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THE SENSITIVITY OF OPTIMAL TRANSPORT STRATEGIES TO SPECIFICATION OF OBJECTIVES

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ABSTRACT

This paper describes a method for devising transport strategies that makes iterative use of transport models to find the optimal levels of pre-defined transport measures. It gives the results from using this method in nine European cities. At the heart of the procedure lies the definition of objective functions which encapsulate policy-makers' objectives with respect to economic efficiency and sustainability. These objective functions include a number of significant parameters and the paper examines the sensitivity of the results to changes in the values of these parameters. The parameters concerned are: the level of shadow price used with regard to public sector financial surplus and deficit; the trade-off between the perspectives of the present generation and a future generation (of importance to issues of sustainability); the trade-off between internal benefits/costs and external (environmental) benefits/costs; and the level of user benefits that can be "value captured" in the sense of raising additional finance for transport policies. Full sets of results are given for these sensitivity tests, and a number of practical transport policy conclusions are made.

1 INTRODUCTION

A recent paper by May et al (2000) has described a procedure for finding optimal urban transport strategies and its application in nine "representative" European cities, as listed in Table 1. The research was carried out within the project FATIMA ("Financial Assistance for Transport Integration in Metropolitan Areas") which was part of the European Union's Fourth Framework Research Programme. The underlying aim of FATIMA was to devise and apply a method for estimating optimal transport strategies within a context of limitations on public finance.

The method for estimating optimal transport strategies consists of an optimisation procedure that makes iterative use of transport models to find the optimal levels of pre-defined transport measures. At the heart of this procedure lies the definition of objective functions which encapsulate policy-makers' objectives with respect to economic efficiency and sustainability (but not their objectives with respect to accessibility or intragenerational equity). With respect to any one specific objective function, the *optimal* transport strategy is defined as the set of transport measures that maximises the value of the function. A number of objective functions were defined in FATIMA, the main difference between alternative objective functions being the differing ways of treating public finance constraints. These objective functions include a number of significant parameters, and assumptions were made about the "best" values to attach to them in the optimisation process. Inevitably, questions arise as to how sensitive the final policy conclusions are to these parameter values.

This paper examines the sensitivity of the results to a number of key parameters in the FATIMA objective functions, with two specific aims. Firstly, an assessment is made of the robustness of the overall policy conclusions to changes in objective function parameter values. Secondly, an examination is made of the appropriateness of the specific values chosen in FATIMA. The parameters concerned are: (1) the level of shadow price used with regard to public sector financial surplus and deficit; (2) the trade-off between the perspectives of the present generation and of future generations (of importance to issues of sustainability); (3) the trade-off between internal benefits/costs and external (environmental) benefits/costs;

(4) the level of user benefits that can be "value captured" (from the private sector) in the sense of raising additional finance for transport policies.

Section 2 gives an overview of the case study cities and transport measures considered in FATIMA, and the transport models used in them. Section 3 gives definitions of the objective functions, whilst Section 4 summarises the results and recommendations from FATIMA, using default values of the above-mentioned parameter values. Section 5 gives the results of the sensitivity tests, and Section 6 provides a number of transport policy conclusions.

2 OVERVIEW OF CASE STUDY CITIES, TRANSPORT MEASURES AND TRANSPORT MODELS USED IN FATIMA

2.1 Selection of case study cities

As stated above, the nine case study cities were selected on the basis that they were "broadly representative" of European cities, although they are not necessarily representative in a formal statistical sense. Table 1 lists the cities and their populations.

Table 1 here

2.2 Transport measures considered

Table 2 shows the measures and their ranges used in the optimisation process. Measures were defined relative to a do-minimum strategy which was already being planned by the city.

Thus, for example, the public transport infrastructure measures considered in the optimisation process were extra to the infrastructure measures already committed by the cities (but not yet built). It should be noted that all the cities were planning local measures to: enhance pedestrian and cyclist mobility; reduce accidents; and increase traffic calming in residential areas. These measures were assumed, in the optimisation process, to be fixed for all transport strategies considered.

In most of the cities, where models permitted, a distinction was made between long stay and short stay parking charges, and between peak and off-peak values for frequencies, fares and road pricing charges.

Table 2 here

2.3 Transport models used

The policy measures were tested using city-specific transportation models which had already been set up, calibrated and used by the city authorities before the start of the project. Differences in the models inevitably imposed a limitation on the study. Ideally it would have been desirable to carry out a transferability analysis which applied more then one model in each city, thus identifying whether there was model-bias in the results. However, such an analysis would have comprised a separate project in its own right. The issue of model-bias is thus treated in this paper by a simple inspection of the model characteristics, along with speculation (at the time of reporting sensitivity test results in Section 5) as to which, if any, of these characteristics might have led to differences in the transport policy results.

Table 3 summarises the characteristics of the models. They fall into two main categories: strategic and tactical models. The former are used for running simulations at a very high level of aggregation in terms of network representation, whilst tactical models are more detailed. Other important differences between the models (apart from the strategic/tactical distinction) lie in the treatment of behavioural responses. Neither Italian model includes redistribution, generation or suppression, and the Austrian models also exclude generation and suppression.

Table 3 here

3 DEFINITION OF OBJECTIVE FUNCTIONS

3.1 Overview of objective functions

All objective functions used in FATIMA were defined relative to a do-minimum strategy, representing a city's committed transport plans over the next 30 years. It follows that, by definition, the value of each objective function for the do-minimum strategy is zero. Three primary objective functions were used in the optimisation process. The *Benchmark Objective Function (BOF)* represents economic efficiency and sustainability objectives, under an assumption of no fixed limit on public finance. The *Constrained Objective Function (COF*) represents the same objectives as in BOF, but under the assumption that the availability of public finance (over a 30 year time horizon) is limited to that specified by the do-minimum strategy. Thirdly, the *Regulated Objective Function (ROF)* represents the same objectives and assumptions as COF, except that there is the possibility of generating additional private finance through value capture.

All three objective functions are discussed in Minken (1999). The strategies that find the maximum values of BOF, COF and ROF are referred to below as *optimal BOF strategies, optimal COF strategies,* and *optimal ROF strategies* respectively.

In order to compute the above objective functions, five secondary objective functions are required: the *Economic Efficiency Objective Function* (EEFP); the *Sustainability Objective Function* (SOF); the *Present Value of Finance* (PVF); the *(present value of net) Benefits (B);* and the *External Costs (EC).* All these objective functions are summarised in Table 4. It can be seen that many of the objective functions are defined over a 30 year time horizon. However, only one future target year (typically 2015) was modelled in the FATIMA project, and it follows that the equations given below are more simplistic than if each future year (over a 30 year time horizon) were modelled separately.

Table 4 here

3.2 Present Value of Finance (PVF)

The Present Value of Finance (PVF) of a set of measures is defined as the net financial benefit to government and other providers of transport facilities, both public and private, over a 30 year time horizon, relative to the do-minimum.

In the FATIMA study, where only one future target year was modelled, PVF was defined as:

$$PVF = -I + \sum_{i=1}^{30} \frac{1}{(1+r)^i} f \qquad (1)$$

where: I is the present value of the cost of public transport infrastructure investment, compared to the do-minimum scenario (it is assumed that all investment takes place immediately in year 0);

f is the net financial benefit to transport suppliers in the modelled target year, compared to the do-minimum scenario, taking into account both revenue and operating costs;

r is the annual (country specific) discount rate.

The value of r used in the FATIMA projects varied between 0.06 and 0.09, in line with the actual discount rates used in the countries whose cities were featured in the case studies. Whilst it was not feasible in FATIMA, it would be useful in further research to identify whether the differing discount rates had an effect on the selection of optimal strategy.

3.3 The present value of net benefits (B)

The present value of net benefits, B, consists of net benefits to travellers, operators and the government, over a 30 year time horizon but ignoring year 0 investment costs.

The net benefits to travellers are evaluated as the generalised consumer surplus from the change in generalised costs on all travel movements, assuming that the demand functions are linear in the relevant region of generalised costs. This is a standard evaluation procedure in cost benefit analyses of transport (see MVA et al, 1994).

The present value of net benefits, B, is given by:

$$B = \sum_{i=1}^{30} \frac{1}{(1+r)^i}(f+u) \qquad (2)$$

where: u is the net benefit to transport users in the target year, compared with the do-minimum scenario;

and f, r are as defined above for Equation (1).

3.4 External costs EC

The external cost indicator for each mode is the change in veh-kms (compared to the do-minimum) in the modelled year, factored by the sum of the accident, noise and pollution costs per veh-km, and summed over a 30 year period.

Let γ_{am}, γ_{nm} and γ_{pm} be the costs per vehicle kilometre for mode m due to accidents, noise and pollution respectively. Let k_m be the change in the vehicle kilometres by mode m in the target year (compared to the do-minimum strategy). The external cost indicator EC is defined as:

$$EC = \delta \sum_m \gamma_m k_m \qquad (3)$$

where $\gamma_m = \gamma_{am} + \gamma_{nm} + \gamma_{pm}$

and $\delta = \sum_{i=1}^{30} \frac{1}{(1+r)^i}$ (4)

Default γ values were based upon costs given by Tinch (1995) as shown in Table 5. However, where alternative local values were available, they were used instead. These local values were broadly similar to the values given in Table 5, especially when aggregated over pollution, noise and accident impacts. However, if the sensitivity results given in Section 5 were to show that policy results are extremely sensitive to variations in γ, the issue of "local values" versus "Tinch values" would need to be explored in more detail.

Table 5 here

3.5 Economic Efficiency Function (EEFP)

The formula for EEFP is given by:

$$EEFP = B - I + \lambda \; PVF - EC \qquad (5)$$

where: B, I, PVF and EC are as defined above;

$1+\lambda$ is the shadow price of public funds (the “standard” value given to λ in FATIMA was 0.25).

EEFP corresponds to a standard approach to cost benefit analysis. Minken (1998) indicates that 0.25 has been a standard value for λ in a number of practical planning exercises, citing a review by Snow and Warren (1996) concerning the theory and estimates of shadow price for the use of public funds. A cause for concern might be that, if λ were to be set too high, “optimal” transport strategies would simply be those that generated large public sector revenues. This issue will be examined further in Section 5.

3.6 Sustainability Objective Function (SOF)

The sustainability objective function (SOF) is given by:

$$
\mathrm{SOF} = \begin{cases} (1+\lambda)\, f + u - y + \text{hard penalty} & \text{(if fuel consumption exceeds do-minimum)} \\ (1+\lambda)\, f + u - y & \text{(otherwise)} \end{cases} \quad (6)
$$

where: y is a "soft penalty" on fuel consumption in the target year, calculated by multiplying the fuel consumption cost (relative to the do-minimum strategy) by a shadow price of 5;

u, f and λ are as defined above.

The main intention of the soft and hard penalties on fuel consumption is to generate "optimal" transport policies that preserve natural resources. The use of a hard penalty effectively ensures that such policies must use less fuel than those envisaged by the do-minimum transport strategy.

A full report of the construction of SOF is given by Minken (1999), who describes how the approach is an adaptation of the work of Chichilnisky (1996) and Heal (1999) for the specific requirements of FATIMA. Essentially, the SOF approach is to create a perspective that could be termed "dictatorship of the future", whereby the welfare of future generations totally outweighs the welfare of the current generation. This perspective should be seen as in opposition to the "dictatorship of the present" perspective which, it is claimed, underlies the EEFP approach.

Ideally, SOF should reflect attributes of the transport system of relevance to future generations such as resource depletion, loss of life, degradation of the local environment, land consumption, ecological impacts and global warming. Furthermore it would also assess these for a series of horizon years. However, such an approach was not feasible in FATIMA due to limitations of the modelling tools. Instead, a consciously simplified approach was adopted in which the major aspect of sustainability was assumed to be the renewability of fossil fuels as measured by the level of fuel consumption, and only one horizon year was modelled. The level of fuel consumption was assumed to act as a proxy for all the other attributes of sustainability listed above. Since fuel consumption is directly related to CO_2 emissions, and closely correlated with atmospheric pollutants and accidents, such an assumption seemed to be reasonable for the purposes of FATIMA, although future research should allow for improvements to be made to the definition of SOF.

3.7 Benchmark Objective Function (BOF)

BOF (Benchmark Objective Function) is a combination of EEFP and SOF which balances the perspectives of current and future generations.

It is defined as:

$$BOF = \alpha EEFP + (1 - \alpha)\, SOF \qquad (7)$$

For the main tests in FATIMA, α was set at 0.1. Since SOF is only concerned with a single target year whilst EEFP is concerned with a (discounted) period of 30 years, it follows that the size of EEFP will be approximately ten times the size of SOF. Thus a value of 0.1 for α was chosen to ensure that the perspective of a future generation would have approximately the same weight as the perspective of the present generation. Since α was a new parameter created by the FATIMA project, no previous literature can be cited as to its "best" value.

It would be interesting to examine how optimal transport strategies generated using BOF varied if the value of α were to be altered. Since investment, such as on public transport infrastructure, is assumed to take place "immediately", it is likely that the building of such infrastructure will appear beneficial to a future generation. Thus the lower the size of α, the more likely it is that investment will be included in a BOF optimal strategy.

The value of BOF is clearly affected by the non-inclusion of external costs in SOF, as discussed above. However, a doubling of the size of γ values would approximately compensate for this omission. This observation leads directly to one of the sensitivity tests considered in Section 5.

3.8 Constrained Objective Function (COF)

COF (Constrained Objective Function) is an extension of BOF that takes into account that there is a fixed constraint on public money. For the sake of simplicity, it is assumed that public finance is constrained to the level implied in the do-minimum scenario.

$$\begin{aligned} \text{COF} &= \text{BOF if PVF} > 0 \\ &= \text{BOF + hard penalty if PVF} < 0 \end{aligned} \qquad (8)$$

3.9 Regulated Objective Function (ROF)

ROF (Regulated Objective Function) is an extension of COF, and recognises that extra (private) finance can be input to the transport system through value capture (VC). VC is defined as a proportion β of user benefits, which are seen as a measure of overall accessibility. The logic here is that companies in the city should (collectively) be prepared to pay for overall city-wide accessibility improvement due to the benefits that they gain from this in terms of efficiency of commuter trips and business trips, inward investment (due to city attractiveness) and general city regeneration.

$$\begin{aligned} ROF &= BOF && \text{if } PVF + VC > 0 \\ &= BOF + \text{hard penalty} && \text{if } PVF + VC < 0 \end{aligned} \tag{9}$$

where:

$$\begin{aligned} VC &= \beta \ \delta u && \text{if } u > 0 \\ &= 0 && \text{otherwise} \end{aligned} \tag{10}$$

and where δ is as defined above.

For the main tests in FATIMA, β was set at 0.1. However, since no evidence was found in the literature on the percentage of benefits that can be captured, it was considered important to carry out sensitivity tests on β.

4 RESULTS AND POLICY RECOMMENDATIONS USING STANDARD PARAMETER VALUES

4.1 Optimal transport packages using standard parameter values

Table 6 summarises the optimal strategies for the Benchmark Objective Function (BOF), the Constrained Objective Function (COF) and the Regulated Objective Function (ROF) for the nine cities. Furthermore it gives the PVF and PVF per capita of these strategies. It can be seen that in six of the cities (Edinburgh, Vienna, Eisenstadt, Oslo, Torino and Salerno) the BOF optimal strategy had a positive PVF so that the revenues generated by the strategies were more than sufficient to cover costs. Therefore, there is no need to calculate a separate (constrained public finance) COF optimal strategy for these cities. Furthermore, since value capture is only considered when optimal strategies lead to public finance deficits, there is no need to calculate separate ROF optimal strategies for them.

For the three remaining cities (Merseyside, Tromsø and Helsinki) distinct COF optimal strategies needed to be calculated. Of these, only the strategy for Merseyside generated sufficient positive user benefit to make the use of value capture a viable option (given the definition of VC in Equation (10) as being a proportion of user benefits). Hence Merseyside was the only city for which there was a separate ROF optimal strategy.

In terms of the optimal strategies produced, Table 6 shows that the BOF optimal policy is most likely to involve: (1) at most limited public transport infrastructure investment on top of what is already planned; (2) low cost increases in road capacity; (3) improvements in public transport by increasing frequency and/or reducing fares; and (4) restrictions on car use involving either road pricing or increased parking charges.

Table 6 here

Inspection of the results in Table 6 leads to the definition of four classes of city:

Class 1. Cities which fulfil two criteria. Firstly, the BOF optimal strategies have large negative PVFs resulting from being supportive of both car and public transport users (so that the city must provide finance). Secondly, there is a significant possibility for value capture to support optimal policies under a regime of hard constraints on public finance. Merseyside is the only Class 1 city out of the nine case study cities. Its BOF optimal strategy has a PVF of -1472 euros per capita.

Class 2. Cities where BOF optimal strategies are supportive of both car and public transport users (and hence have large negative PVFs as in Class 1 cities), but where there is no significant possibility for value capture to support optimal policies under a regime of hard constraints on public finance. Helsinki and Tromsø are both Class 2 cities and their BOF optimal strategies have PVFs per capita of -1955 and -1474 euros respectively.

Class 3. Cities where BOF optimal strategies place financial restrictions on cars but are supportive of public transport users, so that the former are subsidising the latter. In this case, the city makes a surplus, but this surplus would not be expected to be large.

Edinburgh, Eisenstadt, Torino and Salerno are Class 3 cities and their BOF optimal strategies have PVFs per capita of 555, 900, 490 and 591 euros respectively.

Class 4. Cities where BOF optimal strategies place restrictions on both cars and motorised public transport, and the city raises revenues from both user-types through road user charges (parking and/or road pricing) and increased public transport fares (with no significant increase in frequency). In this case, the city makes a surplus which is large. Vienna and Oslo are Class 4 cities and have PVFs per capita of 2534 and 6503 euros respectively.

There is no immediately obvious correlation between the class of a city and its characterstics in terms of population, geographical location or other features. However, further research could explore more formally whether such a correlation exists, considering also characteristics such as: city density; level of income and employment; and the state of the transport system in the do-minimum, including mode shares and transport costs.

A significant question arises though as to whether the allocation of cities to classes is dependent upon the parameters used in the objective functions. It is important therefore to carry out sensitivity tests as to whether or not this is the case, and this will be done in Section 5. Since size of PVF is subsumed within the definition of class, the sensitivity analysis will not consider PVF further in a comprehensive manner (except for the analysis of β), although it will be mentioned sporadically where appropriate.

5 SENSITIVITY TESTS

5.1 Overview of sensitivity tests

FATIMA project resources did not allow for all sensitivity tests to be carried out in all case study cities. However, as Table 7 shows, a selection of sensitivity tests were carried out in eight of the case study cities.

Table 7 here

5.2 The shadow price 1+λ

The "standard" shadow price on public money (1+λ) was set at 1.25 for the results given in Section 4. As was seen, Edinburgh, Oslo, Vienna and Salerno were all either Class 3 or Class 4 cities whose BOF optimal strategies produced finance surpluses (as represented by positive PVFs). It could be argued that the use of a shadow price led directly to such strategies, and that they would not have been produced had there been no shadow price. The sensitivity test used in these four cities was to lower the shadow price to 1.0 (i.e. set $\lambda = 0$) and investigate whether non-revenue generating strategies become optimum. On the other hand, Merseyside was a Class 1 city and produced a highly negative PVF for its optimum BOF strategy. The sensitivity test in this case was to increase λ by steps up to 1.5 to understand at what point, if any, a BOF optimal strategy would be produced that was not expensive for the city. The BOF optimal strategies resulting from all these sensitivity tests are shown in Table 8.

Table 8 here

It can be seen from Table 8 that the reduction of λ from 0.25 to 0 had little or no effect on the BOF optimal strategies in Edinburgh and Oslo. However, such a reduction led to significant changes in Vienna and Salerno. In Vienna, an increase in fares of 77% was altered to a decrease of 15%, whilst in Salerno an increase in fares of 25% was altered to a decrease of 50%. The reduction in λ changes Vienna from being a Class 4 City to a Class 3 City so that although the revised BOF optimal policy generates a net revenue, this revenue is severely decreased. The reduction in λ changes Salerno from a Class 3 city to a Class 2 city, so that BOF-optimal strategy needs to be financed by the city.

For values of λ under 1.0, there was little change in the BOF optimal strategies for Merseyside. However, increasing λ to 1.0 and 1.5 led to: a reduction in increases in peak frequency; smaller fare reductions (70% rather than 100%); and the imposition of a road pricing charge of 1 euro. The revised BOF optimal strategy for higher λ changes Merseyside from a Class 1 City to a Class 3 City.

Comments on model effects

Section 2.2 described how the Vienna and Salerno case studies used models which do not take into account generation and suppression effects (as shown in Table 3), whilst the Edinburgh and Oslo models do represent such responses. Since the decrease in λ from 0.25 to 0 leads to a substantial decrease in traveller finance costs in the optimal strategies for Vienna and Salerno, but not in Edinburgh or Oslo, it could be suggested that the differences between the two city pairs are accounted for by the models.

It is reasonable to assume that in reality the reduction in traveller finance costs, in whatever mode, will lead to an increase in the total level of transport demand. Thus a model which assumes a fixed level of transport demand is liable to underestimate the revenue produced when traveller finance costs are decreased, and to overestimate revenue when such costs are increased. It follows that the "revenue generating emphasis" of the optimal policies when λ is set at 0.25 in Vienna and Salerno might be a result of the lack of representation of suppression and generation in their models. However, such a conclusion is not proven and requires further research.

5.3 α in BOF

Sensitivity tests for six city case studies were performed on the weight α between EEFP and SOF in BOF, as defined in Equation 7. As stated in Section 3.7, the standard value of α=0.1 was based upon the concept of equal weighting between the perspective of the current generation and the perspective of a future generation. A greater emphasis is put upon the perspective of a future generation if α is decreased, and upon the current generation if α is increased. The range of tests was from α=0.0 (corresponding to no emphasis on the perspective on the current generation) to α=1.0 (corresponding to all emphasis on the perspective of the current generation, as in a traditional cost benefit analysis). The optimal strategies resulting from tests with variations in the value of α are given in Table 9.

Table 9 here

In general, the optimal BOF strategies were relatively insensitive to changes in α. In fact, increases in α from 0.1 to 0.25 led to virtually no changes in optimal strategy in any city. The increase to 1.0 led to a change in optimal strategy only in Oslo, where the already high revenue-generating optimal strategy became even more extreme. Probably the most important result for increases in α was that the medium public transport infrastructure options in Edinburgh, Merseyside and Oslo were robust to such increases. Hence, they were still part of optimal strategies even when the full costs of construction were taken into account in the objective function (as is the case when α equals 1.0).

In Edinburgh and Vienna, decreases in α (to 0.015 and 0 respectively) led to a high level of public transport infrastructure being introduced. On the other hand, in the Salerno and Merseyside case studies, no extra infrastructure was introduced when α was set at 0. Since the Eisenstadt and Oslo case studies did not permit high levels of infrastructure being introduced, they do not throw light on this issue. Other results from lowering α were that road pricing increased in Edinburgh, public transport frequency increased in Vienna, fares were reduced in Oslo and free long stay parking was abolished in Merseyside.

The general lack of evidence of sensitivity to higher α suggests that strategies which reflect the present generation's perspective also generally reflect a perspective with equal emphasis on the present and future generations. In other words, optimal strategies under a pure economic efficiency objective are liable to be the same as under a balanced economic efficiency / sustainability objective.

The setting of α to 0 is likely to lead to a higher level of extra infrastructure being introduced (on top of the do-minimum level), but this cannot be guaranteed in all cases. This result is not surprising since the construction costs of extra (present day) infrastructure are not met by future generations. However, this conclusion should be qualified by a recognition that setting α to zero, and thus ignoring current infrastructure costs, is almost certainly unrealistic in practical policy-making.

5.4 The external cost parameters γ

The γ parameters feature in the definition of external costs (EC), as given in Equation 3, and are concerned with the effects of strategies on the local environment and safety. As described above, EC is used in the definition of EEFP (Equation 5) but not in the definition of SOF (Equation 6). The case studies of Edinburgh and Merseyside tested increases in γ whilst the Merseyside, Vienna, and Eisenstadt case studies tested decreases. The optimal BOF strategies resulting from changing the value of γ are given in Table 10.

Table 10 here

It can be seen from Table 10 that if γ values take the order of magnitude given in Table 5, they have little effect on the overall optimal BOF strategies, in the sense that there is virtually no difference in the specification of optimal strategies if external costs are ignored (with γ being set at 0). A doubling of the value of γ had no effect in Merseyside but led to a doubling of road pricing charges in Edinburgh. A ten-fold increase in γ in Merseyside led to an imposition of an all-day road pricing charge of 3.5 euros and changed the city from Class 1 to Class 3.

These results can be interpreted in two alternative ways. Firstly, it can be argued that the values used for γ are based upon the best estimates of costs of externalities that are available. It is clear that these costs would have to be increased several-fold to change the optimal strategies. It follows immediately that the strategies which are optimal without considering externalities under a balanced economic efficiency / sustainability objective are the same as those that are optimal if externalities are considered. However, on the other hand, if one is suspicious of the process of valuing externalities and thinks that γ values should be higher, it can be noted that in some cases they need to be higher by more than a factor of two in order to affect the nature of the optimal strategies.

5.5 β for value capture

The raising of finance through value capture was considered, in FATIMA, to be mainly concerned within scenarios in which optimal BOF transport strategies led to a public sector financial deficit. If it were assumed that hard constraints on public spending were imposed, then such strategies would be unaffordable without some extra financial input from the private sector. Value capture is potentially a mechanism for providing such finance. Ideally, the use of value capture would make it (financially) feasible to implement optimal transport strategies whilst still remaining within strict public sector spending limits.

As the classification of cities (in Section 4) has shown, there was a public sector deficit with regard to BOF optimal strategies in only three of the nine city case studies: Merseyside, Tromsø and Helsinki. In these cities, the optimal COF strategies (assuming hard constraints on public spending with no value capture) were significantly different from the optimal BOF strategies, as shown in Table 6. In such cities, ROF optimal strategies were found in which extra finance was available from value capture.

β was defined as being the proportion of user benefits that could be "captured" (from the private sector) to help create optimal transport strategies: the standard value given to β was 0.1. At this level, it was found that only Merseyside would benefit significantly from value capture, in the sense that the optimal ROF strategy was significantly different from the optimal COF strategy. Hence Merseyside was defined as a Class 1 city whilst Tromsø and Helsinki were defined as Class 2 cities (as reported in Section 4).

The standard value of 0.1 given to β was somewhat arbitrary, since there is little experience of using value capture on a strategic level (as opposed to using it for one spatially-specific infrastructure project). It could be argued that a value of 0.1 was somewhat pessimistic. Thus it was considered necessary to carry out an analysis on this value to determine the level of β, if any, at which optimal BOF strategies would be financially feasible, even under strict public spending limits, using value capture.

Table 11 shows the user benefits (UB) and values of PVF for the BOF optimal strategies of Merseyside, Tromsø and Helsinki. Furthermore, it shows the level that β must be in order to raise a sufficient amount of value capture for funding the optimal BOF strategy under a constrained public finance regime. This level is calculated simply by dividing PVF by UB.

Table 11 here

For Helsinki the required value of β is 0.76 so that 76% of user benefits would need to be recaptured through value capture. Such a figure might be considered unattainable. On the other hand, the comparable figures for Merseyside and Tromsø were 0.37 are 0.30 respectively. Further research is required to examine whether this level of value capture is feasible.

Merseyside is a Class 1 city whatever the value of β. However, with sufficiently high values of β for Tromsø and Helsinki, they move from being Class 2 cities to Class 1 cities.

6 TRANSPORT POLICY CONCLUSIONS

In many cases the optimal strategy is sensitive to decisions on the use of a shadow price for public funds, and the level at which this should be set. A shadow price indicates that there are opportunity costs involved in the use of public funds for transport. Where an increase in public expenditure on transport is justified with a shadow price, this suggests that it is justifiable either to increase taxation to pay for improved transport, or to reduce expenditure in competing policy areas. Where an increase in revenue is justified with a shadow price, this suggests that it is appropriate to reduce public expenditure on transport, by increasing the cost to the user or reducing the service offered. This can result either in reduced taxation or increased expenditure in competing policy areas. It is clear from the results given in Section 5 that it is important to test the sensitivity of strategies to the use, and level, of a shadow price. Where strategies are sensitive, the policy implications require careful assessment.

The optimal strategies given in Section 4 were relatively insensitive to the balance between the perspectives of current and future generations, except when this balance was strongly in favour of future generations. Thus the strategies which reflect the present generation's perspective are also likely to reflect an equal balance of perspectives between current and future generations. When the perspective of future generations becomes paramount, strategies are likely to change in favour of increased car user costs and reduced public transport fares. High investment in further public transport infrastructure (on top of what has already been committed) appears to be optimal only when such a perspective is paramount.

The optimal strategies are relatively insensitive to the costs of externalities. When externality costs are based upon currently accepted values, optimal strategies are similar to those with no value assigned to the externalities. This implies that those strategies which are most effective in achieving a balanced economic efficiency / sustainability objective also perform best when this objective is extended to take into account the local environment and safety, using standard values for the costs of these. However, if greater emphasis were to be put on the local environment and safety by evaluating their costs at a much higher level, optimal strategies would be likely to involve imposing higher charges for car use.

When hard constraints on public funds are applied and the revenue for optimal strategies cannot be met by user charges (as was the case in three of the case study cities), a potentially attractive option lies in raising extra finance through value capture. With regard to the three case studies concerned, it was found that a minimum of 30% of net user benefits would need to be captured. If this level were achievable, value capture would provide an important mechanism for injecting extra finance into the transport sector.

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City	Country	Population (k)
Eisenstadt	Austria	10
Tromsø	Norway	57
Salerno	Italy	149
Edinburgh (MA)	UK	420
Helsinki (MA)	Finland	910
Oslo (MA)	Norway	919
Merseyside (MA)	UK	1440
Torino (MA)	Italy	1450
Vienna	Austria	1540

MA : metropolitan area

Table 1 : The FATIMA case study cities

Policy measure		Range	
Name	**Aggregation**	**Min Value**	**Max Value**
High public transport infrastructure investment	n/a	0	1 (dummy)
Medium public transport infrastructure investment	n/a	0	1 (dummy)
Increase/decrease of road capacity	whole city	-20%	+10%
Increase/decrease in public transport frequency	whole city; all-day, peak, off-peak	-50% (-30% for Torino)	+100% (+30% for Torino)
Road pricing to enter city centre	city centre; all-day, peak, off-peak	0	5.0 euros
Increase/decrease in parking charges	city centre; long & short term, long term, short term	-100%	+300% (+100% for Torino)
Increase/decrease in public transport fares	whole city; all-day, peak, off-peak	-100% (-50% for Helsinki)	+100%

Table 2: Measures tested in FATIMA, their aggregation and ranges

	Edinburgh	Merseyside	Vienna and Eisenstadt	Oslo	Tromsø	Helsinki	Salerno	Torino
Model	START	START	VW	RETRO and EMME/2	EMME/2 based	PKS model and EMME/2	T.Model T.Road,T.Bus	T.Model and MAESTRO
Strategic/ tactical	Strategic	Strategic	Strategic	Tactical	Tactical	Tactical	Tactical	Tactical
Responses	Mode, Route, Time of day, Distribution, Generation/ Suppression	Mode, Route, Time of day, Distribution, Generation/ Suppression	Combined distribution and mode choice, Route, Pedestrian delay	Mode, Route, Time of day, Distribution, Generation/ Suppression	Mode, Route, Time of day, Distribution, Generation/ Suppression	Combined distribution and mode choice, Route	Mode, Route	Mode, Route
Periods	AM peak PM peak Rest of day	AM peak PM peak Rest of day	All day	AM peak Rest of day	AM peak PM peak Rest of day	AM peak PM peak Rest of day	Peak period	Peak period

Table 3: Model characteristics

Objective function	**Acronym**	**Description**
Present Value of Finance	PVF	Present value of net financial benefits to operators and government, calculated over a 30 year time horizon.
(Present value of net) Benefits	B	Present value of net benefits to travellers, operators and the government, calculated over a 30 year time horizon but ignoring initial infrastructure costs.
External Costs	EC	Present value of costs of pollution, noise and safety calculated over a 30 year time horizon.
Economic Efficiency Function	EEFP	Present value of net benefits to travellers, operators and government, combined with external costs, calculated over a 30 year time horizon. There is a shadow price on government revenues and costs, determined by the parameter λ.
Sustainability Objective Function	SOF	SOF focuses entirely upon the net benefits of travellers, operators and government in a future target year. It imposes a high shadow price on fuel and dictates that the fuel consumption of the do-minimum strategy is the maximum allowable.
Benchmark Objective Function	BOF	BOF trades off economic efficiency (EEFP) and sustainability (SOF). The relative weights accorded to EEFP and SOF are determined by the parameter α.
Constrained Objective Function	COF	Extension of BOF which assumes that public finance is constrained to the do-minimum level.
Regulated Objective Function	ROF	Extension of COF, which recognises that extra (private) finance can be input to the transport system through value capture. The level of value capture is determined by the parameter β.

Table 4: Summary of the FATIMA objective functions

	Pollution	Noise	Accidents	Total cost
Car	0.0275	0.0373	0.0222	0.087
Bus	0.2176	0.0746	0.0453	0.3375
Tramway	0.0	0.0622	0.0453	0.1075
Total	0.2451	0.1741	0.1128	0.532

Table 5: Pollution, noise and accident costs in euros per veh-km (γ values) given by Tinch (1995)

Measures / Cities	Objective function	PT Infrastructure investment - High, Medium or None	Increasing/ Decreasing Road capacity	PT frequency †	PT fares †	Road Pricing †	Parking Charges @	PVF (Meuros)	PVF / Popn (Euros per capita)
Edinburgh	BOF, COF, ROF	Medium	10%	85%(70%)	-90%(-35%)	1.6(1.6)	~(300%)	233	555
Merseyside	BOF	Medium	10%	50%(-40%)	-100%(-100%)	0(0)	-100%(100%)	-2120	-1472
Merseyside	COF	Medium	10%	20%(-50%)	-65%(-40%)	1(1)	0%(200%)	32	22
Merseyside	ROF	Medium	10%	20%(-50%)	-75%(-40%)	1(1)	0%(100%)	-152	-106
Vienna	BOF, COF, ROF	None	-10%	0%	77%	0	0%(245%)	3903	2534
Eisenstadt	BOF, COF, ROF	-	-15%	-50%	-50%	0	-50%(115%)	9	900
Tromsø	BOF	-	10%	46%(0%)	-100%(-50%)	2(1.6)	-100%	-84	-1474
Tromsø	COF, ROF	-	5%	25%(15%)	-50%(+40%)	2(3)	-100%	9	158
Oslo	BOF, COF, ROF	Medium	10%	-15%(0%)	-5%(-15%)	5(5)	0%	5976	6503
Helsinki	BOF	No	0	25%(13%)	-12%(-50%)	0(0)	0%(0%)	-1779	-1955
Helsinki	COF, ROF	No	0%	0%(-10%)	-5%(-15%)	0(0)	20%(90%)	52	57
Torino	BOF, COF, ROF	No	10%	30%	100%	0	100%	710	490
Salerno	BOF, COF, ROF	No	0	80%	25%	0	300%	88	591

- not included

~ indicates irrelevant around the optimum

† off peak values are shown in ( ) for Edinburgh, Merseyside, Tromso, Oslo, Helsinki

@ long stay; short stay values are shown in ( ) for Edinburgh, Merseyside, Vienna, Eisenstadt, Tromso, Oslo, Helsinki

Table 6 : Optimal Strategies (with default parameter values): BOF, COF and ROF

	λ (1+λ) is shadow price on PVF in EEFP	α weight on current/future generations in BOF	γ weight on external costs in EEFP	β proportion of user benefits captured in VC
Edinburgh	√	√	√	-
Merseyside	√	√	√	√
Vienna	√	√	√	-
Eisenstadt	-	√	√	-
Oslo	√	√	-	-
Tromsø	-	-	-	√
Helsinki	-	-	-	√
Salerno	√	√	-	-

Table 7 : sensitivity tests conducted in city case studies

Measures / Cities	Value of λ	Infrastructure investment - High, Medium or None	Increasing/ Decreasing Road capacity	PT frequency †	PT fares †	Road Pricing †	Parking Charges @	Class of city
Edinburgh	*0.25*	*Medium*	*10%*	*85%(70%)*	*-90%(-35%)*	*1.6(1.6)*	*~(300%)*	*3*
Edinburgh	0	Medium	10%	85%(70%)	-90%(-35%)	1.6(1.6)	~(300%)	3
Merseyside	1.5	Medium	10%	20%(-40%)	-70%(-40%)	1(1)	0(200%)	3
Merseyside	1.0	Medium	10%	20%(-40%)	-70%(-40%)	1(1)	0(200%)	3
Merseyside	0.5	Medium	10%	34%(-50%)	-100%(-100%)	0(0)	-100%(300%)	1
Merseyside	*0.25*	*Medium*	*10%*	*50%(-40%)*	*-100%(-100%)*	*0(0)*	*-100%(100%)*	*1*
Vienna	*0.25*	*None*	*-10%*	*0%*	*77%*	*0*	*0%(245%)*	*4*
Vienna	0.2	None	-10%	0%	50%	0	0%(245%)	4
Vienna	0.1	None	-9%	3%	4%	0	0%(225%)	4
Vienna	0	None	-7%	3%	-15%	0	-13%(150%)	3
Oslo	*0.25*	*Medium*	*10%*	*-15%(0%)*	*-5%(-15%)*	*5(5)*	*0%*	*4*
Oslo	0	Medium	10%	-10%(0%)	-5%(-15%)	5(5)	0%	4
Salerno	*0.25*	*None*	*0%*	*80%*	*25%*	*0*	*300%*	*3*
Salerno	0	None	10%	50%	-50%	1	-50%	2

~ indicates irrelevant around the optimum

† off peak values are shown in ( ) for Edinburgh, Merseyside, Oslo

@ long stay; short stay values are shown in ( ) for Edinburgh, Merseyside, Vienna, Oslo

Table 8 : Optimal BOF Strategies when the value of λ is varied

Measures / Cities	Value of α	Infrastructure investment - High, Medium or None	Increasing/ Decreasing Road capacity	PT frequency †	PT fares †	Road Pricing †	Parking Charges @	City Class
Edinburgh	0	High	10%	53%(100%)	-100%(0%)	3.3(3.2)	~(300%)	3
Edinburgh	0.015	High	10%	53%(100%)	-100%(0%)	3.3(3.2)	~(300%)	3
Edinburgh	*0.1*	*Medium*	*10%*	*85%(70%)*	*-90%(-35%)*	*1.6(1.6)*	*~(300%)*	*3*
Edinburgh	1.0	Medium	10%	85%(70%)	-90%(-35%)	1.6(1.6)	~(300%)	3
Merseyside	0	Medium	10%	50%(-40%)	-100%(-100%)	0	0%(200%)	1/3
Merseyside	*0.1*	*Medium*	*10%*	*50%(-40%)*	*-100%(-100%)*	*0*	*-100%(100%)*	*1*
Merseyside	1.0	Medium	10%	50%(-40%)	-100%(-100%)	0	-100%(100%)	1
Vienna	0	High	-11%	12%	80%	0	0%(200%)	3
Vienna	*0.1*	*None*	*-10%*	*0%*	*77%*	*0*	*0%(245%)*	*4*
Vienna	0.25	None	-12%	0%	77%	0	0%(245%)	4
Eisenstadt	0	-	-15%	-50%	-50%	0	-50%(115%)	3
Eisenstadt	*0.1*	-	*-15%*	*-50%*	*-50%*	*0*	*-50%(115%)*	*3*
Eisenstadt	0.25	-	-15%	-50%	-50%	0	-50%(115%)	3
Oslo	0	Medium	10%	0%(-10%)	-10%(-30%)	5(5)	0%	4
Oslo	*0.1*	*Medium*	*10%*	*-15%(0%)*	*-5%(-15%)*	*5(5)*	*0%*	*4*
Oslo	0.25	Medium	10%	-15%(0%)	-5%(-15%)	5(5)	0%	4
Oslo	1.0	Medium	10%	-15%(-15%)	20%(20%)	5(5)	0%	4
Salerno	0	No	0	80%	25%	0	300%	3
Salerno	*0.1*	*No*	*0*	*80%*	*25%*	*0*	*300%*	*3*
Salerno	0.25	No	0	80%	25%	0	300%	3

- not included, ~ indicates irrelevant around the optimum, † off peak values are shown in ( ) for Edinburgh, Oslo
@ long stay; short stay values are shown in ( ) for Edinburgh, Vienna, Eisenstadt, Oslo

Table 9: Optimal BOF Strategies when the value of α is varied

Measures / Cities	Multiply original γ by:	Infrastructure investment - High, Medium or None	Increasing/ Decreasing Road capacity	PT frequency †	PT fares †	Road Pricing †	Parking Charges @	Class of city
Edinburgh	*1*	*Medium*	*10%*	*85%(70%)*	*-90%(-35%)*	*1.6(1.6)*	*~(300%)*	*3*
Edinburgh	2	Medium	10%	85%(70%)	-90%(-35%)	3.5(3.2)	~(300%)	3
Merseyside	0	Medium	10%	50%(-40%)	-100%(-100%)	0(0)	-100%(100%)	1
Merseyside	*1*	*Medium*	*10%*	*50%(-40%)*	*-100%(-100%)*	*0(0)*	*-100%(100%)*	*1*
Merseyside	2	Medium	10%	50%(-40%)	-100%(-100%)	0(0)	-100%(100%)	1
Merseyside	10	Medium	5%	25%(-40%)	-100%(-100%)	3.5(3.5)	0%(200%)	3
Vienna	0	None	-8%	0%	77%	0	0%(245%)	4
Vienna	*1*	*None*	*-10%*	*0%*	*77%*	*0*	*0%(245%)*	*4*
Eisenstadt	0	-	-15%	-50%	-50%	0	-50%(115%)	3
Eisenstadt	*1*	-	*-15%*	*-50%*	*-50%*	*0*	*-50%(115%)*	*3*

- not included

~ indicates irrelevant around the optimum

† off peak values are shown in ( ) for Edinburgh, Merseyside

@ long stay; short stay values are shown in ( ) for Edinburgh, Merseyside, Vienna, Eisenstadt

Table 10 : Optimal BOF Strategies resulting from changing the value of γ

	Merseyside	Tromsø	Helsinki
User benefits for optimal BOF strategies (UB) (million euros)	5740	280	2330
PVF for optimal BOF strategy (million euros)	-2120	-84	-1779
Required value of β to implement optimal BOF strategy under a constrained public finance regime	0.37	0.30	0.76

Table 11: Value capture and PVF for BOF optimal strategies