams), dispersion of particles is based on the total particulate matter (TPM) (in ppm), and the noise level is measured in the speed of 50 km/hour (decibels). We deviate from Kortelainen and Kuosmanen (2005) in that the environmental impacts are here evaluated over the entire use life as total discounted net present impacts.

It is worth noting that the high fuel tax and the higher vehicle tax for diesel engine cars are at least partly motivated by environmental arguments. To avoid double-counting of the environmental costs, we exclude the expenses associated with the fuel tax and the extra vehicle tax for diesel engine cars from the economic costs when calculating the NPV, but imposed an additional constraint in problem (5) that requires that the NPV of the environmental costs must be at least as high as the tax expense of the evaluated vehicle (i.e., $\sum_{m=1}^{M} \hat{p}_m Z_{nm} \geq tax_n$).

Our data set includes 88 different SUV models from 8 different manufacturers (Chevrolet, Hyundai, Jeep, Land Rover, Mitsubishi, Nissan, Suzuki and Toyota). A total of 41 models yield negative economic benefit at the tax free prices and are thus excluded. Of the remaining 47 models, introducing the environmental taxes renders the NPV of 22 models negative. Thus, only 25 models can provide a positive NPV of economic benefits, excluding the environmental costs.

Table 2 presents the results of the DEA model (5) for the 25 models that yield a positive NPV of the economic net benefit. Of these 25 models only two models yield a positive comparative advantage (CA) score: Suzuki Jimny JX 4 WD 3dr and Land Rover Freelander 2.0 Td4 E. The competitive advantage measure €809.05 for the first model indicates the maximum monetary benefit over the second best alternative (which is SUZUKI Jimny JX 4WD 3d ABS), using the most favourable prices for this model. The negative CA values indicate the minimum loss in NPV terms relative to the efficient alternatives. Regarding the prices, Suzuki Jimny can assign positive prices for all environmental impacts, while Land Rover Freelander assigns positive prices for smog and noise. As in the conventional DEA, the shadow prices for the efficient models need not be unique. For the inefficient models, positive values are assigned to those environmental impacts in which the model performs relatively well.

Table 2: Results of the DEA model

Model	Engine	CA* (€)	Climate (€/g)	Acidific. (€/g)	Smog (€/g)	Particles (€/ppmkm)	Noise (€/dBkm)
SUZUKI Jimny JX 4WD 3d	gasoline	809.05	$3.7\cdot10^{-4}$	$1.4\cdot10^{-5}$	$1.4\cdot10^{-5}$	$1.4\cdot10^{-5}$	$1.6\cdot10^{-4}$
LAND ROVER Freelander 2.0 Td4 E	diesel	728.15	0	0	4.00	0	$15\cdot10^{-4}$
LAND ROVER Freelander 2.0 Td4 S	diesel	-728.15	0	0	4.00	0	$15\cdot10^{-4}$
SUZUKI Jimny JX 4WD 3d ABS	gasoline	-809.05	$3.7\cdot10^{-4}$	$1.4\cdot10^{-5}$	$1.4\cdot10^{-5}$	$1.4\cdot10^{-5}$	$1.6\cdot10^{-4}$
LAND ROVER Freelander 2.0 Td4 Sport hardback	diesel	-1546.19	0	0	5.88	0.76	0
LAND ROVER Freelander 2.0 Td4 E A	diesel	-2615.38	0	0	11.71	0.31	0
LAND ROVER Freelander 2.0 Td4 Sport	diesel	-2840.68	0	0	3.74	0	$11.4\cdot10^{-4}$
LAND ROVER Freelander 2.0 Td4 SE	diesel	-3002.49	0	0	3.74	0	$11.1\cdot10^{-4}$
SUZUKI Jimny JLX 4WD 3d ABS	gasoline	-3236.22	$3.7\cdot10^{-4}$	1.4E-05	1.4E-05	$1.4\cdot10^{-5}$	$1.6\cdot10^{-4}$
LAND ROVER Freelander 2.0 Td4 S A	diesel	-3367.58	0	0	11.23	0.17	0
SUZUKI Grand Vitara 1.6 4WD Wide 3d AC.	gasoline	-4471.04	0	0	0	0	$31.7\cdot10^{-4}$
SUZUKI Jimny JLX 4WD 3d ABS Aut.	gasoline	-4803.16	0	0	0	0	$31.1\cdot10^{-4}$
LAND ROVER Freelander 1.8 E hardback	gasoline	-6238.65	0	0	0	17.26	0
SUZUKI Grand Vitara 1.6 4WD Wide 3d AC Aut.	gasoline	-6537.01	0	0	0	17.26	$16.1\cdot10^{-4}$
SUZUKI Grand Vitara 2.0 4WD 5d AC	gasoline	-8215.60	0	0	0	17.26	$12.9\cdot10^{-4}$
LAND ROVER Freelander 1.8 E	gasoline	-8396.13	0	0	0	17.26	0
LAND ROVER Freelander 1.8 S	gasoline	-9124.28	0	0	0	17.26	0
SUZUKI Grand Vitara 2.0 4WD 5d AC Aut.	gasoline	-9220.02	$2.5\cdot10^{-20}$	0	3.64	0	0
HYUNDAI Santa Fe2.0 CRDi VGT GLS 5d A/C	diesel	-11159.95	0	0	3.05	0	0
LAND ROVER Freelander 1.8 SE	gasoline	-11398.62	0	0	0	17.26	0
NISSAN X-TRAIL 2.0 Comfort 4x4	gasoline	-11929.73	0	0	2.82	0	0
HYUNDAI Santa Fe2.4 GLS 5d A/C	gasoline	-12386.28	0	0	0	16.27	0
SUZUKI Grand Vitara 2.0 TDi 4WD 5d AC	diesel	-12776.53	0	0	0	0	$11.2\cdot10^{-4}$
SUZUKI Grand Vitara 2.5 4WD 5d AC	gasoline	-12912.87	0	19.34	0	0	0
LAND ROVER Freelander 1.8 HSE	gasoline	-14622.94	0	0	0	$2.3\cdot10^{-5}$	$11.7\cdot10^{-4}$

The results of Table 2 mean that the rational investment decision boils down to a choice between two efficient SUV models. Table 3 presents the emission data and the NPV of economic benefits for the two remaining models. We note that Suzuki Jimny performs better in terms of the green-house gases, NOX, particles, and the economic benefits. By contrast, Land Rover Freelander is superior in HC, and somewhat better in terms of noise. Thus, the choice between the two top candidates critically depends on the valuation of the HC and noise, as Suzuki Jimny is superior in all other criteria.

Table 3: Discounted emissions of the two top candidate models.

Model	Engine	CO2	NOX (g)	HC (g)	Particles ppmkm	Noise dBkm	NPV
SUZUKI Jimny JX 4WD 3d	gasoline	**$125 \cdot 10^5$**	**432**	3316	**360**	$53.0 \cdot 10^5$	**16912**
LAND ROVER Freelander 2.0 Td4 E	diesel	$147 \cdot 10^5$	31860	**649**	3099	**$51.9 \cdot 10^5$**	4996

Figure 1 presents the price regions for HC and noise at which the top candidates can yield the highest NPV. In this diagram we assign zero prices for CO_2, NOX, and particle emissions, and focus on the prices that could rationalize the choice of Land Rover (compare with the profile of Land Rover Freelander in Table 2). The horizontal axis represents the price of noise (€/dbkm) and the vertical axis represents the price of HC (€/g). The Blue triangle indicates the range of prices at which Land Rover Freelander yields the highest NPV such that NPV is positive. The red area describes the similar price range for Suzuki Jimny. The white area describes the price range at which no investment in SUV achieve a positive NPV and thus we fall back to the public transportation option. This figure indicates that Suzuki Jimny is a very robust choice when the prices of HC and noise are relatively low. Land Rover Freelander can be rationalized only for a relatively small price range where the price of HC is quite high while the price of noise is low. Interestingly, Suzuki Jimny can bear much higher prices for noise than Land Rover Freelander, even though the latter has lower noise. This is because the economic benefits of Suzuki Jimny are higher. For example, at price of 0.003 €/dbkm the costs of noise are €15,894 for Suzuki Jimny and €15,570 for Land Rover Freelander. Subtracting this cost from the economic benefits still leaves Suzuki Jimny a positive value but renders Land Rover Freelander to deficit.

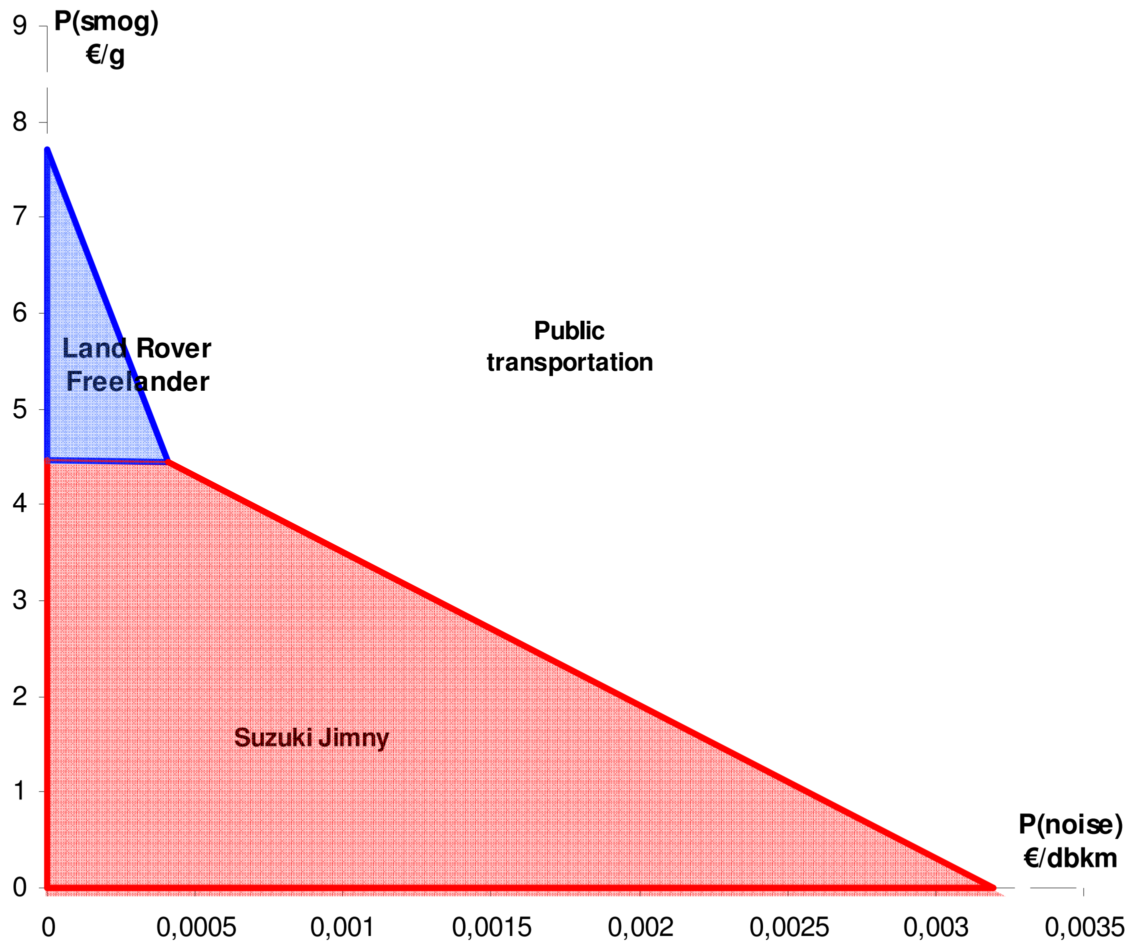

Figure 1: Price regions for HC and noise at which the two top candidates maximize the NPV

Figure 2 presents the similar price regions for climate change and acidification, assigning zero prices for all other environmental impacts. Suzuki Jimny is the only competitive alternative in these performance dimensions, so the purpose of this diagram is to illustrate whether the investment to this model is profitable at all. Figure 2 suggests that the investment can be profitable even if one assigns very high prices for the climate change and acidification. For example, the spot prices for a ton of CO_2 in the EU carbon pool have been less than 30 €/CO_2ton, which stays easily within the critical limits for the SUV investment.

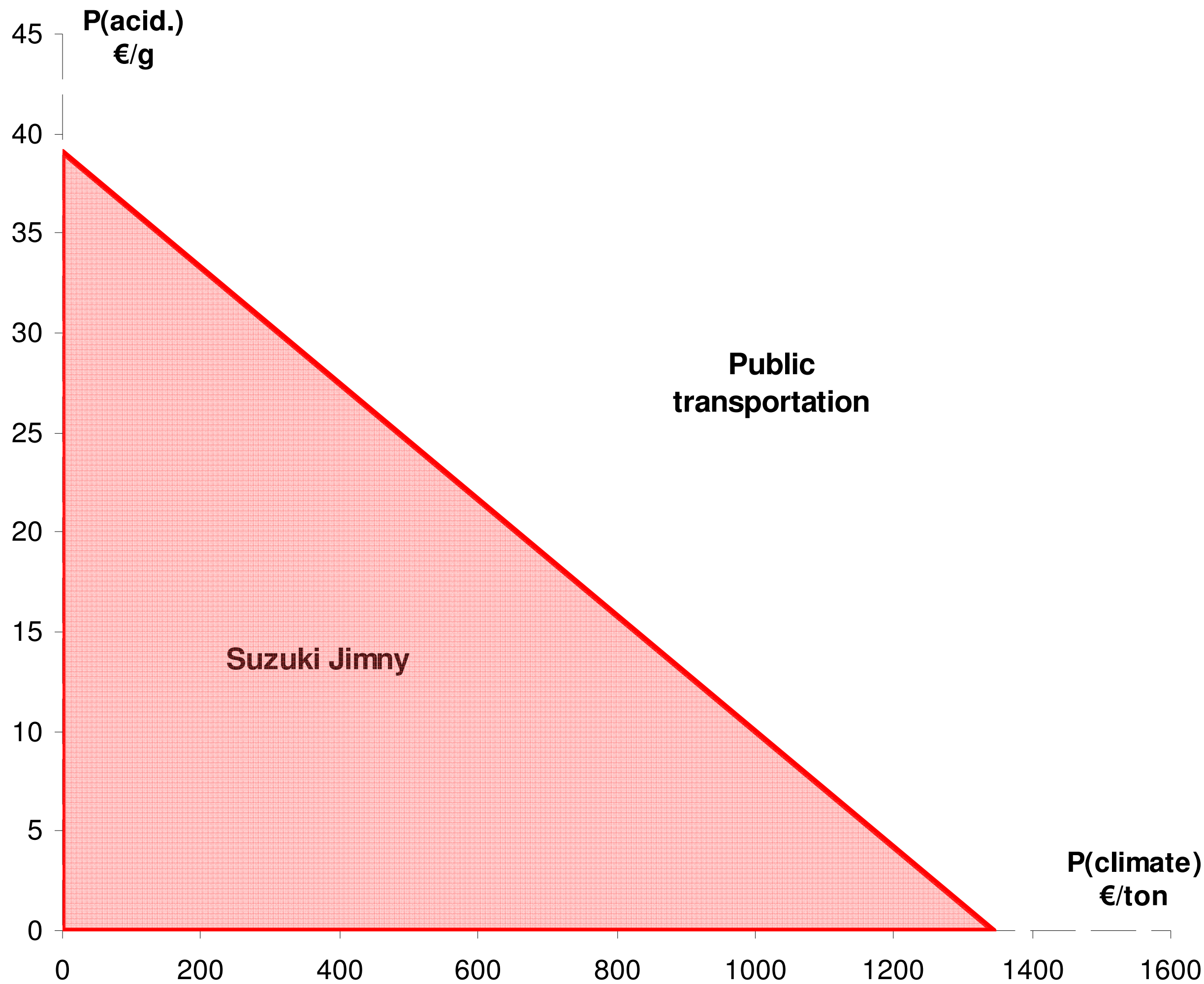

Figure 2: Price regions for HC and noise at which the two top candidates maximize the NPV

In conclusion, the example illustrates with the real-world data how our approach helped to cut down the number of economically rational alternatives from 88 to 2, and identify the more robust of those two. The method also identified the most critical environmental impacts and the critical price regions, which can be useful information when complementary valuation techniques are implemented.

7. Concluding remarks

We have presented a new approach for environmental valuation within ECBA framework that is based on data envelopment analysis (DEA). In contrast to stated preference methods, our approach does not depend on hypothetical price estimates; in our analysis the prices are neither estimated nor given *a priori* but are endogenously determined within our model, like the usual shadow prices in DEA. However, in contrast to traditional DEA, we measure environmental costs in terms of absolute rather than relative shadow prices. Although our approach does not require subjective valuation, it is possible to include value judgments and other stated preference information into model when needed. This is important property, because it enables sensitivity analysis and combination of the DEA evaluation with the more traditional valuation techniques.

To illustrate the potential of this approach we also considered numerical example where an environmentally conscious household considers investment to a new sport utility vehicle. Although this example reveals some important advantages of our approach, a full-scale empirical analysis would yet confirm the reliability of the proposed model. In fact, it would be interesting to compare the results given by our approach to more traditional valuation methods in a full-scale empirical application.

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