Reverse-engineering of the rule-of-half in order to retrofit an assessment procedure based on resource consumption

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Abstract

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1 Introduction

The German evaluation procedure for the Federal Transport Infrastructure Plan ['Bundesverkehrswegeplan', e.g. BVU et al., 2003] is a large-scale and comprehensive modelling, simulation, and analysis effort. It is performed roughly every 10 years by the German federal government, and forms the decision basis for all major federal investments into long-distance surface transport infrastructure.

An important component of the evaluation procedure is a cost-benefit analysis, based on the concept of resource consumption. This concept means that new transport infrastructure causes changes in the consumption of time, money, safety, environment, etc. Monetized changes of those attributes are brought into relation to the construction and maintenance cost borne by the federal government, and the resulting benefit-cost ratio provides an indicator which helps to prioritize investment decisions [BVU et al., 2003]

This assessment approach works well as long as all mode-specific demand remains fixed, and the remaining question thus is to serve that demand as efficiently as possible. Over the past decades, however, there were efforts to include the effects of mode choice and latent demand (induced traffic). The introduction of these effects into the established forecast and evaluation procedure had some undesired side effects [see e.g. Helms, 2000]. The archetypical example is the acceleration of a rail connection, while still remaining slower than the competing road connection. Any logit model or similar would, in that situation, predict that some users switch from road to rail. In terms of resource consumption, those travellers would afterwards consume more time than before; in the absence of additional effects, for those travellers the project would have a negative benefit according to the resource consumption approach.

The conceptual shortcoming here is that the trip by rail causes additional benefits which are not included in the (observed) variables used for the monetarization of benefits. This problem is typically avoided when the so-called rule-of-half is applied. According to this rule new users of an improved infrastructure gain on the average half of the benefits of existing users [e.g. UK Department for Transport, 2011, Worldbank, 2005, HEATCO, p. 17]. The first new user gains almost as much as the average existing user, while the last new [switching or mode changing]

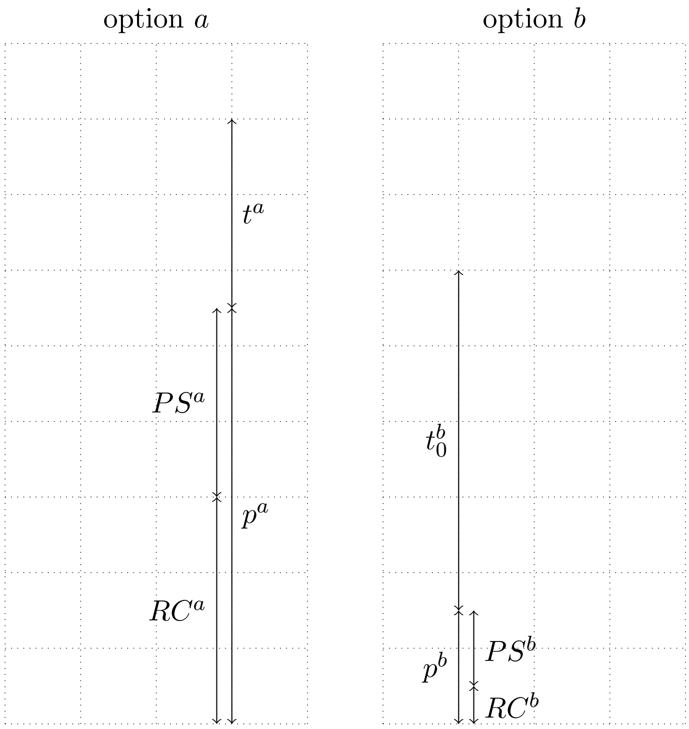

Figure 1: Resource costs, user prices, producer surplus, and travel times of two options a and b.

user is almost indifferent between both alternatives. Assuming linear demand functions, the average new user gains 1/2 of the benefits of existing users.

The rule-of-half greatly simplifies the estimation of user benefits, as one only needs the initial and final quantities and the changes in generalized costs, instead of all demand functions and cross-demand relations [Small and Verhoef, 2007, p. 183]. It has proved a very powerful tool in assessment activities [Button, 2001, p. 73].

The rule-of-half is an approximation; and newer research suggests the use of the logsum term directly derived from the logit model as evaluation measure [e.g. de Jong et al., 2005, Winkler, 2011]. However, given the nature of the problem here, the issue is not to discuss the limitations of or alternatives to the rule-of-half [for some proposals see e.g. Nellthorp and Hyman, 2001], but rather the question if, and how, the established German assessment procedure can be made consistent with basic consumer theory.

This paper will discuss illustrative examples for the cases of mode switches and induced traffic. It will propose an easily applicable procedure to include the logic of the rule-of-half into the existing evaluation approach based on resource consumption. Finally, it will discuss how another assessment scheme that was also used in Germany fits into the approach.

2 Going into the details

2.1 Comparing options a and b

We start by comparing options a and b. In transport, a might be car and b might be train. If we plot generalized costs vertically, one obtains a diagram like Fig. 1.

Here, t^a and t^b are the travel times and p^a and p^b are the user prices of options a and b, respectively. The user price, p, can be decomposed into the resource cost, RC, and the producer surplus, PS. The resource cost would typically be the same as the marginal cost, MC.

We assume that travel times, as well as other costs, are given in monetary units.

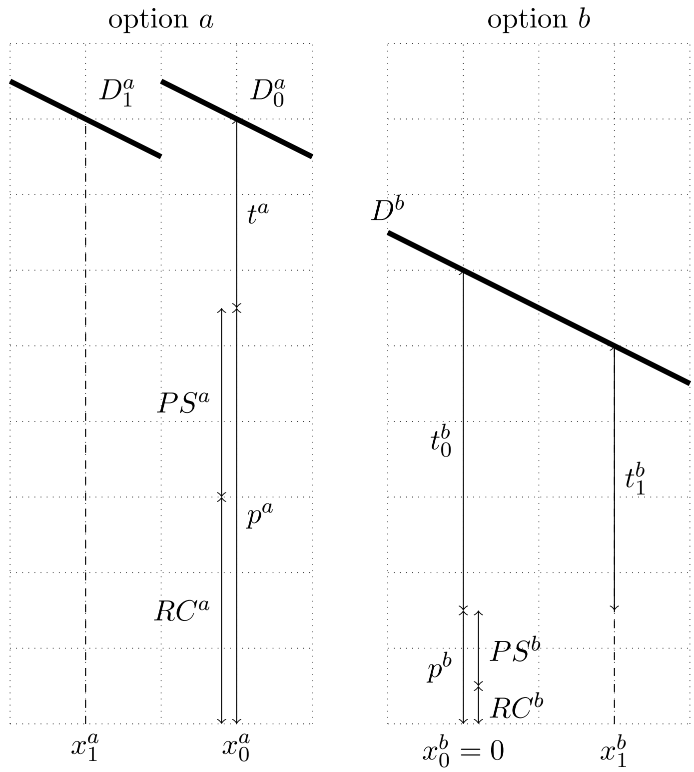

Figure 2: Including demand curves, an improvement (reduction in travel time) for b, and switching travelers.

2.2 Switching from a to b

Now let us assume that there is an improvement on the travel time of t^b, from t_0^b to t_1^b, and as a result some demand shifts from option a to option b. The diagram would look as in Fig. 2.

We make the assumption that there is no change in generalized cost at the option a so the only reaction there is a horizontal shift of the demand curve to the left.

We also assume that there are only switchers, i.e. there was nobody on option a before. This is just for illustration.

2.3 Welfare computation

The standard welfare effects of this infrastructure measure are given by the three red areas of Fig. 3:

- Consumer surplus: $\frac{1}{2} \times (t_0^b - t_1^b) \cdot \Delta x$ — the usual rule-of-half
- Producer surplus on option b: $PS^b \times \Delta x$
- Loss of producer surplus on option a: $-PS^a \times \Delta x$

For this to be valid, it is assumed that the rule-of-half is an applicable approximation, and that there are no complications such as income effects or income-dependent values-of-time.

2.4 Resource consumption

The German national assessment exercise typically computes "resource consumption" rather than welfare effects. The change in resource consumption of this infrastructure measure are the four green areas of Fig. 4:

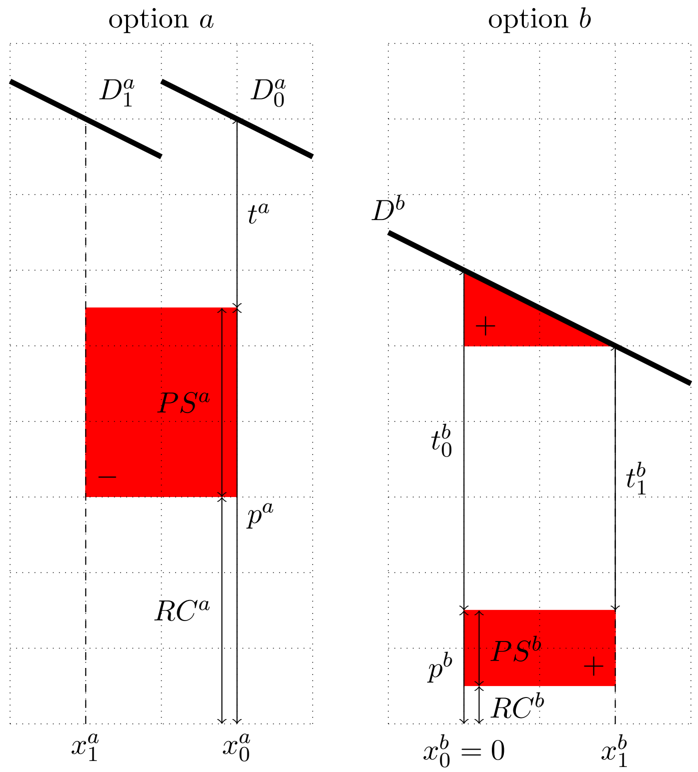

Figure 3: The red areas make up the (consumer + producer) surplus computation. A "+" in the shape means that a larger shape increases the benefit; a "−" in the shape means that a larger shape reduces the benefit.

- Reduction in time consumption $-t_a \times \Delta x$.
- Reduction in resource costs $-RC^a \times \Delta x$.
- Additional time consumption $t_1^b \times \Delta x$.
- Additional resource costs $RC^b \times \Delta x$.

2.5 Comparison

Fig. 5 shows the different areas together in one figure. It is difficult to draw immediate visual conclusions since the economic benefit is

- according to the welfare computation: the red areas on the right *minus* the red area on the left
- according to the resource consumption computation: the green areas on the left *minus* the green areas on the right.

It is, however, immediately clear that the two computations will, in general, not lead to the same result: One could, for example, assume that t^a changes while everything else remains the same. As consequence, the related green area would change while all red areas remain the same. In consequence, the result of the calculation according to resource consumption would change while the result of the calculation according to consumer surplus would remain unchanged. Thus, in general they cannot yield the same result.

2.6 Implicit utility

When looking at Fig. 5, it seems that the red and green areas completement each other, with the exception of the area above the D^b demand curve. This can be corrected by including that

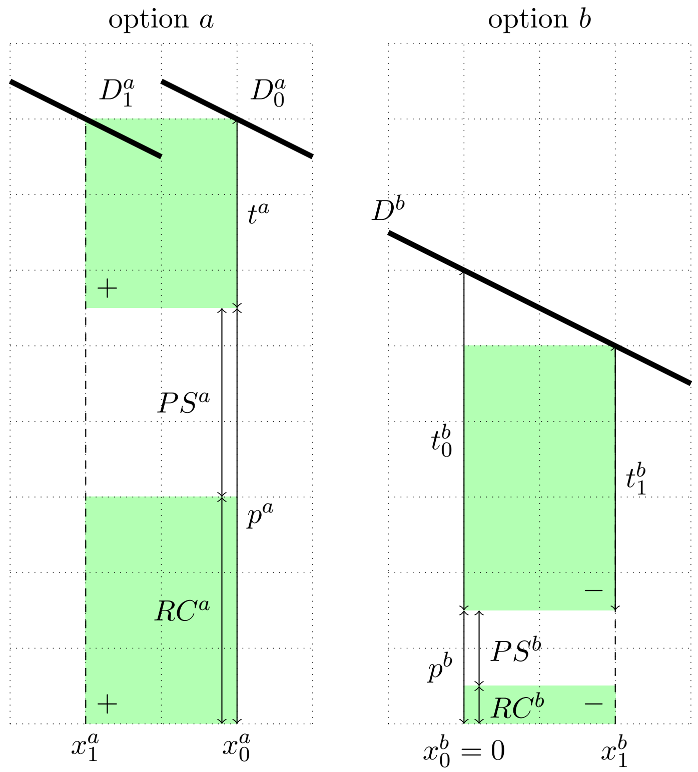

Figure 4: The green areas make up the resource consumption computation. Again, a "+" in the shape means that a larger shape increases the benefit; a "−" in the shape means that a larger shape reduces the benefit.

area into the computation, see Fig. 6. We then have

$$RC^a + PS^a + t^a = RC^b + PS^b + t_1^b + CS + blue \ .$$

From this, we get

$$CS + PS^b - PS^a = (RC^a - RC^b) + (t^a - t_1^b) - blue$$

or

$$welfare = RCC - blue \ , \tag{1}$$

where RCC means "resource consumption calculation". That is, when the blue area is deducted from the result of the resource consumption calculation, the two computations are equivalent.

The average height and therefore the size of the blue area can be computed from this. Since the computation in Sec. 2.7 will yield the same result, this will be skipped here.

2.7 Behavioral interpretation of the blue area: implicit utility

The behavioral interpretation of the blue area is that there needs to be a reason why users do not switch from a to b in spite of the fact that $t_b + p_b$ is much smaller than $t_a + p_a$. It is plausible to assume that this is caused by some difference in generalized cost or utility which is not included when considering only travel time and price. This is the blue area.

It can also be computed. For the marginal user at x_0:

$$p^a + t^a + GC^a_{implicit} = p^b + t_0^b + GC^b_{implicit,0} \ ,$$

where $GC^a_{implicit}$ and $GC^b_{implicit,0}$ are implicit, unobserved, generalized costs associated with the options a and b. Therefore,

$$GC^b_{implicit,0} - GC^a_{implicit} = (p^a + t^a) - (p^b + t_0^b) \ .$$

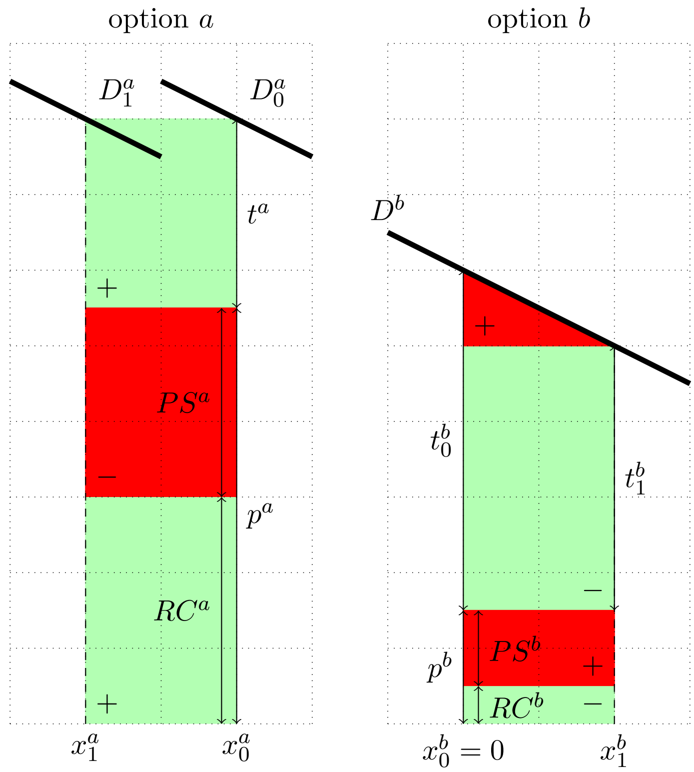

Figure 5: Visual comparison of the calculations according to the surplus (red) and resource consumption (green). Again, a "+" in the shape means that a larger shape increases the benefit; a "−" in the shape means that a larger shape reduces the benefit.

This is indeed exactly the "missing" difference: The length of the left side of the blue area.

Similarly, for the marginal user at x_1:

$$p^a + t^a + GC^a_{implicit} = p^b + t^b_1 + GC^b_{implicit,1}$$

and therefore

$$GC^b_{implicit,1} - GC^a_{implicit} = (p^a + t^a) - (p^b + t^b_1) \ .$$

For that user, the implicit generalized cost difference must be even larger, because she does not switch until the travel time has been improved to t^b_1.

The average between these two values is

$$\overline{GC^b_{implicit}} - GC^a_{implicit} = (p^a + t^a) - (p^b + \overline{t^b}) \ .$$

We find it easier to think of an implicit utility (more precisely: benefit) rather than an implicit cost. The equation then becomes:

$$\overline{U^b_{implicit}} - U^a_{implicit} = (p^b + \overline{t^b}) - (p^a + t^a) \ .$$

In this paper, "utility" is always meant as a quantity in monetary terms. Clearly, the conversion of travel time into monetary terms may be non-linear, e.g. income-dependent [Jara-Díaz and Videla, 1989]. This is, however, not considered here.

2.8 Negative implicit disutility (= positive implicit disutility) of switching

In the above examples, the implicit utility of switching was negative, i.e. the implicit generalized cost of switching was positive. This was done so that the complementarity of the shapes in Fig. 6 becomes visible. This term can, however, also have the opposite sign. For the above examples,

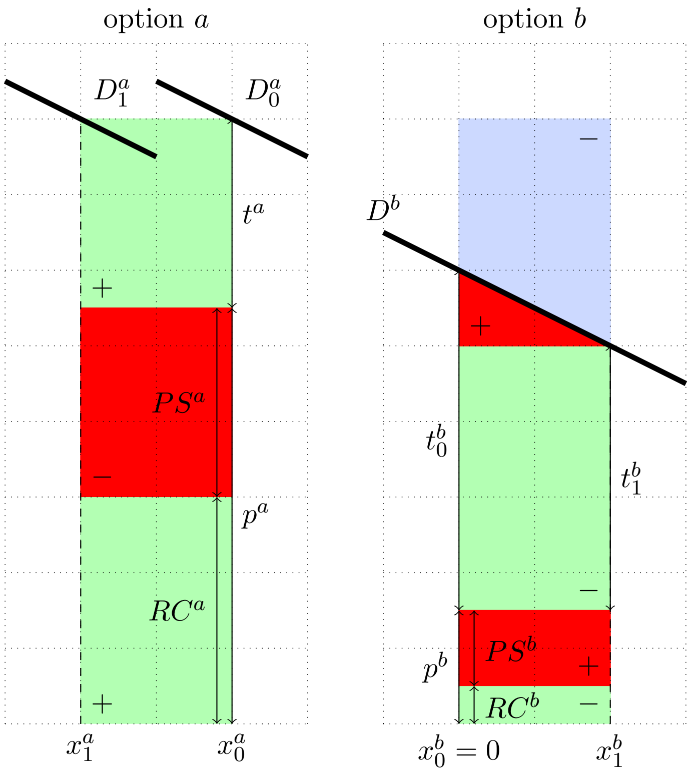

Figure 6: Adding the "implicit utility" (in blue). Also here, a "+" in the shape means that a larger shape increases the benefit; a "−" in the shape means that a larger shape reduces the benefit.

this would be the case when $p^b + t^b > p^a + t^a$, i.e. when persons use b or switch to b in spite of the fact that the observed utility for option b is smaller.

In this situation, the right part of the figures, corresponding to option b, would stretch vertically beyond the left part of the figures, corresponding to option a. And the blue area would need to be *deducted* from option b in order to pull it back to the level of option a. Naturally, *such a* blue area would then have to be counted as a positive contribution to the benefit.

3 Adding the implicit utility to the resource consumption calculation

3.1 Approach

The above insights can be used to add a term to the established resource consumption calculation in order to make it consistent with the welfare calculation. This term stems from the fact that the area of the blue shape can be computed from the "average" switcher. The average switcher switches when the infrastructure improvement is at half of its value. For this user,

$$-p^a - t^a + U^a_{implicit} = -p^b - \overline{t^b} + \overline{U^b_{implicit}} \,,$$

where $\overline{t^b}$ is again used to denote the average of the travel times before and after the modification, and $\overline{U^b_{implicit}}$ to denote the implicit utility of option b for the "average" switcher at this point. From this,

$$\boxed{\overline{U^b_{implicit}} - U^a_{implicit} = (p^b + \overline{t_b}) - (p^a + t^a) = (p^b - p^a) + (\overline{t^b} - t^a)} \,. \tag{2}$$

A resource consumption table would now look as follows:

	base case	policy case	resource difference	gain in monetary terms
prod cost a	$RC^a \times x_0^a$	$RC^a \times x_1^a$	$-RC^a \times \lvert\Delta x\rvert$	$+RC^a \times \lvert\Delta x\rvert$
travel time a	$t^a \times x_0^a$	$t^a \times x_1^a$	$-t^a \times \lvert\Delta x\rvert$	$+\beta_t \times t^a \times \lvert\Delta x\rvert$
prod cost b	0	$RC^b \times x_1^b$	$+RC^b \times \lvert\Delta x\rvert$	$-RC^b \times \lvert\Delta x\rvert$
travel time b	0	$t_1^b \times x_1^b$	$+t_1^b \times \lvert\Delta x\rvert$	$-\beta_t \times t_1^b \times \lvert\Delta x\rvert$
impl. utl. diff.				$[(p^b - p^a) + \beta_t \times (\overline{t^b} - t^a)] \times \lvert\Delta x\rvert$

Here, for completeness, the conversion of travel time into monetary terms, β_t, and the number of switchers, $|\Delta x|$, has been included.

Adding these terms up and rearranging leads to

$$G = \Big[\beta_t \times (\overline{t^b} - t_1^b) + (p^b - RC^b) - (p^a - RC^a)\Big] \times |\Delta x| \ .$$

This is, however, exactly the calculation of the rule-of-half:

- $\beta_t \times (\overline{t^b} - t_1^b) = \beta_t \times (t_0^b - t_1^b)/2$ is the consumer surplus,
- $p^b - RC^b$ is the producer surplus on option b,
- $-(p^a - RC^a)$ is the loss of producer surplus on option a.

That is, after including such an implicit utility difference into the resource consumption calculation, it yields the same result as the welfare calculation according to consumer and producer surplus. Or, in other words, the insights provided by the welfare computation including the rule-of-half were used to retrofit the calculation according to resource consumption.

3.2 Consequences of including the implicit utility into the resource consumption calculation

The implicit utility difference of switching, and therefore its contribution to the economic benefit, is

- positive if $p^b + t^b > p^a + t^a$,
- negative if $p^b + t^b < p^a + t^a$.

As a tendency,

- a further acceleration of an already fast (train or car) connection would lose compared to the existing approach, and
- a further acceleration of a still slow (train or car) connection would gain compared to the existing approach.

That is, including the implicit utility into the German national assessment exercise would, as a tendency, *increase the benefit-cost-ratio for measures that improve below average elements* of the infrastructure to the average. And similarly, it would, as a tendency, *decrease the benefit-cost-ratio for measures that improve already above average infrastructure* elements.

3.3 Advantages and disadvantages

The welfare computation is much simplified if one assumes that a and b are competetive markets. In that situation, $p^a - RC^a$ and $p^b - RC^b$ can both be approximated by zero, which simplifies the computation significantly.

If, however, the competetive markets assumption is not applicable, then the computation of the producer surplus will be based on the difference of two relatively large numbers, namely the user prices minus the producer costs. In the German assessment exercise, they are computed by vastly different approaches: The producer costs RC are calculated based on fairly complex models of rail companies, airline companies, or freight companies. The user prices, p, however are based on some average assumptions, and are often calibrated implicitly by the mode choice models.

The computation via resource consumption arguably has advantages especially in areas where there is a tradition of doing the assessment exercise in this way. The existing approach, including intuition for most of its numbers, can be kept, and just a term is added. Also, the term has a plausible interpretation: It is the utility difference of switching to the improved infrastructure. This becomes, in fact, particularly clear when considering completely new traffic, i.e. not just a switch from an other mode. Here, the utility difference is exactly the implicit benefit from doing an activity at another location (see Sec. 3.4).

It is important to note that the value of the implicit utility difference changes with the level of improvement, because $\overline{t^b}$ changes. The interpretation is that, with a different (level of) infrastructure improvement, different people are affected, and for them the implicit utility may be different.

3.4 "Induced" traffic

A welcome consequence of the above retrofitting of the resource consumption approach is that it also works for so-called induced traffic, i.e. activated traffic demand that was latent before the infrastructure improvement (more trips, longer trips, completely new trips). On the one hand, this is to be expected, since the rule-of-half approximates the utility effects of changes from *any* alternative, including the alternative of not having made a trip before. On the other hand, it is instructive to go through the calculation:

$$U^a_{implicit} = \overline{U^b_{implicit}} - p^b - \overline{t^b} \ ,$$

where t^a and p^a are zero since no trip takes place for that option. From this,

$$\overline{\Delta U_{implicit}} = \overline{U^b_{implicit}} - U^a_{implicit} = p^b + \overline{t^b} \ .$$

That is, the implicit utility difference for the average switcher is exactly as large as the generalized cost of the travel for the average switcher. In other words, the equation yields an estimate for the implicit utility of additional mobility. As stated, from the perspective of the rule-of-half this is not a surprise. From the perspective of the German national assessment exercise, it provides a straightforward solution to a situation that is difficult to resolve otherwise, because in (the basic verson of) the resource consumption calculation, *any* additional travel just leads to increase resource computation and thus a negative benefit.

4 Partial inclusion of the consumer surplus — The German standardized assessment for public transit investments

Practitioners have been aware of the problem for a long time. In particular, it seemed counter-intuitive that persons switching to an improved train connection would *reduce* the benefits of a measure since the travel time might still be longer than by car. In order to improve upon this, a version of the rule-of-half was introduced into the process [ITP and VWI, 2006, BVU and ITP, 2010]. As far as we understand the documentation, what was done is equivalent to using the rule-of-half for the travel times but staying with ressource consumption for the production costs. The result can be seen in the above figure. t_a is no longer considered.

The "story" for this is quite plausible: One the one hand, there is the consumer, and she reaps the consumer surplus. On the other hand, there is the "producing economy", and it needs to spend resources to produce the service. However, the result is (still) not the same as from the welfare computation. Here is an example:

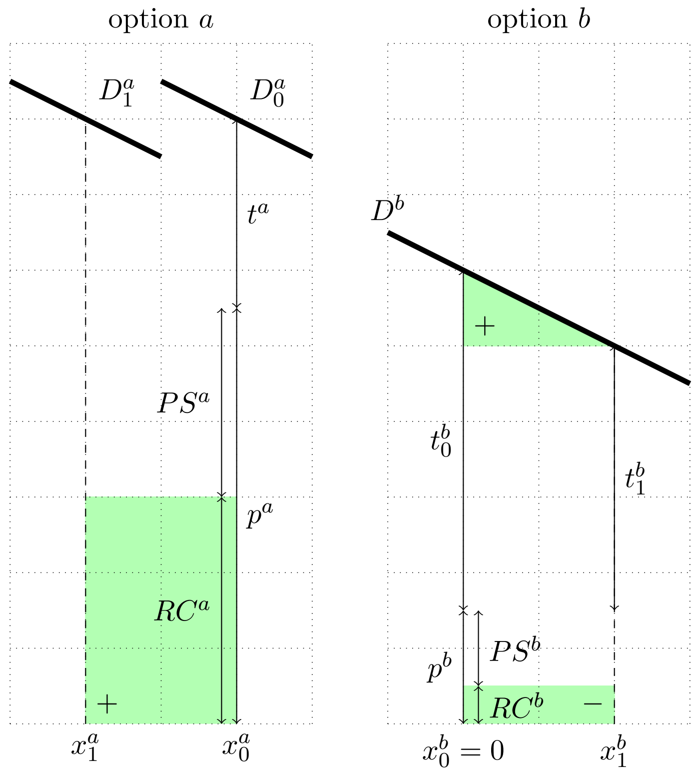

Figure 7: Areas that are considered for the benefits calculation in the German standardized assessment for public transit investments [“standardisierte Bewertung”; see ITP and VWI, 2006] and in the intermediate revision of the CBA numbers of the German national assessment exercise [“Bedarfsplanüberprüfung”, see BVU and ITP, 2010]. Again, a “+” in the shape means that a larger shape increases the benefit; a “−” in the shape means that a larger shape reduces the benefit.

- Assume $PS^a = PS^b = 0$, i.e. prices are competitive and thus there is no producer surplus.
- In consequence, the surplus calculation would *only* yield the consumer surplus.
- Yet there may still be a difference in the resource consumption, yielding a (positive or negative) contribution in the resource consumption calculation.

What is the explanation for this difference? It might be easiest to understand this from a comparison with a standard welfare computation, similar to Sec. 2.6. Adding up the areas in Fig. 8 leads to

$$RC^a + PS^a + t^a = RC^b + PS^b + t_1^b + CS + blue$$

or

$$CS + PS^b - PS^a = [RC^a - RC^b + CS] - CS + (t^a - t_1^b) - [(p^a + t^a) - (p^b + \overline{t^b})]$$

or

$$welfare = GSAC + (p^b - p^a) \ ,$$

where $CS = (t_0^b - t_1^b)/2$ and $\overline{t^b} = (t_0^b + t_1^b)/2$ were used, and $GSAC$ means “German standardized assessment computation”.

That is, while the resource consumption calculation RCC (Eq. (1)) needs to be corrected by $(\overline{t^b} - t^a) + (p^b - p^a)$ (Eq. (2)), the “standardized assessment” only needs to be corrected by $(p^b - p^a)$ in order to be consistent with the standard welfare computation.

The consequence of introducing this term would be:

- Projects where $p^b > p^a$ will improve their benefits-cost-ratio.
- Projects where $p^b < p^a$ will decrease their benefits-cost-ratio.

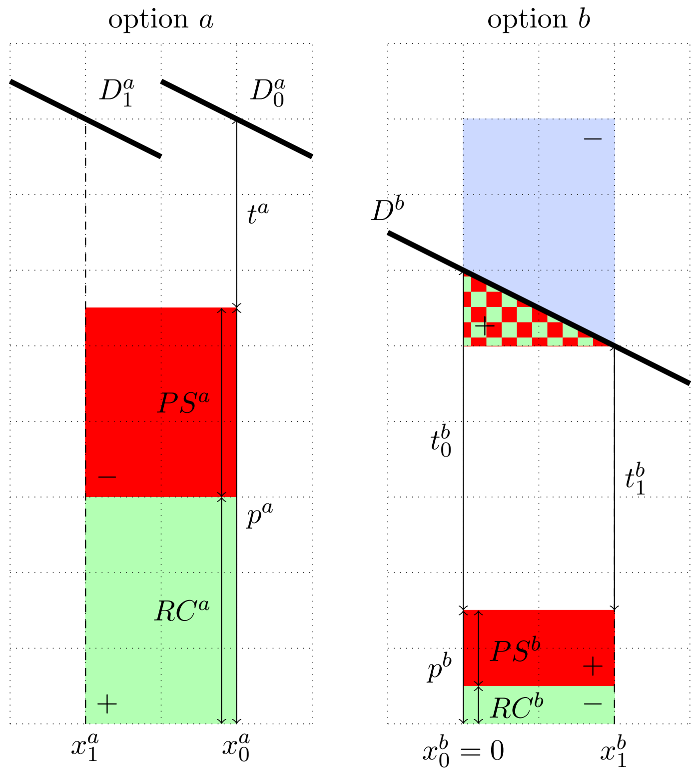

Figure 8: "Standardized assessment", full comparison

That is, adding this term into the German standardized assesssment computation would, as a tendency, *increase the benefit-cost-ratio for improvements of infrastructure elements that charge above average prices*. And similarly it would, as a tendency, *decrease the benefit-cost-ratio for improvements of infrastructure elements that charge below average prices.*

A bigger problem may be that the approach still produces implausible results for induced traffic. Consumer surplus is calculated correctly, but on the production side the additional resource cost is *deducted* from the benefit. The welfare calculation, in contrast, would include the difference between the additional resource cost and a (higher) price as *positive* benefit.

In German assessment practice, the first point may not matter so much since there is a tendency to take public transit schedules as given, meaning that in the models additional travelers are served without additional resource cost. Yet the second point, the difference between resource cost and paid price, may be quite significant, especially for rail as mode.

5 Conclusion

The objective of this paper was to propose a way to adapt the current German national CBA approach for infrastructure projects, which is based on resource consumption, to the international evaluation standard of welfare computations, in particular to the approximation based on the rule-of-half. As shown in our calculations, adding an implicit benefit component to the resource consumption leads to the equivalence of both approaches. We also analysed the concrete consequences of including these implicit user benefits for the assessment results. With the inclusion of that benefit component, the current evaluation procedure could largely be kept, while illogical and counterintuitive effects in conjunction with mode switchers or induced traffic would be avoided.

Acknowledgments

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