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# Should values of time be differentiated?

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**ABSTRACT**

We explore the issue of differentiating the valuation of travel time savings (VTTS) in transport cost-benefit analysis, summarising and discussing theories forming the basis for arguments for and against VTTS differentiation. We stress some important implications, insights and consequences of different assumptions relating to these theories, many of which we feel have been underappreciated in much of the CBA literature and practice. We derive a welfare rule including a social cost for monetary redistributions and show the implications for how the VTTS can be defined in different choice situations. Crucially, the applicable VTTS definition depends on whether travel costs (fares) are under public control and to whom benefits accrue in the long run. In some choice situations, the VTTS should be controlled for differences in *income*, but it is important to always take into account differences in marginal utilities of time (e.g. across travel time components, modes and trip purposes). Using Swedish data, we show that controlling the VTTS for income differences changes the VTTS only slightly; the variation in VTTS across modes, trip lengths, trip purposes apparently stems primarily from differences in marginal utilities of time rather than income.

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## 1. Introduction

To what extent the value of travel time savings (VTTS) should be differentiated in applied transport cost-benefit analyses (CBA) is a contentious issue. The purpose of this paper is to summarise and discuss some theories forming the basis for arguments for and against differentiation of VTTS in transport CBA.[1] We stress some important implications, insights and consequences of different assumptions relating to these theories, many of which we feel have been underappreciated in much of the CBA literature and practice. To draw some conclusions for applied CBA we also include some empirical evidence from Sweden.

The Kaldor-Hicks criterion is a cornerstone of social cost-benefit analysis: if winners can compensate losers, then the project is considered to improve welfare. Clearly, this means that project evaluation should assign the same values to the project consequences as the affected individuals do. On the other hand, since the VTTS is known to increase with income (Abrantes & Wardman, 2011; Amador, González, & Ortúzar, 2005; Axhausen

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et al., 2008; Börjesson, 2014; Cherchi & Ortúzar, 2010; Fosgerau, 2005, 2006; Hess, Bierlaire, & Polak, 2005; Ramjerdi, Flügel, Samstad, & Killi, 2010; Wardman, 2001), some authors (Mackie, Jara-Díaz, & Fowkes, 2001) argue that the Kaldor-Hicks criterion gives more weight to rich people's time savings than to poor people's. Insofar as transport investments are paid for by the public purse, and in the absence of compensation schemes, this is clearly inequitable.

The scientific literature and appraisal practice are divided on this issue. Some authors and applied appraisal guidelines support using actual VTTS:s (often called *behavioural VTTS*), and hence differentiating the VTTS among user groups (e.g. Sugden (1999), Harberger (1978); appraisal guidelines in Sweden, Norway and New Zealand). Other authors and appraisal guidelines take the opposite extreme, arguing that a single or very few VTTS:s (often called *equity VTTS*) should be used for all private journeys (e.g. Pearce and Nash (1981), Mackie et al. (2001); the current German and British appraisal guidelines). The Netherlands used to apply equity VTTS but the new official VTTS:s (Kouwenhoven et al., 2014) are differentiated by mode in the appraisal guidelines. The differentiation of the new English VTTS (Arup, ITS Leeds, & Accent, 2015) is under consultation at the time of writing. To our knowledge, differentiating VTTS *explicitly* by income is not applied or suggested anywhere; the question is rather whether the VTTS should be differentiated by mode, trip purpose, trip length and potentially other trip characteristics as well (e.g. time of day or geography). But since travel patterns vary systematically with income, differentiating the VTTS in these dimensions will have consequences for the average value put on time savings for each income group. It is a well-known fact that the VTTS usually varies in these dimensions, but much less is known about to what extent these variations are driven by differences in income. As we shall see, this is a crucial issue.

Section 2 is devoted to a theoretical derivation of a welfare rule and a VTTS for applied appraisal. It builds on the framework developed by Galvez and Jara-Díaz (1998), who derive a welfare rule where variations in the VTTS due to differences in marginal utility of income should be removed. If one *also* assumes that projects are completely tax-funded, that travel costs do not change, and that variation in marginal utilities of time is negligible (which Mackie et al. (2001) argue is a "defensible assumption"), this leads to a constant single VTTS for all travellers. However, if any of these assumptions are violated, a single VTTS does not follow (which Gálvez and Jara-Díaz also point out) and leads to paradoxes and inconsistencies. This lies (implicitly) at the heart of the argument by Sugden (1999), who advocated using behavioural VTTS. We will show precisely where these previous authors' assumptions and lines of argument diverge.

We extend Gálvez and Jara-Díaz framework in three ways. First, we introduce a social cost of monetary redistribution, which allows us to explain why even in a situation welfare-maximizing government, marginal utilities of income may vary between citizens. Second, we consider situations where price mechanisms transfer time savings benefits from travellers to other groups, for example land owners and transport operators. Third, we consider situations where certain prices are under public control (such as transit fares or road user charges), and policy makers hence can choose to spend money to lower fares or increase fares to help fund travel time savings. This extended framework allows us to show that the definition of the VTTS in applied CBA should be different in different choice contexts, for example depending on whether travel costs are under public control or not and whether benefits accrue to travellers or to other stakeholders.

The extended framework also allows us to explain precisely where the line of argument of Galvez and Jara-Díaz differs from that of e.g. Sugden and Harberger. We conclude that in some contexts, the VTTS should be controlled for income differences, but in some cases it should not. An important conclusion is that the VTTS should always account for differences in marginal utilities of *time*, for example across travel time components, modes or trip purposes.

The conclusion that the VTTS should sometimes be controlled for income differences raises the question to what extent this actually changes the VTTS, and how much of the variation in the VTTS can be attributed to other factors than income, such as travel comfort. We investigate this using Swedish data in Section 3, finding that a relatively small share of VTTS differences across modes, purposes and trip lengths can be attributed to differences in income. This means that the practical difference between the income adjusted and the behavioural VTTS positions are in fact small. It also demonstrates that that removing *all* VTTS differences across modes, journey types etc. (the extreme equity position) throws the baby out with the bathwater. CBA becomes less informative for project prioritisation if it does not acknowledge that the values of travel time savings do indeed vary substantially between contexts, even for a given individual, or for individuals with the same income.

## 2. The model

### 2.1. Setting the stage

Let $q$ be an index of user groups with homogenous preferences.[2] Consider a project which changes travel times $\{\Delta t_q\}$, travel costs $\{\Delta c_q\}$ and monetary transfers (such as taxes) $\{\Delta z_q\}$.[3] Let $\lambda_q$ be the marginal utility of income, $\mu_q$ the marginal utility of time and $\Omega_q$ the social weight[4] of group $q$. We assume (for now) that the changes are so small that the marginal utilities and social weights $\Omega_q$ can be treated as constant. The change in social welfare $\Delta W$ of a project is by definition

$$\Delta W = \sum_q \Omega_q(\mu_q \Delta t_q + \lambda_q \Delta c_q - \lambda_q \Delta z_q) \quad (1)$$

In standard CBA, travel time savings are converted to money using each group's valuation of travel time savings (VTTS) $(\mu_q/\lambda_q)$, so monetised benefits become $\Delta B$:

$$\Delta B = \sum_q \frac{\mu_q}{\lambda_q} \Delta t_q + \Delta c_q - \Delta z_q. \quad (2)$$

Comparing (1) and (2), it is clear that using (2) as a welfare measure is equivalent to setting the social weights inversely proportional to marginal utilities of income, i.e. $\Omega_q = (1/\lambda_q)$. If the marginal utility of income $\lambda_q$ decreases with income, this implies that the social weight of each group $\Omega_q$ increases with income, which means that the welfare measure in (2) is regressive by definition.

This is one of the main points in Galvez and Jara-Díaz (1998). Gálvez and Jara-Díaz continue by arguing that instead of using (2), one should define the *social utility of money* $\lambda_s$ as a weighted average of marginal utilities of income with weights equal to each group's tax contribution: $\lambda_s = (\Sigma_q \lambda_q \Delta z_q / \Sigma_q \Delta z_q)$. When the government designs the taxation system, it takes $\Delta z_q$ from each group $q$. This determines the disutility of each group $q$ imposed by a marginal increase in the tax revenues. Dividing (1) with $\lambda_s$ and setting $\Omega_q$=1 ∀q yields Gálvez' and Jara-Díaz' "neutral" welfare measure.

$$\Delta B' = \sum_q \frac{\mu_q}{\lambda_s}\Delta t_q + \frac{\lambda_q}{\lambda_s}\Delta c_q - \Delta Z. \tag{3}$$

Here, $\Delta Z = \Sigma_q z_q$ is the aggregate tax take needed for the project. Gálvez and Jara-Díaz call the ratio $(\mu_q/\lambda_s)$ the *social* VTTS. Note that it will not be equal across traveller groups $q$: it will vary with $q$ to the extent that the marginal utility of time $\mu_q$ varies across groups. Note also that the social VTTS is not simply the VTTS controlled for differences in income; it is the marginal utility of time of each group divided by the social utility of money as defined above.[5]

Gálvez and Jara-Díaz continue by noting that *if* marginal utilities of time are equal across groups, projects are tax-funded, and travel costs remain unchanged, (3) leads to a social VTTS $(\mu/\lambda_s)$ which is equal across groups, since the welfare rule becomes

$$\Delta B' = \frac{\mu}{\lambda_s}\sum_q \Delta t_q - \Delta Z. \tag{4}$$

In a follow-up paper, Mackie et al. (2001) argue that it is a "defensible assumption" that differences in marginal utilities of time can be disregarded – in other words, that differences in income is the only important source of variation in VTTS – leading them to recommend the equity VTTS approach.

The way the welfare rule (4) has been applied in practice raises concerns, because there is no strong reason to believe that the assumptions leading to (4) hold. Below, we will change or extend this model in three ways: first, we consider situations where travel costs change; second, we extend to model to explain why there may be differences in marginal utilities of income even under a benevolent government; third, we consider the case where not all benefits accrue to travellers, but are dispersed to e.g. land owners or transport operators. This changes how the VTTS should be defined when evaluating and ranking projects.

### 2.2. Allowing for changes in travel costs

Consider situations where travel costs change – either because prices are under public control (e.g. local transit fares), or they change by markets forces as a result of a project, or users change behaviour as a result of a project (for example switching modes). Using an "equity" VTTS can then quickly lead to anomalies and paradoxes.

Sugden (1999) demonstrates how the use of equity VTTS can lead to inconsistencies. His example concerns a suggested high-speed railway line, where operation costs would be partly subsidised with public money. The subsidy is justified because the high-speed trains would generate external benefits in the form of reduced road congestion, and the value of the external benefits would be greater than the required subsidy. The operator of the service intends to charge high fares and to attract high-income passengers. According to the welfare measure (2), the project and the subsidy are justified. However, if the equity VTTS is used in (2) it might not be, because the time saved by train passengers would be assigned a lower value than the passengers' actual ("behavioural") VTTS. This can yield a negative consumer surplus for the new train passengers, incorrectly showing that they are worse off – which cannot be the case since they are voluntarily switching to the new train.

Similar anomalies might arise in the case of subsidised public transport where fares are under public control. Consider a case with a subsidised bus service, where the government chooses between two ways to increase the attractiveness of a bus service: reduce the bus fare by increasing the public subsidy, or reduce the travel time through infrastructure investments. Assume that the bus passengers' behavioural VTTS is lower than their equity VTTS (for example because they are poorer than average). Using the equity VTTS may then show that the faster bus is the preferred option, even if the bus passengers would prefer having reduced fares over the shorter travel time.

In both Sugden's and our examples, the inconsistencies arise because the assumption that travel are unchanged is violated.

### *2.3. Explaining differences in marginal utilities of income*

The Gálvez and Jara-Díaz framework, does not explain how each group's tax contribution, $\Delta z_q$, are determined. It is implicitly assumed that $\{\Delta z_q\}$ is a bargaining outcome without any moral or economic interpretation or justification. However, many governments are in fact both willing and able to undertake substantial monetary redistributions, in particular in many countries where social appraisal is most widely used. Presumably, the aim of such income redistributions is to maximise social welfare. But then, why does the government not redistribute money among the groups $q$ up to the optimal level? The assumption that the government uses the welfare measure (3) and has the power to redistribute money between citizens is not consistent with heterogeneous marginal utilities of income. The optimal policy would be to take money from all groups and give it to the group with the highest marginal utility of income, until marginal utilities of income are equal across all groups. This is not consistent with empirical observations of government policy.

If we want to keep the assumption that the government strives to maximise aggregate social utility, there must be some social disutility involved with redistributing money (this is also noted by Drèze and Stern (1987) as a side note (p. 958)). Redistributing money can be associated with two different kinds of social disutility. First, most tax sources cause deadweight losses. The net social loss caused by a marginal increase in tax revenue is called the marginal cost of public funds (MCPF). Second, it can be argued that there is a *direct* disutility associated with redistributing money, which can be called the *moral* cost incurred when the government seizes money from someone and gives it to someone else. Whether this is a cost at all, and the extent to which this practice is ethically defensible, has been debated at least since Rousseau (1762) and Hume (1777), with relatively recent contributions by philosophers such as Nozick (1974) and Rawls (1971) (taking almost opposite positions). It can also be interpreted as a public acceptability restriction.

The observation that most governments do make substantial redistributions between groups is in fact an important justification of the Kaldor-Hicks welfare criterion. The redistribution system may not be perfect, but it seems strong to assume that it is completely irrelevant. To take this argument into account, we proceed by setting up a model relying on the assumptions (i) that the government is benevolent and maximises total utility in society by using the redistribution systems, (ii) that equal social weights are assigned to all groups $q$, and (iii) that there is a cost associated with redistributing money between individuals.

Let $D_q$ be the marginal disutility (deadweight loss plus moral cost[6]) of a transfer from group $q$, and assume unitary welfare weights. This gives us the following welfare measure of a policy $\{\Delta t_q, \Delta c_q, \Delta z_q\}$:

$$\Delta W = \sum_q \mu_q \Delta t_q + \lambda_q \Delta c_q - D_q \lambda_q \Delta z_q \tag{5}$$

Consider the government's problem to raise a revenue d$z$ while imposing minimal disutility d$W$ on the population:

$$\mathrm{d}W = \min_{\{\Delta z_q\}} (\Sigma_q D_q \lambda_q \Delta z_q) \ s.t. \Sigma_q \Delta z_q \geq \mathrm{d}z \tag{6}$$

The optimality conditions of this problem are

$$D_q \lambda_q = \pi \quad \forall q \tag{7}$$

where $\pi$ is the Lagrange multiplier of the constraint. This shows that $D_q \lambda_q$ must be equal across all groups $q$ in equilibrium.[7] Using the envelope theorem, we can then define the marginal disutility of public funds $D\lambda \equiv dW/dz = \pi$ as the minimal marginal total disutility to raise funds for the government. This is the product of two factors: the marginal social utility of money $\lambda$ and the marginal social cost of public funds $D$. If there are no moral costs associated with monetary transfers, $D$ is the conventional marginal cost of public funds (MCPF). The marginal social utility of money $\lambda$ is a conversion factor from utility to money, and can be interpreted as the marginal utility of income for a "representative" individual. The definition of "representative" is necessarily to some extent a matter of choice; in the empirical section we will simply use the average income. This necessary arbitrariness is of limited importance, however, since the definition of $D$ follows from the choice of $\lambda$ and hence changes to accommodate for different possible $\lambda$ definitions. Note that $\lambda$ differ between different populations of taxpayers and therefore depend on which "government" is financing the project (e.g. local, regional, or national governments).

The social cost of public funds $D$ is, as noted above, at least as high as the marginal deadweight loss of generating public funds (the MCPF). But there may be several reasons why $D$ may be larger than the MCPF.[8] A potentially possible way to determine $D$ empirically is to observe a government's actual policy choices. Consider a policy which changes travel times by $\{\Delta t_q\}$ and travel costs by $\{\Delta c_q\}$ and with the costs of public funds $\{\Delta z\}$ (the optimal way to raise this amount of public funds from different groups $q$ is implied by the solution to the optimisation problem (6)). This improves welfare if

$$\Delta B = \sum_q \frac{\mu_q}{\lambda} \Delta t_q + \frac{\lambda_q}{\lambda} \Delta c_q - D \Delta z > 0, \tag{8}$$

where utilities have been converted to a monetary metric. Continuing to assume that the government strives to maximise welfare, $D$ can now be determined by observing the total budget that the government spends on transport projects, if we assume that all possible projects are ranked according to their benefit/cost ratio $(\Sigma_q (\mu_q/\lambda)\Delta t_q + (\lambda_q/\lambda)\Delta c_q)/\Delta z$, and the government implements the projects starting at the top of the list, continuing until this benefit/cost ratio is less than *D*. In practice, this assumption can be questioned. First, not all costs and benefits are easily quantified and monetised in a cost-benefit analysis; second, there are certainly other factors, besides measurable costs and benefits, influencing government decisions. In particular, it is common that governments choose to implement certain projects with very low benefit/cost ratios for various political reasons (Flyvbjerg, 2009). In fact, in both Sweden and Norway, the infrastructure budget is larger than what is needed for realising all socially beneficial projects (Eliasson, Börjesson, Odeck, & Welde, 2015).

### *2.4. Dispersion of benefits "off the road"*

The analyses and argumentations above do not take into account that the benefit of a project may not accrue to travellers. In the long run, at least some of the benefits of a transport investment are likely to be dispersed across the economy, rather than staying with the travellers. This is mediated through prices which change as a consequence of the project: operators may increase fares, housing prices may increase, retail prices and parking costs may change and so on. Through such mechanisms, parts of the benefits will be transferred to a mixture of land owners, taxpayers, transport companies, employers, businesses, customers and travellers. There is a massive body of theoretical and empirical evidence of increasing land values in response to transport investments (see Smith and Gihring (2006)), indicating that at least some of the benefits from transport investments are transferred from the travellers to the land owners (Batt, 2001; Mohring, 1961). That transport operators such as commercial railway companies are able to capture some of the benefits through increased fares is obvious. In a reality with imperfect competition, income taxation and price and planning regulations, the final, long run incidence is not possible to assess precisely. The final benefits will tend to accrue to agents who control a scarce resource, for instance land. The essential point is that the distribution of the benefits and losses between the groups *q* will differ from those of the direct first-order effects assumed in (8). The consequences of this possibility do not seem to have been acknowledged properly in the debate on whether to use behavioural or equity values of time. Taking this into account has consequences for how the VTTS in applied appraisal should be defined, which we will discuss in detail below.

The standard CBA tradition does not deal with to whom the final benefit of transport investments will accrue, and in what market they will end up (SACTRA, 1999). Instead this tradition relies on the result that total benefits can be measured "on the road" (as user benefits), under the assumption that related markets are perfect (Jara-Díaz, 1986). Surprisingly, however, the literature on equity and social VTTS tacitly makes the strong assumption that the benefits also *stay* "on the road" even in the long run, i.e. that no other prices – fares, housing prices, profits, wages etc. – are affected by the policy. But this assumption is clearly contradicted by both theory and empirical results. This can be contrasted with the debate about the valuation of travel time savings for business trips, where it has long been an explicit discussion about to what extent benefits accrue to the traveller and to the employer, respectively. The argument that at least some part of (and perhaps all) benefits of business trip time savings accrue to the employer is a fundamental reason for business trip VTTS being higher than the VTTS for private trips in CBA guidelines.

The problem is that how much of the benefits (for private trips) that accrue to different agents in the long run will depend on a number of context-specific questions, and it will normally not be possible to calculate this. But the evidence that some or all of the benefits will be transferred from the travellers is an argument for using the behavioural VTTS in transport appraisal, since it is the behavioural VTTS that determines WTP and this in turn is the value that is dispersed in the economy as a whole through price changes.

### 2.5. Different VTTS in different decision contexts

We will now formalise the considerations discussed above in a formal model. Consider again the problem a welfare-maximizing planner faces. The task is to select what projects $q$ to implement, where the total utility of these projects can be written as in (8), so travel time savings are weighted by $(\mu_q/\lambda)$, and travel costs savings by $(\lambda_q/\lambda)$. The crux is of course to estimate these weights. Whether this is possible or not comes down to what econometric assumptions one is willing to make. The assumptions required to estimate $(\mu_q/\lambda)$ are (arguably) weaker than those required to estimate $(\lambda_q/\lambda)$. Under two assumptions defined in Section 3 we will show that $(\mu_q/\lambda)$ equals the behavioural VTTS controlled for income.

The weight $(\lambda_q/\lambda)$, on the other hand, measures differences in marginal utilities of income between population groups. While this ratio also comes out from the estimation (as shown in Section 3), trusting this requires quite a lot more confidence in the data and the econometric specifications. Choice situations where we can usefully apply (8) without knowing $(\lambda_q/\lambda)$ are therefore particularly relevant. We will consider three different such choice situations – and as we shall see, what is even more interesting is that they lead to different conclusions regarding how the VTTS should be specified, and also explain precisely why Galvez/Jara-Díaz/Mackie's conclusions differ from Sugden/Harberger's.

First, consider a situation where travel costs are fixed ($\Delta c_q = 0$): they cannot be changed by the planner, nor do they change as a second-order effect of the projects. This gives

$$\Delta B = \sum_q \frac{\mu_q}{\lambda} \Delta t_q - D\Delta z_q. \tag{9}$$

This eliminates the need to estimate ratios of marginal utilities of income $(\lambda_q/\lambda)$. Most importantly, it is operational: if the planner's problem is to pick a number of projects subject to a budget constraint $\Sigma_q \Delta z_q \leq \Delta Z$, then the expression leads to a standard knapsack problem. The solution is to value time savings with the corresponding VTTS but controlled for differences in income across the population (but keeping all other VTTS variation!), rank projects in descending order according to the ratio $(\mu_q/\lambda)(\Delta t_q/\Delta z_q)$, and pick projects from the top of the list until the budget constraint is met. This ordering is independent of $\lambda$, so the *ordering* of projects is independent of how $\lambda$ is defined. The optimal value of this problem – the maximal achievable utility, measured in tax money – is a function of the budget constraint $\Delta Z$. Choosing this budget constraint, i.e. how much money the government should spend on transport projects, will eventually depend on the social cost of public funds $D$. The advantage of expression (9) is that it gives an unambiguous project selection given any overall budget constraint; this is an advantage since deciding the *total* public transport budget is for several reasons a much more complicated task.

Second, consider a case where the planner can change travel costs as well as travel times. An important example would be regional public transport, which is often subsidised and run by an operator under public control. Moreover, assume that the affected population have a common marginal utility of income $\lambda^*$. This gives

$$\Delta B' = \sum_q \frac{\mu_q}{\lambda^*} \Delta t_q - \Delta c_q - D \frac{\lambda}{\lambda^*} \Delta z_q \tag{10}$$

This transformation of (8) highlights that the planner must choose between spending money on reducing travel costs and spending it on reducing travel time. A key difference between (9) and (10) is that the tax money spent on reforms is multiplied by a factor $(\lambda/\lambda^*)$, which captures the difference in marginal utilities of income between the taxpaying population and the population affected by the reforms under consideration.

This case could reflect investments in regional public transport. If the average public transport user has the same marginal utility of income as the average tax payer, then this ratio is 1 and there is neither a benefit nor a loss from transferring money from taxpayers to public transport users. However, if public transport users are (say) poorer than the representative taxpayer, there is an *additional* benefit stemming from this multiplier. The converse holds if the population affected by the reforms are richer than the representative taxpayers (think e.g. of high-speed railways); then, there will be a *disbenefit* of transferring money from the taxpayers to the richer population.

Another example is selecting what projects to implement in a given geographic region. In practice, it is common that national planners take regional distribution into account, such that infrastructure funding is spread evenly across a country. In such cases, each region has effectively a budget constraint of its own. Now, if the variation in the marginal utility of income among the travellers within the region is small, (10) can be used to separate the question of how to spend the money in a region (decreasing travel costs or travel times, say) from the question of whether certain regions need extra funding just because they are poorer.

The reason why any difference in marginal utilities can exist ultimately stems from our assumption that various redistribution costs (the $D$ factor) keeps the government from implementing all monetary redistributions that would be beneficial from a pure marginal-utility-of-income viewpoint.

The advantage of formulating the problem as in (10) is that it separates the problem of selecting reforms – changes in travel times and travel costs – from the problem of whether it is desirable to transfer funds from the general taxpayer collective to the particular population at hand. Equation (10) says that time-saving reforms should be evaluated and ranked using the actual VTTS of the population at hand. If a time-saving project is not worth its cost according to this CBA criterion, it means that the money is better spent on reducing travel costs instead.

An important special case is evaluating project packages with no external funding, i.e. reforms which need to be financed by increased travel costs (fares) – a common decision situation for a public transport planner. (Note that this is precisely the Sugden-like "paradox" we presented earlier.) Clearly, the time savings in such a package need to be evaluated with the affected population's VTTS – since they are also the ones paying the increased fares.

A second special case is congestion pricing. In this case, $\Sigma_q \Delta z_q$ will be a surplus from the charges, rather than a cost for the public purse. Equation (10) says that the congestion pricing reform (the time savings and congestion charges) should be evaluated using the actual VTTS of the car drivers. Then the surplus should be multiplied by the social cost of public funds $D$, and also with the ratio between marginal utilities of income ($\lambda/\lambda^*$). Assume, as an example, that the charged car drivers are richer than the average taxpayer. Then this ratio will be greater than 1, and the reform will generate an extra social utility. The fundamental reason that this is possible is of course, just as before, that the congestion charge opens up a way to "tax" people previously prevented by the redistribution costs.

Third, consider a situation where benefits do not stay "on the road", but are transferred away from travellers to, for example, land owners or transport operators. To incorporate this in our notation, let the cost changes $\Delta c_q$ represent not only changes in travel costs but changes in rents, housing costs, wages etc. Just as in the two preceding cases, costs change – but not because they are under public control, but because they react to market forces and hence change as a *result* of the reforms. For simplicity, assume that all the increases in costs accrue to some group $r$, which is essentially capturing a windfall rent. This means that we can write the social benefit as

$$\Delta W = \sum_q \mu_q \Delta t_q + \lambda_q \Delta c_q - D\lambda \Delta z_q - \lambda_r \sum_q \Delta c_q. \qquad (11)$$

Consider the extreme case where *no* benefits accrue to travellers: fares, rents etc. change such that *all* benefits accrue to the group $r$. This means $\Delta c_q = -(\mu_q/\lambda_q)\Delta t_q$, which we can plug into (11) and divide by $\lambda$ to get

$$\Delta B = -D\sum_q \Delta z_q + \frac{\lambda_r}{\lambda}\sum_q \frac{\mu_q}{\lambda_q}\Delta t_q. \qquad (12)$$

Hence in this case time savings should be valued with the VTTS of travellers, since it is through these VTTS:s benefits are mediated to become monetary profits for the group $r$. This transfer of benefits may cause an additional benefit or loss depending on whether the multiplier ($\lambda_r/\lambda$) is greater or smaller than 1. If the group $r$ receiving the final benefits is richer than the average taxpayer, the ratio will be less than 1, and this will incur an extra social loss – and vice versa.

The cases above show that whether the VTTS should be controlled for income differences depend on the choice situation. In reality, choice situations are seldom as clear cut as above. It is extremely difficult to predict the final, long-run incidence of benefits. A policy maker thus needs to decide whether the choice situation is closest to the first case (travel costs are constant, and all benefits accrue to travellers) or the other cases (travel costs change, due to policy or as a market reaction). In the first case, the VTTS should be controlled for income; in the others it should not. However, in *all* cases, the VTTS must account for variation in the VTTS stemming from differences in the marginal utility of time, for example due to different travel time component, modes and trip purposes. The obvious question is then of course how much of the observed variation in VTTS can be attributed to income differences, and how much can be attributed to differences in marginal utilities of time. This is the topic of section 3.

## 3. Empirical findings

In this section, we explore how much of the observed VTTS variation can be attributed to differences in income, and how much that can be attributed to other factors – presumably differences in the marginal utility of time. We use the Swedish national VTTS data collected in 2008, and focus on the dimensions that applied appraisal usually considers: travel mode, trip length and trip purpose. For a detailed description of the data and the model applied the reader is referred to Börjesson and Eliasson (2014).

### 3.1. The model

The estimation uses a model specification suggested by Fosgerau (2006), in which the VTTS is estimated directly in willingness-to-pay space, rather than computing it as the ratio between estimated time and cost parameters. The Fosgerau specification requires binary choices between an observed reference trip and either a slower but cheaper trip or a faster but more expensive trip.[9] Call the travel times and costs ($c_1$, $t_1$) and ($c_2$, $t_2$), define $V = (c_2 - c_1)/(t_1 - t_2)$ and let the response variable $y$ be 1 if the respondent chooses alternative 1 and 0 otherwise. This gives:

$$y = 1\left\{\frac{\mu_q}{\lambda_q} < V\right\}. \tag{13}$$

Parameterising the VTTS as an exponential function,

$$\frac{\mu_q}{\lambda_q} = \exp(\beta x_q + \beta_Y \ln(Y_q) + \delta_q), \tag{14}$$

gives a better model fit than a linear function. Here $\boldsymbol{\beta}$ is a vector of parameters, $\mathbf{x}$ is a vector of covariates, and $\delta_q$ is a random constant, assumed to be constant for each individual but normally distributed in the population. Taking the log of income, rather than income, results in a better model fit. Index $q$ refers to individuals rather than groups, but can be interpreted as representative individuals. This parameterisation ensures that $(\mu_q/\lambda_q)$ is positive, but $\boldsymbol{\beta}$ and $\delta$ are unrestricted. The distribution of $\delta_q$ is taken to be normal, such that the VTTS has a lognormal distribution. This assumption is not rejected in a formal statistical test (Börjesson, Fosgerau, & Algers, 2012a).

To estimate the parameters of (14) we use (13), take logs and add an logistic error term $\varepsilon$, which gives $y = 1\{\log(\mu_q/\lambda_q) < \log V + \varepsilon/\mu\}$ where $\mu$ is a scale parameter. We need to assume that $\mathbf{x}$ and $\delta$ are independent. The parameters in $\beta$ are easily interpreted, for instance a parameter value $\beta_1$ for a dummy variable means that the VTTS increases with a factor $\exp(\beta_1)$.

Estimating the VTTS $(\mu_q/\lambda_q)$ directly, rather than estimating marginal utilities $\mu_q$ and $\lambda_q$ separately and calculating the VTTS as the ration between them, means that we need some (mild) assumptions given in the next section to control the VTTS for income.

Despite this disadvantage, there are several arguments to prefer estimating the VTTS directly. Most important, it fits the data better. This is connected to a second argument: heterogeneity in the marginal utilities cannot be separated from heterogeneity in the response scale, so these distributions will be confounded. Moreover, it easily becomes confusing and combinatorially difficult to simultaneously interact many covariates with the time and the cost parameters. Third, computing the VTTS as the ratio between the two randomly distributed marginal utilities usually implies (depending on the assumption of the distribution of the cost parameter is) that the resulting VTTS distribution does not have a finite mean (Daly, Hess, & Train, 2012).

### 3.2. Controlling the VTTS for differences in marginal utilities of income

To control the VTTS for differences in respondents' marginal utilities of income, we need two assumptions:

(1) The marginal utility of time is not affected by income.
(2) The marginal utility of income is *only* affected by income, and not by any other socio-economic or trip characteristics.

These assumptions need a certain leap of faith. To support them, note that they are consistent with the marginal utility of income being the Lagrange multiplier relating to the income constraint, while the marginal utility for time is the Lagrange multiplier relating to the time constraint (the resource value of time) plus the direct disutility of travel time (DeSerpa, 1971; Jara-Díaz & Guevara, 2003). The direct disutility of travel time depends on the comfort and productivity during the trip, and there is no strong reason to assume that this would be directly affected by income. The resource value of time should increase the less available time the traveller has in general. Hence, we may expect it to be higher for employed people and for parents of small children, but again, there is no strong reason to believe that it would be influenced by income. The marginal utility of income is clearly related to the income.

These assumptions enable us to separate the expression (14) into

$$\ln(\mu_q) = \beta x_q + \delta_q$$
$$\ln(\lambda_q) = -\beta_Y \ln(Y_q). \tag{15}$$

This makes it easy to control the VTTS for income differences. Defining $\lambda$ as the marginal utility of income of an individual with average income $Y = (1/N)\sum_q Y_q$, we have[10]

$$\ln(\lambda) = -\beta_Y \ln\left(\frac{1}{N}\sum_q Y_q\right) \tag{16}$$

which gives us the VTTS of an individual with average income

$$\frac{\mu_q}{\lambda} = \exp\left(\beta x_q + \delta_q + \beta_Y \ln\left(\frac{1}{N}\sum_q Y_q\right)\right). \tag{17}$$

Note that this also enables us to compute the ratios of marginal utilities of income appearing in expression (8):

$$\frac{\lambda_q}{\lambda} = \exp\left(-\beta_Y \ln\left(Y_q \frac{N}{\sum_q Y_q}\right)\right). \tag{18}$$

In principle, this enables the analyst to weigh changes in travel costs differently depending on differences in the marginal utilities of income of the respective group.

### 3.3. Results

Complete estimation results and descriptive data can be found in Börjesson and Eliasson (2014). Different models were estimated for (i) car drivers, (ii) local and regional public transport (bus and train) and (iii) long distance public transport (bus and train). A large number of trip characteristic variables were tested but only purpose (work and other purposes) and travel mode (bus or train) were significant. In addition, a large number of socio-economic variables were tested, but only four were significant: employment status, income, whether there were children in the household and whether the respondent lived in the county of Stockholm. The two latter were only significant for drivers.

All else equal, the VTTS is higher for employed and those having children in the household, which is consistent with the expectation that the resource value of time increases the less available time the traveller has (note that income differences are controlled for separately). Interestingly, there is no difference in the VTTS between men and women, all else equal.[11] Stockholm drivers have a higher VTTS, even after controlling for income. Potential explanations are differences in comfort of the trip decreasing the direct utility of travel time (road congestion is considerably higher in Stockholm than elsewhere) and tighter time constraints increasing the resource value of time (Stockholm inhabitants have on average longer total travel time than the rest of the Swedish population, giving them less residual time for activities). Differences in VTTS across modes may either depend on differences in the direct utility of travel time, such as the comfort and productivity of the time spent in the vehicle, or on self-selection with respect to the opportunity cost of time: travellers with high opportunity cost of time will tend to choose faster but more expensive modes. Fosgerau, Hjorth, and Lyk-Jensen (2010) show that between-mode differences are consistent with both self-selection and comfort differences.

The income elasticity varies across travel modes, being highest for car (0.5) and lowest for long distance public transport (0.17). Since the income is correlated with some of the other covariates in the model (such as employment), the income elasticity become slightly higher when the other socio-economic variables are excluded (0.68 for car, 0.33 for regional public transport and 0.29 for long distance public transport).

In all models the standard deviation of the individual specific parameter $\delta$ is substantial. The VTTS thus exhibits great variation, both because of observable characteristics of the trip and the traveller and because of idiosyncratic variation.

The estimated elasticity of 0.5 for car is consistent with estimates in previous literature, which are usually in the range 0.5–1 (Abrantes & Wardman, 2011; Börjesson, Fosgerau, & Algers, 2012b; Fosgerau, 2005). The lower estimate for public transport, 0.17, cannot be explained by low variation in income among public transport users. In fact, the standard

**Table 1.** Averages of simulated VTTS: $(\mu_q/\lambda_q) = \exp(\beta x_q + \delta_q + \beta_Y \ln(Y_q))$ and average VTTS at mean-income $(\mu_q/\lambda) = \exp(\beta x_q + \delta_q + \beta_Y \ln(Y))$.

| | Short distance, Commute | | | | Short distance, other purposes | | | | Long distance, all purposes | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\frac{\mu_q}{\lambda_q}$ | $\frac{\mu_q}{\lambda}$ | Rel. diff | After-tax monthly income (k€) | $\frac{\mu_q}{\lambda_q}$ | $\frac{\mu_q}{\lambda}$ | Rel. diff | After-tax monthly income (k€) | $\frac{\mu_q}{\lambda_q}$ | $\frac{\mu_q}{\lambda}$ | Rel. diff | After-tax monthly income (k€) |
| Car, Stockholm | 12.1 | 10.9 | 11% | 2.1 | 7.8 | 7.6 | 3% | 1.8 | 14.9 | 14.0 | 6% | 2.0 |
| Car, other regions | 9.2 | 8.3 | 11% | 1.8 | 5.9 | 5.7 | 4% | 1.5 | 11.4 | 10.6 | 8% | 1.7 |
| Car, all regions | 9.8 | 8.8 | 11% | 1.9 | 6.1 | 5.9 | 3% | 1.6 | 11.7 | 10.9 | 7% | 1.7 |
| Bus | 5.3 | 5.3 | 0% | 1.7 | 2.8 | 3.3 | −15% | 1.1 | 3.8 | 3.9 | −3% | 1.2 |
| Train | 7.2 | 7.0 | 3% | 1.9 | 5.0 | 5.3 | −6% | 1.2 | 7.3 | 7.4 | −1% | 1.4 |

deviation of the income distribution is larger among public transport users than among drivers. Moreover, the pooled sample for all travel modes and travel distances (in which the standard deviation of the income distribution is higher than in the subsamples) results in an income elasticity of 0.26.

Table 1 shows the average VTTS simulated for all individuals in the estimation sample (weighted with travel distance), differentiated with respect to mode, trip purpose, distance and region (which are the dimensions in which applied appraisal can usually be differentiated). The table also shows the mean income, weighted with trip distance. Columns marked $(\mu_q/\lambda_q)$ show the behavioural VTTS, while columns marked $(\mu_q/\lambda)$ show VTTS controlled for income. The difference between the two depends on the income elasticity of the VTTS, and the income differences in the dimensions in which the VTTS is differentiated: trip purpose, trip length, travel mode and region. For example, the mean income of long-distance car drivers is almost twice the mean income of the short-distance bus users. Still, most of the differences between the behavioural and income-controlled VTTS are modest. The largest relative difference is for short other-purpose bus trips ($(\mu_q/\lambda)$ is 18% higher), and for commuter car trips ($(\mu_q/\lambda)$ is 10% lower).

Hence, the issue of whether income differences should be allowed to influence the VTTS does not have any major effect on the difference in average VTTS between trip purpose, trip length, travel mode and region. However, the VTTS does vary substantially across purposes, modes and trip lengths – even after income effects have been removed. It is therefore clear that the main driver of VTTS variation in these dimensions is not income differences.

One reason for the relatively small differences could be that Sweden is a rich country with relatively small income differences, especially after tax (Sweden has one of the lowest income inequalities in the world as measured by the Gini coefficient (Central Intelligence Agency, 2018)). Hence, whether our results are transferable to other counties is an empirical matter. It should be stressed that the VTTS still depends on income, and that income still influences travel behaviour, both in terms of car ownership, car use, trip length and long-distance trip frequency. In many of these respects, Sweden is similar to many other rich countries.

## 4. Conclusions

This paper explores the theoretical and empirical arguments for differentiating the VTTS between groups of travellers in applied transport appraisal. We have extended the framework by Galvez and Jara-Díaz (1998) and Mackie et al. (2001) by introducing a social cost of monetary redistributions, allowing for price changes (either by direct policy intervention or as a second order effect), and taking into account that benefits may be transferred away from travellers to other stakeholders, such as land owners and transport operators, through changes in e.g. fares, rents, wages and other prices.

We use this framework to show that in certain choice contexts, the VTTS should be controlled for income differences, whereas in other it should not.[12] The two most important factors to consider is whether prices are under public control (and can hence be changed by policy interventions) and whether benefits accrue to other groups than the travellers, mediated through price changes. If either of these conditions hold, a decision maker wanting to maximise social welfare should most likely use actual "behavioural" VTTS:s, rather than trying to control it for income differences. We present some simplified choice contexts, highlighting how distributional concerns can be separated from the task of choosing efficient project portfolios.

We stress that a *single* VTTS should *not* be used in any choice context. The VTTS should always account for variation stemming from differences in the marginal utility of time, for example due to different travel time component, modes and trip purposes. We show that – at least in our data set – by far the largest part of the observed variation in VTTS across modes, trip lengths and trip purposes is driven by other factors than income differences: controlling the VTTS for income changes it only slightly.

The choice contexts faced by policy makers are seldom as clear cut as the examples presented here, so a judgment call must be made depending on what the real choice context looks like. There is no obvious answer to this; but we are inclined to think that on balance, using actual, behavioural VTTS is more likely to yield efficient overall transport policy than controlling it for income difference. This is for two reasons.

First, many travel costs are under some form of public control, through user charges, such as transit fare and fuel taxes. Even if this control is relatively crude, since prices can seldom be finely differentiated, this means that there is a choice between spending money on reducing travel costs and spending money on reducing travel times through investments. Consider a project which is worth realising according to the project evaluation if the VTTS is adjusted for income but not if the behavioural VTTS is applied. Then there is a strictly Pareto-preferred policy which reduces travel costs instead. We have already given an example: consider a project to reduce travel times for a group of relatively poor tram users. If the poor tram users are not willing to pay for the reductions in the travel time by higher fares, the attractiveness of the tram would increase more if money is spent on reducing travel costs instead. Using the behavioural VTTS avoids such inconsistencies. We would argue that in this kind of analysis, it is better to keep out of the analysis any possible desire to spend public money on the tram users out of distributional concerns; this makes it easier to select the most efficient projects.

Second, it is unlikely that all, or even most, benefits stay "on the road", with the travellers. The consideration of to whom the benefits of the project accrue in the long run seems to be severely underappreciated in the discussion about VTTS differentiation. The (implicit) assumption that benefits stay with travellers might certainly be reasonable in some situations – say, reducing bus fares to an area with predominantly rental housing with public rent controls. However, in most cases it is well established that at least some of the benefits arising from transport investments will be transferred to other markets, for instance as increased land values and operator revenues. Benefits are measured "on the road" (as user benefits) because this is usually the only feasible way; but this does not mean that benefits *stay* "on the road", i.e. accrue to users. If the benefits arising on the transport market are transferred to other markets and agents to a large extent, it is the behavioural VTTS which is relevant for evaluation, since it is the users' willingness to pay for the improvement that determines how these benefits translate into prices and values in other markets.

Regarding equity concerns in general (and not due to income differences only), it should be stressed that most people make many kinds of trips, with different modes, purposes and trip lengths, and that the VTTS varies considerably between different trips even for a given person (Börjesson, Cherchi, & Bierlaire, 2013). It is perfectly logical that an individual values a travel time saving during her morning car commute higher than a during her Saturday bus trip to a museum. Using only one single VTTS for appraisal destroys this distinction and may hence misallocate resources since it assumes that a time saving on the morning car commute is valued just as much as a time saving on the Saturday museum trip.

Based on the considerations we have presented, a policy maker needs decide whether control the VTTS for income differences or not. However, the importance of this decision problem should not be exaggerated – especially in countries like Sweden, where we have shown that the VTTS variation is mainly driven by variation in the marginal utility of time due to self-selection and differences in trip comfort etc. This is illustrated by Börjesson, Eliasson, and Lundberg (2014), who show that controlling the VTTS for income differences has a very small effect on project ranking.

This paper focuses mainly on the effect of income on the VTTS, and the related distributional effects. However, even more important is to differentiate the valuations of different travel time components, such as in vehicle time, waiting time and walking time, and other time-related quality factors such as travel time variability (Hensher, 2015; Hensher, Greene, & Li, 2011) and crowding (Swärdh & Björklund, 2017). Indeed, especially in metropolitan areas are such factors are probably more important motivations of infrastructure investments and policies than mere time savings. Having different VTTS:s depending on various contextual and quality attributes is rarely questioned; and after all, it should be just as natural to differentiate the VTTS with respect to travel mode and so on. As shown in this paper, controlling the VTTS for income differences may in certain contexts be motivated; but using these arguments to remove *all* variation in the VTTS is severely detrimental to the usefulness of transport CBA: it reduces the information contained in the appraisal, and is likely to lead to misallocation of resources across the transport sector.

## Notes

1. A preliminary version of this paper has been circulated as a working paper (Börjesson & Eliasson, 2017).
2. One individual can have different VTTS:s, and therefore belong to different groups $q$, for different trips (Börjesson et al., 2013). For simplicity we assume that all groups included the same number of individuals. If not, group size would enter the equations below.
3. For simplicity we assume that the demand for trips is constant.
4. Social weights are defined as the derivative of the social welfare function with respect to the utility of each member of group $q$.

5. The marginal utilities ($\mu_q$ and $\lambda_q$) cannot be directly observed, but the ratio between them can be obtained from discrete choice models, assuming that the random error is independent of the marginal utilities.
6. We assume that D is symmetric for gains and losses. This assumption can be questioned but distributing money to people might also have a cost since it discourages people to work, which reduces the productivity and possibly also subjective well-being.
7. To reach this equilibrium, we must assume that the $D_q\lambda_q$:s are not constant, but change as a result of monetary redistributions, and the government implements such redistributions until an equilibrium is reached
8. This is consistent with the UK Department for Transport's criterion that only projects which yield "very high value for money" are built.
9. Two-attributes SC surveys have been criticised for its simplicity. Australian work (Hensher, 2006; Hensher & Rose, 2007) underscores the importance of including all attributes that may be relevant to the respondents in the choice.
10. Another possible assumption is to take $\lambda$ to be the average marginal utility of income: $\lambda' = (1/N)\Sigma_q Y_q^{-\beta_Y}$ We have simulated the VTTS in Table 1 using also $\lambda'$ and found that the effect on the resulting VTTS is marginal.
11. There are, however, differences between the genders regarding the VTTS for accessing public transport arising from differences in the perceived insecurity in different built environments (Börjesson, 2012).
12. Already Nash, Pearce, and Stanley (1975) discuss the idea of re-weighting valuations with marginal utilities of income in CBA.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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