A SUSTAINABILITY OBJECTIVE FUNCTION FOR LOCAL TRANSPORT POLICY EVALUATION

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Abstract

The two main objectives of urban transport policy are economic efficiency and sustainability. Economic efficiency is evaluated by Cost Benefit Analysis. But even if accidents and some environmental impacts are included in a CBA, it can never be made to include the main objectives of sustainability. Sustainability implies taking into account the utility of future generations - including generations in the very distant future. This is not compatible with the discounting used in CBA. It also implies that utility is derived from stocks of natural resources, not only from consuming them. Graciela Chichilnisky has shown that under simple and reasonable assumptions, an intertemporal welfare function that is able to reflect sustainability must be a linear combination of two terms. The first term is in fact an ordinary cost benefit analysis, using a discount rate to form a net present value. This term reflects the interest of present generations. The second term is the undiscounted yearly welfare in a future sustainable state. In the OPTIMA project, a simplified version of the Chichilnisky criterion has been employed to assess the sustainability of urban transport policies in nine European cities.

INTRODUCTION

More and more people are beginning to realize that the transport system of our cities is unsustainable in the long run. This increased awareness of sustainability issues is reflected in the transport plans of many cities. In the OPTIMA project[i], we conducted a brief survey of the transport policy objectives of the 9 European cities studied. In most cases, the objectives were laid down in transport plans approved in recent years. We found that objectives that obviously reflected concerns about the sustainability of the transport system made up a prominent part of all objectives in these plans (Minken 1997). Typically, these objectives were cast in terms like

- increase public transport's modal share,
- reduce the growth of private car travel,
- reduce energy consumption in the transport system or CO_2 emissions from it,
- keep the city structure dense,
- reduce overall levels of motorized transport within the city,
- improve conditions for pedestrians and cyclists, and
- reduce accidents and local pollution.

Except for reductions in accidents and local pollution, such objectives are not reflected in ordinary cost benefit analyses. This is why concerns about sustainability often goes hand in hand with rejection of traditional formal evaluation methods.

In OPTIMA, local transport models were used in each city to predict the outcomes of 18 "initial" urban transport strategies, including a "do minimum" strategy, for some target year (typically 2010 or 2015). One of our tasks was then to use a heuristic optimization procedure to find an *optimal* strategy with regard to sustainability, using these initial runs of the model and further runs as required. This task required formal evaluation of the sustainability of strategies. It would not do to just record the levels of a set of indicators reflecting the different sustainability-related objectives in the transport plans, and then pass informal judgment on which of the initial strategies that was the best, and perhaps try to guess how it could be improved. To optimize, we needed a *sustainability objective function*, perhaps together with some constraints that reflected the scarcity of non-renewable resources and some minimum requirements on the transport system.

Obviously, our sustainability objective function might be cast as a multicriteria objective function, using subjective weights to add together indicators of all or some of the objectives listed above. However, after having optimized such an objective function, we would not be able to explain to anybody what it was that had been optimized, and why we called the result an optimal strategy with regard to sustainability. We would not even know if the result was sustainable! The reason is that most of the listed objectives are not ends in themselves, but seem to be means to achieve a single more fundamental end. Discarding the multicriteria approach, the only option left was to define as clearly as possible what we actually meant by the concept of sustainability, and to work out an objective function that reflected directly the key characteristics of that very concept.

In defining sustainability and setting out the objective function, we drew heavily on the works of Graciela Chichilnisky (1993, 1996) and Geoffrey Heal (1995, 1998). In fact, apart from possible misinterpretations of their work, our only contribution is to provide our own motivation for introducing Chichilnisky's intertemporal welfare function, make it operational in a transport planning setting, and to reflect on some implications and some difficulties that arose.
Before we go on to define sustainability and set out the sustainability objective function, it may be noted that the results in OPTIMA and its follow-up project FATIMA confirm that the list of cities'

objectives that we set out above, does seem to capture some important aspects of the concept of sustainability. To capture all aspects of it, probably some indicator of user benefit in the transport system should be added. It would then be possible to regress the level of the sustainability objective function on these indicators, using the quasi-empirical material of all the transport model runs performed in each of the cities during the OPTIMA project, to arrive at coefficients that, if used as weights in a multicriteria objective function, would give us an objective function similar to the one we actually have used[ii]. The coefficients of each city could then be inspected to see if they differ much, and an optimization using this kind of multicriteria objective function could be performed to see if the identified optimum is the same as that in OPTIMA. This is left for possible future work.

DEFINING SUSTAINABILITY

Initially, there is a fundamental value issue to be resolved. Does nature have a value in its own right, or only insofar as it affects the welfare of some human being? If we opt for the first alternative, any irreversible man-made change to ecosystems seems to be ruled out. This seems to confine our permissible actions to a very narrow range. We choose to follow the old sophist Protagoras, who said that man is the measure of all things, and allow irreversible changes to ecosystems if it serves the welfare of human beings.

But this choice immediately brings further ethical questions to the fore. First, who is going to decide on "the welfare function", the present generation alone, or should future generations be allowed a saying? The preferences of future generations may be different from our own preferences, as I hope they will be. This seems to imply that as many options as possible should be left open to be decided in the future (Vercelli 1996). However, it is unavoidable that we decide what options they might like to have. We might be wrong and, without knowing it, run down some non-renewable resource that may be very highly valued in the future, perhaps in the very process of trying to save some other resource for the future. But there is a danger of becoming too timid, too. So to a fair extent, it is up to us to decide what serves human beings best.

Next, we must make up our minds on what weight to attach to the welfare of future generations of human beings, compared to the welfare of those living now. We must assume that man is not destined for extinction regardless of what we and our children will do. So, for a given society, there must be some ways of living that can be carried on indefinitely into the future. The welfare level associated with such a way of living is what we call a sustainable welfare level. We suppose that there is a choice between different sustainable ways of living, and that society at such a point in time will chose the maximal sustainable welfare level. However, our actions now may influence that choice set and the maximum attainable sustainable welfare level. Running down some non-renewable resource now may mean that a lower welfare is attainable in the future sustainable situation. In the worst case, it may mean that there is no such sustainable welfare level any more. That is why we will have to decide what weight to attach to the welfare of future generations of human beings, compared to the welfare of those living now.

The growing concern over the sustainability of our economic strategies stems from this awareness of the impacts that our actions now may have on the maximum attainable welfare level in a future sustainable society. People are not only aware of this as a fact, they are also to a greater or lesser degree willing to make sacrifices to improve living conditions in the very distant future. This ethical stand should be reflected in the welfare function that we use to assess economic strategies.

One of the two defining characteristics of sustainability as an objective is precisely that it includes both the welfare of the present society and the society of the very distant future. Whereas the former may be adequately reflected in a traditional cost benefit type of objective function (a utilitarian welfare function), the latter is not. Regardless of what discount rate we use, the discounting procedure of traditional cost benefit analysis means that far to little weight is attached to the welfare of the society in the distant future. F.P. Ramsey (1928) called discounting "a practice that is ethically indefensible and arises merely from the weakness of the imagination". This is certainly true in case our actions now will have repercussions into the distant future, as may be the case for CO_2 emissions and destruction of natural ecosystems and cultural heritage.

This brings us to the second defining characteristic of sustainability as an objective, namely that it implies conservation of natural resources. Put in other words: *natural resources should be valued not only as something that may be consumed (in production or consumption), but also as stocks that benefit us even when not being consumed.* Many reasons can be given for that, but in my mind, the fundamental reason is that we are dependent on some basic qualities of our surrounding ecosystems for our quality of life and indeed to continue to exist. At a less basic level, most people would recognize that a forest, for example, is useful not only for getting timber, but also for recreation, walking, skiing, having something green to look at. Which means that it renders us services as a stock, not only by being consumed or harvested.

Placing more weight on the future than is implied by the the traditional cost benefit analysis, and attributing value to environmental stocks, these are the two defining characteristics of sustainability according to Heal (1995,1998). There is probably also an intragenerational and international equity aspect to sustainability as the concept is commonly used, but in the context of urban transport strategy, which is where we need the concept, Heal's definition is sufficient. We adopt it here.

Our definition of sustainability seems to imply that it is actions and strategies with irreversible effects that need to be evaluated by a sustainability objective function, while other actions, or the reversible effects of a strategy, can still be satisfactorily assessed by traditional cost benefit analysis, even if there would be costs of reversing them. This is helpful in simplifying the long lists of indicators of sustainability that have been worked out by different agencies and research projects. Environmental effects and costs do not neccessarily belong on such lists, unless they are irreversible. That does not mean, of couse, that they should not be included when formally evaluating strategies, but only that they may be satisfactorily accounted for by traditional evaluation methods.

CHICHILNISKY'S INTERTEMPORAL WELFARE FUNCTION

Our definition of sustainability has direct implications for the form of the sustainability objective function. Suppose that the stock of natural resources at time t can be expressed by a scalar s_t. The consumption of natural resources at time t is likewise expressible as a single number c_t. In line with our definition of sustainablity as an objective, we assume that society's welfare at time t is a function $u(c_t,s_t)$ of both the consumption of natural resources and the level of the stock.

In line with the other defining characteristic of sustainability, we demand of our intertemporal welfare function that it should be sensitive both to the welfare of the present and near future, and the welfare of the very far future. These requirements are formalized by Chichilnisky (1993) into two axioms, which she call "no dictatorship of the future" and "no dictatorship of the present". Adding three reasonable axioms (continuity, the Pareto condition and that the intertemporal welfare measure is linear in the welfare of generations), she is able to deduce a welfare function of a particular kind. Adding two more axioms to the effect that the discount rate is constant (see Heal 1998), Chichilnisky's intertemporal welfare function can be written

$$W = \alpha \int_0^\infty u(c_t, s_t) e^{-rt} dt + (1-\alpha) \lim_{t \to \infty} u(c_t, s_t), \quad 0 < \alpha < 1 \qquad (1)$$

where r is the discount rate and α is a parameter to be chosen.

All welfare functions satisfying the axioms and embodying the requirement that stocks be valued for the services they render as stocks, must be of this form. W is a mixture of two terms, a traditional net present value term and a term measuring the instantaneous welfare in the very far future, or rather the sustainable welfare level towards which society moves. This second term is undiscounted, so the time when such a sustainable welfare level is reached has (practically) no effect on the weight it carries in W.

If our strategies now have neglible long run effects, the second term will be constant across strategies, and can be ignored in a formal evaluation. In this case, maximizing Chichilnisky's welfare function is the same as using an ordinary cost benefit criterion. But if they do have long run effects, using ordinary cost benefit criteria means to impose a "dictatorship of the present". Conversely, setting $\alpha = 1$ means to impose a "dictatorship of the future". To avoid these two forms of dictatorship, α must be strictly greater than 0 and strictly less than 1. If $\alpha = 1$, any sacrifice now, including any investment regardless of its cost, would be beneficial if it could improve welfare in the distant future. And $\alpha = 0$, which is what is implicitly assumed in all cost benefit analyses, means that any unsustainable pattern of production and consumption is sanctified if it pays off in the short run. It can be shown (Heal 1995,1998) that optimizing with Chichilnisky's welfare function in the case of non-renewable resources leads to less of the stock being consumed along the optimal development path, consumption stops earlier, and the shadow price of the resource is higher.

A TRANSPORT PLANNING APPLICATION

In the OPTIMA project, 6 policy variables (public transport frequency and fares, road pricing, parking charges, road capacity and public transport infrastructure investment) along with their ranges were specified in the same way in 9 European cities. Any set of permissible policy variable levels was called a strategy. The aim of the project was to find optimal strategies in the 9 cities, and to compare them across cities to draw conclusions on how the optimal strategy depended on city-specific features and on the specification of the objective function. Two objective functions were used, one reflecting economic efficiency objectives (an ordinary cost benefit analysis of the strategies) and the other reflecting sustainability objectives. Implementation issues were also considered.

We sought a sustainability objective function (SOF) to carry out optimization with regard to sustainability, and to compare the optimal sustainability solution to the optimal solution obtained with an ordinary cost benefit criterion. We specified the SOF to reflect as closely as possible the distinguishing features of Chichilnisky's function. Obviously, we could build upon our other objective function, the economic efficiency function (EEF). This function summed up user benefits in the transport system (using the rule of a half), net benefits to operators and net benefits to government. External costs (accidents and local pollution) was not included, but has since been included in the follow-up project FATIMA. In principle, if feedbacks from the transport system to the rest of the economy could be ignored, only two features distinguished the EEF from the first term in Chichilnisky's function: it only considered a time period of 30 years, and it did not explicitly include benefits derived from stocks. Using discount rates in the range 6-9%, the first feature was deemed inconsequential. Also, for this 30 year period, the level of the stocks of natural resources would not differ so much between strategies as to merit inclusion in the first term.

The real problems in applying Chichilnisky's function to urban transport appraisal rests with its second term. In the rest of this paper, we first sum up what we actually did in the OPTIMA project, and then discuss how it could have been improved upon. We also point out the most important inherent difficulties in assessing the sustainability of urban transport strategies. These must be the subject of further research. The last section concludes.

THE OPTIMA SUSTAINABILITY OBJECTIVE FUNCTION

The sustainability objective function (SOF) used in OPTIMA is a linear combination of a utilitarian welfare function, the EEF, and a function describing the sustainable welfare level. Welfare is relative to the welfare of the "do minimum" transport strategy. Welfare changes in the economy outside the transport sector that arises from the tested strategies, or from the constraints imposed on the transport system by the sustainability requirements, are not considered. This is a difficult point to which we will return.

To construct the second term of the SOF, we first defined the resources whose depletion might hurt the welfare of future generations. We took these to be "stable atmospheric conditions" and land. However, as our transport models were not integrated land use-transport models, we were unable to model the changes in land use that would result from our strategies. Therefore, we had to assume that a sustainable land use policy could be followed in all transport strategies, and that such a policy was already included in the exogeneously defined path of development from the base year to the horizon year. A fuller inclusion of landtake into the SOF can be postponed until the effect can be adequately modelled.

The resource of "stable atmospheric conditions", we thought, could be depleted by energy consumption in transport, leading to global warming from CO_2 emissions. Two factors led us to concentrate on CO_2 emissions as the factor in current transport patterns that could most seriously affect the welfare of future generations. First, most local and regional pollution effects are not irreversible in the long run. Second, practical experience with backcasting (Ramjerdi 1997) has shown that of all the criteria of a sustainable transport policy that has been set by experts, the CO_2 criterion is the most difficult to fulfill. In a situation were the CO_2 criterion is met, the other criteria are likely to be met as well.

It was thought impossible to include directly into the SOF the welfare losses at a world scale from a marginal increase in CO_2 emission in one of our cities. Assuming, however, that experts have solved a Chichilnisky type of welfare function for the world at large for the CO_2 problem (they haven't), and that they have worked out an optimal path for CO_2 reductions in the future (they may have), the problem is transformed to its dual, that is, to assess the shadow price of fuel consumption that would keep consumption within the constraints of this path if it were implemented as a market price together with the optimal use of the other policy instruments. What we need then, is to break down the CO_2 targets from experts to targets on fuel consumption in the transport sector in each of our cities, and add these as constraints when optimizing the SOF.

To do this, we made a guess at what the CO_2 targets should be for the transport sector in cities of our type. Next, an exogeneously given path for the development of fuel efficiency had to be given. It was then possible to compute the predicted level of CO_2 emission for any strategy in all future years that were tested by the model. The predicted levels could be compared with the targets to impose a penalty on strategies not meeting these constraints. In accordance with the properties of the Chichilnisky model, the penalty should probably be higher for overruns in the far future. The penalties should also be such that the SOF-optimal strategy would just meet the targets.

In the event of OPTIMA and FATIMA, we only run the tranport models for one "horizon" or "target" year (2010 or 2015). This means that the welfare levels or net benefits for the other years of the planning period, which we need to compute the EEF, are interpolated values. It also means that we only use one CO_2 target for the one target year. Consequently, we assume that the optimal CO_2

reductions path can be approximated by a linear path from the base year to the target year, and constant CO_2 levels after that, so that transport in the target year is in fact sustainable.

This simplified procedure can be rationalized in the following way: It may be that the 2015 CO_2 target is in fact only a step on the way towards a sustainable level of CO_2 emissions. Further reductions can be expected to follow from improved fuel technology in the years after 2015 if the price of fuel is adjusted by taxes so that fuel costs per kilometer stay the same. If so, the required adjustments in travelling behaviour are supposed to be completed by 2015, but the reductions due to improved technology continue. This timing of the two kinds of instruments to achieve the required reductions, behavioural changes and technological progress, is in fact very appealing. Technological progress may be difficult and very costly to rush, while there is little to be said for waiting to use relative cheap pricing instruments etc. to influence behaviour.

In OPTIMA, we used a system of a soft and a hard constraint to steer the optimization process so that the optimal strategy would fullfil the CO_2 target. Fuel costs at fixed prices were used as proxies for CO_2 emission. This of course presupposes that technological change will affect all modes in the same way. Introducing some notation, we can now specify the sustainability objective function in a slightly more general version than was used in OPTIMA.

Let b be the net benefit from the strategy in the target year, consisting of benefits to travellers, operators and government, and of the reduction in external costs. Let c be the fuel costs in the target year, c_T the targeted fuel costs and c_0 the fuel costs of the "do minimum" strategy. I is investment and r is the discount rate. Finally, let y be the shadow price associated with deviations from the c_T constraint and z the penalty on not meeting the c_0 constraint. These were taken to be 4 and 1000 respectively.

$$SOF = \begin{cases} \alpha EEF + (1-\alpha)(b - y(c - c_T) - z(c - c_0)) & \text{if } c > c_0 \\ \alpha EEF + (1-\alpha)(b - y(c - c_T)) & \text{if } c \leq c_0 \end{cases} \qquad (2)$$

$$\text{where } EEF = I - \sum_{t=1}^{30} \frac{1}{(1+r)^t} \cdot b, \text{ and } \alpha \in [0,1] \text{ is chosen freely}$$

PROPERTIES OF THE OPTIMA SOF

To the extent that (a) the price of fuel is adjusted to counteract improvements in fuel efficiency after the target year, (b) the CO_2 target for the target year is correct and further required reductions can be trusted to follow from improved fuel efficiency, and (c) external factors stay the same, the second term of the OPTIMA SOF reflects net benefits in the transport system not only in the target year, but in any future year. The function values investment now lower than ordinary cost benefit analyses by a factor of α, and value fossile fuel (or stable atmospheric conditions) as a stock. These are properties of the SOF that accord with the Chichilnisky welfare function.

OECD's EST Project (OECD 1996) defines environmentally sustainable transport (EST) in the following way:

> "Transportation that does not endanger public health and ecosystems and meets needs for access consistent with (a) use of renewable resources at below their rates of regeneration, and (b) use of non-renewable resources at below the rates of development of renewable susbstitutes."

Provided "needs for access" can be measured by user benefits in transport, and that targets for local and regional pollution are met if the CO_2 target is met, the OPTIMA SOF broadly measures sustainablility in transport according to this definition, too. However, land use objectives and other objectives not considered in OPTIMA may also form a part of EST. This may call for additional indicators.

When we constructed the SOF, we assumed that world wide CO_2 targets could be broken down to the city level and further down to city sectors like transport. In this perspective, sustainability is seen as a decomposable multi-level dynamic planning problem (see for example Williams 1990 on such problems). In a decomposable multi-level planning problem, decentralization can be achieved either by the central agency allocating shares of the scarce common resources to the departments, or by fixing shadow prices. In our case, we assumed decentralization by quantities. The departments then solve their own optimization sub-problem using this information. In turn, the results from the departments can be used by the center to modify their initial allocation or prices, and the process repeated. From this property of the SOF as an objective function of a department in a multilevel planning process, it can be seen that its validity depends on correct information from the center, and the center's allocation depend for its correctness on information from urban transport planning using the SOF objective function.

SOME RESULTS

In OPTIMA, α was chosen to be 0 and 1 respectively to contrast two objective functions, one being a "dictatorship of the future" and the other a "dictatorship of the present". Optimization was carried out for both functions in all of the 9 cities. Here, we only relate the resulting optimal modal splits in the target year. Fuller results are reported in OPTIMA Concortium (1997).

Table 1 - OPTIMA results. Modal split (trips) in the target year in the "do minimum" strategy and optimal modal split for $\alpha = 1$ and $\alpha = 0$. Car/public transport/slow modes in percent.

	Do minimum	$\alpha = 1$	$\alpha = 0$
Edinburgh	63/37/n.a	52/48/n.a.	47/53/n.a.
Merseyside	62/15/23	59/22/19	59/22/19
Vienna	39/34/27	35/39/27	31/46/22
Eisenstadt	45/3/52	41/8/51	41/8/51
Tromsø	73/11/16	72/12/16	65/17/18
Oslo	68/22/10	67/24/9	53/37/10
Helsinki	49/30/21	52/25/22	35/46/19
Torino	57/43/n.a.	50/50/n.a.	49/51/n.a.
Salerno	59/14/27	56/17/27	53/22/25

n.a. = not available

Although the $\alpha = 1$ (dictatorship of the present) and $\alpha = 0$ (dictatorship of the past) cases give the same optimal split in Merseyside and Eisenstadt, there are shifts from the car to the public transport mode in all other cities, and very large shifts in Oslo and Helsinki. For the most part, the share of walking and cycling is only marginally affected. This may be due to the fact that no policies of walking and cycling were included in the strategies tested. Also, land use stayed the same in all strategies.

POSSIBLE IMPROVEMENTS

We assumed that the optimal use of the two major classes of instruments to achieve CO_2 reductions from transport, was to apply a wide range of instruments that influence travel behaviour at once (the first 15 years), and rely on technology and fuel taxation to achieve the targets in the long term. The appropriateness of this assumption should be researched further. If it turns out to be untenable, one course of action is to run the transport models for two or more target years, taking the last of them to mirror net benefits in a sustainable situation.

Our method of ensuring that the optimal sustainability strategy respects the CO_2 constraint, was to use two constraints, one soft and one hard. To see how this might be improved upon, a little formalization of the problem to be solved in OPTIMA is required.

Let us denote a strategy by the vector **x** of levels of the policy variables, and let Ω be the cartesian product of the permissible ranges of the policy variables. Let **a**(t) be the exogeneously given data on demography, incomes, land use etc. at time t that is used by the transport model, and let **a** be the vector of **a**(t)'s for each of the years that the transport model is run. Our assessment of the sustainability of strategies by the combined use of a transport model and an objective function that uses the outcome of the transport model, can be seen as a function f: $\Omega \to R$ that associates a real number to every point in Ω. This function cannot be expressed in a formula, but at every point **x** the value f(**x**;**a**) can be computed. Similarly, there exists functions g(t): $\Omega \to R$ that associates a real number, the level of CO_2 emissions from the transport sector in the city in year t, to every permissible strategy. Let **g** be the vector of such functions that we utilize in the appraisal, that is, the g(t)'s of those years for which the experts have set CO_2 targets. We express these targets in the form **g**(**x**;**a**) = **d**.

The optimization problem of OPTIMA can then be expressed as

$$W(\mathbf{d},\mathbf{a}) = \mathop{Max}_{\mathbf{x}} \; f(\mathbf{x};\mathbf{a}) \quad \text{s.t. } \mathbf{g}(\mathbf{x};\mathbf{a}) = \mathbf{d}, \; \mathbf{x} \in \Omega \tag{3}$$

The constraint must be regarded as «soft» - the character of the problem may make it impossible to satisfy them completely.

One possible way of attacking such problems is by "inverse optimization" (see for example Bitran *et al* 1981). It consists of three steps. At step 1, we solve the problem to maximize $L(\mathbf{d},\mathbf{a},\mu) = f(\mathbf{x};\mathbf{a}) - \mu(\mathbf{g}(\mathbf{x};\mathbf{a}) - \mathbf{d})$ with respect to **x** for a suitably chosen vector of "Lagrangian multipliers" μ. This step was performed in OPTIMA. At step 2, we minimize $H(\mathbf{d},\mathbf{a}) = \text{Max}_x\,[f(\mathbf{x};\mathbf{a}) - \mu\mathbf{g}(\mathbf{x};\mathbf{a}) + \mu\mathbf{d}]$ with respect to μ, which in our case means to repeat the optimization procedure for a wide range of μ's to form an initial set of "step 1-optimal" strategies, then use the heuristic optimization procedure of OPTIMA to find a minimal point. This raises the number of transport model runs involved in an optimization considerably, and was not done in OPTIMA. Step 2 performs a check on the shadow price of 4 on fuel costs that was assumed in OPTIMA. It may also generate information for a decentralization of the two-level planning problem mentioned in section 6 by way of prices, if that seems preferable, or for the revised break-down of CO_2 targets.

If there are no indivisibilities involved, then step 2 brings the solution. However, the policy instrument of investment is a discrete measure. Thus, there may be a "duality gap", meaning that the solution of step 2 does not meet the constraint exactly. Step 3 is to reduce this duality gap by a systematic procedure.

To assist in setting the shadow price of fuel costs and improve the validity of SOF objective functions in use, at least step 2 above should be performed in some cities.

INHERENT DIFFICULTIES

Sustainability involves the distant future, and may require large changes in the transport systems. An inherent problem with the formal evaluation of sustainability in transport, therefore, is that the further into the future we go, the less reliable are the results from our transport models. There are also definitely limits to the size of policy changes whose effects can reasonably be predicted by transport models.

The interactions between the transport system and the rest of the economy poses another very difficult problem. For small changes in the transport system, they may be ignored, but for larger changes and in the longer run, we have to face the fact that a certain transport system can only sustain a certain class of development paths for the economy as a whole. This means that our exogeneous factors **a** may be functions **a(x)** of **x**. A first step to alleviate this problem, is to make assumptions about the exogeneous variables (demography, income levels, land use) that are as far as possible not only sustainable in themselves, but also compatible with the optimal transport system resulting from optimizing the SOF. A further step is to broaden the definition of the system whose objective function SOF is, to include land use and labour markets, etc.

CONCLUSION

The defining characteristics of sustainability as an objective are two: concern with the long term future, and recognition of the values of stocks of natural resources as stocks. This definition of sustainability, coupled with some reasonable axioms, leads to the Chilchilnisky intertemporal welfare function. The sustainability objective function used in the OPTIMA project mirrors the main features of the Chichilnisky function at a local transport level. It seems to lead to a "greener" optimal transport strategy than the one implied by ordinary cost benefit analysis.

Of all possible criteria of sustainable transport, the requirements on CO_2 are probably the most difficult to fullfil, and if they are fullfilled, the others probably will be, too. That is why recognition of the values of stocks of natural resources as stocks is implemented in the SOF as a constraint on fuel consumption. This choice situates the SOF as the objective function of a department in a decomposable multi-level planning problem.

Although it requires a lot of resources, it is possible to use the optimization procedure of OPTIMA to find the shadow prices associated with the local CO_2 targets assumed in OPTIMA, and to use this information in a broader setting to revise the local targets. It is also possible to study the relation of the SOF to commonly used indicators of sustainability in transport like the modal split, to find a multicriteria objective function that performs in the same way as the SOF.

Limitations in the ability of transport models to predict the outcome of large changes and in years far ahead, can limit the usefulness of the SOF. The same is true of interdependencies between the transport system and the rest of the economy, which may force us to broaden the system definition from the local transport system to the local economy as a whole.

The use of only one target year in OPTIMA, some 15 years ahead, may be sufficient if behavioural changes to the transport system should be carried out at once and finished by that time, leaving the rest of the CO_2 reductions to be achieved by increased fuel efficiency. Research is needed to verify if this is indeed the optimal timing of the two broad classes of policy instruments.

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Endnotes

[i] See Acknowledgments

[ii] Because land use policies and changes in the conditions for pedestrians andcyclists were not tested in OPTIMA and FATIMA, and accidents and local pollution were ignored in OPTIMA, these indicatorsmust be dropped from the regression.