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The effect of health benefits on the value of travel time savings in active transport

Stefan Flügel [*], Knut Veisten, Hanne Beate Sundfør, Guri Natalie Jordbakke, Nina Hulleberg, Askill H. Halse

The Institute of Transport Economics (TØI), Norway

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ABSTRACT

Introduction: The valuation of travel time savings and the valuation of health effects are crucial in the economic appraisal of infrastructure projects that affect cycling and walking for transport. Current practices treat the two in separate; but if individuals perceive the positive health effects from active transport, then they should also be expected to factor in these benefits in their valuation of time savings. There ought to be a downward-adjusting effect on their valuation of travel time savings. While this is widely acknowledged within transport economics, there is little empirical evidence on how large the effect from health benefits on the value of travel time savings is.
Method: We have applied two types of choice experiments. The first was a travel mode choice, that enabled a quantification of the effect of cyclist's/pedestrian's motivation for additional physical activity on their valuation of travel time savings. In the second choice experiment, cyclists/pedestrians chose between alternatives that differed in "negative" and "positive" side effects of the physical activity, like sweating and burning calories, as well as differing in travel time.
Results: Based on the first choice experiment, we find that cyclists/pedestrians motivated by health benefits have significantly lower valuation of travel time savings. From the second choice experiment, we find that the valuation of travel time savings decreases as the levels of positive side effects of physical activity in the choice set increase. Taken together, we estimate the decreasing health-benefit effect on the value of travel time savings in active transport in the range of 20–65 percent.
Conclusions: The results support the notion that expected health benefits are influencing the decisions to cycle and walk, with a subsequent negative effect on the valuation of travel time savings. Our study offers new evidence on this relationship as well as new methods for quantifying it.

1. Introduction

With the prospect of promoting active transport, many cities have invested heavily in improving the infrastructure for cyclists and pedestrians (Winters et al., 2018; Gualdi & van den Noort, 2013; Marqués et al., 2015; Kornas et al., 2017; Hong et al., 2019). If infrastructure development and other measures yield increased active transport and increased physical activity, there might be

* Corresponding author.
E-mail address: sfl@toi.no (S. Flügel).

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positive benefits to society (Sturm, 2005; Santos et al., 2010; Götschi and Hintermann, 2014). How should such benefits be treated in economic appraisal of infrastructure projects?

When health effects due to some activity materialize in terms of fitness or prevented illness, part of the effects will be external to the individual. Third parties that incur costs of illness and absenteeism will save costs when health improves and illness decreases (Sælensminde, 2004; Heron et al., 2019; Kriit et al., 2019). However, the major part of total economic valuation of health effects is represented by the individuals' ex-ante valuation of their own health risk change (Cameron et al., 2010; Lindhjem et al., 2011; Hammitt and Haninger 2017). If individuals control part of their own health risk in their transport choices, their individual valuations can be expected to be "internalized" in their choices (Börjesson and Eliasson, 2012).

The expected extent of health benefits from a certain physical activity is positively correlated with the duration of that activity (Åstrand et al., 2003). Because of this time-dependent effect, the valuation of travel time saving (VTTS) is an obvious candidate for a measure that ought to be affected by perceived health benefits.

The micro-economic foundation of the VTTS are so-called time allocation models (Becker 1965, deSerpa, 1971; Jara-Díaz and Guevara, 2003). By including health benefits in this framework, one can show that the VTTS for active transport.

1. Increases with the opportunity cost of time
2. Increases with the discomfort of the cycling/walking
3. Decreases with the associated health benefits.

The main insight from such theoretical consideration is that the VTTS is lower the higher the (perceived) health benefits from active transport.[1]

Does empirical evidence support the theoretical predictions? Individuals' VTTS are influenced by several features of the trip, e.g. the comfort level due to cycle/walk infrastructure. Thus, disentangling the impact of health on VTTS in active transport remains challenging. One approach to the estimation of expected health gains on the VTTS for active transport is the application of discrete choice experiments (CE), where individuals choose between transport modes and/or between route alternatives (Wardman et al., 1997; Börjesson and Eliasson, 2012).

Several CE studies have investigated how VTTS for active transport varies with respect to infrastructure type/quality, finding that respondents assessing alternatives with better cycle/walk infrastructure indicate a lower VTTS (Wardman et al., 1997; 2007; Börjesson and Eliasson, 2012; Björklund and Mortazavi, 2013; Flügel et al., 2018). Few have tried to include the health aspect into the estimation of VTTS. Börjesson and Eliasson (2012) include a split-sample test in their CE of cycling versus an alternative mode (public transport and private car). The sample is split between those stating (post-choice) exercise as the most important reason for cycling and those stating other reasons as most important. The authors do not find that those most motivated by exercising valued time savings lower than the others.

Björklund and Mortazavi (2013) carried out a similar CE study to that of Börjesson and Eliasson (2012), involving travel time, cost of an alternative mode, and type of cycling infrastructure facility. They include a latent health variable measured by the following question items (with response alternatives from 1, "No importance at all", to 5, "Very large importance"): "A time-efficient way to exercise", "A good way to keep weight/lose weight", "Improves fitness", and "Good for one's own health" (Björklund and Mortazavi, 2013, p. 14–15). Their procedure thus enabled differentiating between higher and lower health-based motivation, not just identifying the share stating physical activity and health as the most important motivation. The authors find lower VTTS estimates for respondents with higher score on the latent health variable, but differences are not statistically significant in all split-sample comparisons.

In this paper, we combine two types of CE for the assessment of how much the individuals' own health benefits affect their VTTS. One CE is a travel mode choice with a post-choice question about the motivation for cycling/walking, having some similarity to the studies by Börjesson and Eliasson (2012) and Björklund and Mortazavi (2013). The other CE includes physical activity elements directly into the choice sets, both the direct cycling/walking efforts (getting tired, sweating, etc.) and the indirect health benefits (feeling in good shape, improving future health, etc.). To our knowledge, this is a novel approach to the assessment of active transport users' inclusion of health effects in their travel choices and VTTS. We combine the results from both CEs for an estimation of how much individual health benefits affect VTTS.

The remainder of the paper is structured as follows. Section 2 explains the experimental design of the choice experiments. Section 3 presents the data and section 4 the modelling and estimation results. Section 5 provides a discussion of results and practical implications for project appraisal. Finally, section 6 provides the main conclusions.

2. Experimental design

The two CEs (CE1 and CE2) were applied to samples of active transport users, with slightly different questionnaire and choice designs for cyclists and pedestrians. We will refer to them as CE1-cyc, CE1-ped, CE2-cyc and CE2-ped. The hypothetical choice settings in both CEs are based on a reference trip, a trip that the respondent had recently made. The reference trip had to be longer than 500 m

[1] A mathematical derivation in a simple model where health benefits from activities are additive separately from the enjoyment of these activities is given in the appendix. Note that in the economic framework of time allocation models, the VTTS from active transport would still be positive (other thing equal, agents prefer to save travel time). By definition, if health benefits would be so large as to reduce the VTTS to zero or negative numbers, the associated activity (cycling/walking) would be classified as a leisure activity, for which the concept of VTTS makes little sense.

and to have been carried out for a specific purpose (excluding pure sport/recreational trips). Cycling/walking for public transport access/egress was also excluded.

2.1. Design of choice experiment 1 (CE1)

CE1-cyc consists of a sequence of eight choice cards, each with four alternatives: Two cycling alternatives and two alternatives with a paid mode that is available to the respondent in real life (private car or public transport). In case respondents state that they did not have a paid alternative, we ask them to imagine a hypothetical bus service going « door-to-door».

For each choice task, respondents are first asked to select the worst alternative of the four alternatives, then the best alternative of the three remaining ones, and finally the best of the two remaining. With this setup, we get a complete rank order of preferences for the four alternatives (Marley and Louviere, 2005); that includes one route choice for cycle, one route choice for the paid mode, and at least two choices that include alternatives with different modes.

The main motivation to include route choice for the paid mode is to force respondents to make trade-offs between the travel time and the cost attribute within the paid mode; thereby getting more information about the marginal disutility of travel cost. This parameter is crucial for the estimation of the absolute value of VTTS for cycling/walking.

Fig. 1 shows the set-up of the choice cards for cycling (the choice cards for walking have an analogous set-up). Prior to the choice cards, the following introduction was given: "*Imagine that you were to make the trip you have described again, but that you could choose between the bicycle and other transport modes and choose between different routes. In the next questions, we present four options with different characteristics. All other features are similar to those of the trip you described. Imagine that you have to pay for the cost of the trip yourself.*"

The attributes describing the paid mode alternatives ("bil" = car, in Fig. 1) are travel time and travel cost. Attribute values were chosen such that implicit trade-offs would be distributed within the range of expected VTTS values, i.e. between 10 and 1250 Norwegian krone per hour (NOK/h)).

The cycling alternatives are characterized by the attributes travel time, the main type of road, the number of signalised crossings, and the number of other crossings. The predominant type of cycling infrastructure is specified as either "shared road with cars or pavement", "on-road cycle lane", "shared off-road cycle/walk path", "off-road cycle path" or "off-road cycle highway" (a currently non-existent but planned separated cycle path of higher quality). The category reported by the respondent to be the dominant infrastructure type on the reference trip always appeared in one of the cycling alternatives.

The corresponding CE for pedestrians (CE1-ped) had a very similar set up; the infrastructure attributes are given as "shared road with cars", "shared off-road cycle/walk path", "pavement", and "off-road pedestrian path".

For both CE1-cyc and CE1-ped the attributes travel time, signalised crossings and other crossings have five levels, where the level values are calculated as percentage changes with respect to the reported reference values. Attribute values for the cycle alternatives are combined into choice sets by means of an orthogonal design, omitting dominant alternatives.

2.2. Design of choice experiment 2 (CE2)

In the second choice experiment for cyclist (CE2-cyc), the choice is between two unlabelled cycling routes, Alternative A and Alternative B, that differ in the type of cycle, travel time, negative effects of physical effort, and positive effects of physical effort. The

Please choose...

	Alternative A	Alternative B	Alternative C	Alternative D
Travel mode	Bicycle	Bicycle	Car	Car
Travel time	35 min.	30 min.	25 min.	32 min.
Travel cost			60 NOK	47 NOK
Main road type (cycling)	Off-road walk and cycle path	On-road cycle lane		
Signalised crossings	5	4		
Other crossings	5	6		
1. I prefer the least...	Alternative A	Alternative B	Alternative C	Alternative D
2. I prefer the most...	Alternative A	Alternative B	Alternative C	Alternative D
3. Of the remaining ones, I prefer...	Alternative A	Alternative B	Alternative C	Alternative D

Fig. 1. Example of a choice card in CE1 for cycling (translated from Norwegian). Respondents first selected the least preferred alternative among the four (1.), then the best alternative of the three remaining ones (2.), and finally the best of the remaining two (3.). NOK: Norwegian krone.

corresponding choice experiment for pedestrians (CE2-ped) is similar, except that the attribute “type of cycle” is omitted.

Prior to the choice tasks, negative effects are introduced to the respondent as follows:

> Cycling requires physical effort that can be experienced as uncomfortable.
>
> Which of the following do you experience as negative when cycling for transport?
>
> We ask you to consider these elements on their own, disregarding that the physical effort can also have positive effects.

- *Panting*
- *Sweating*
- *Getting physically tired*
- *Getting sore muscles*

The response alternatives were “very negative”, “somewhat negative”, and “not negative”; and effects that the respondent considered very or somewhat negative were included in his/her choice sets. If a respondent ticked “not negative” to all four effects, a follow-up question determined the “least positive” of the four effects. That effect was then included for the verbal description of negative effects in the choice cards.

Positive effects are introduced to the respondent as follows:

> Cycling can have various elements that can be perceived as pleasant/positive.
>
> Which of the following do you experience as positive when cycling for transport?
>
> We ask you to consider these elements on their own, disregarding that these may require physical effort that may be perceived as negative.

- *Burning calories*
- *Improving future health*
- *Achieving a desirable physical activity level*
- *Feeling in good shape*

Similar as for negative effects, those elements that the respondent ticked as “very” or “somewhat” positive (opposed to “not positive”) are included in the choice experiments. If a respondent ticked “not positive” to all four effects, a follow-up question determined the “least negative” of the four effects. That effect was then included for the verbal description of positive effects in the choice cards.

There are three attribute levels for every negative and positive effect, specified by verbal descriptions like “no/few”, “some”, and “much/very” (or “large”). The design levels for travel time are similar to those in CE1, i.e. five design levels where the reference value is the medium level, design level 3.

The attribute “type of cycle” is binary and either “regular bicycle” or “e-bike”. The value is randomly assigned and can be identical for both alternatives.

Similar to CE1, attribute levels in CE2 are blocked into choice sets by means of an orthogonal design.

Fig. 2 shows a choice card for cycling, where 3 negative effects and 3 positive effect are included (based on the respondent’s pre-selection). Prior to the choice, the following introduction was given: “*You will now face more choices between different types of bikes, travel routes, different positive/negative effects, and different travel times. If you find that the combination of characteristics appears strange, consider that your travel route may have different gradients (either uphill or downhill) or other characteristics that can explain the given combinations. Then choose the alternative you prefer.*”

3. Data

3.1. Recruitment

Survey participants to both CE studies were recruited from three different sources: i) an email register operated by the Norwegian postal service, ii) an internet panel, and iii) intercepted cyclists/pedestrians in major cities.[2] The data collection of CE1 was carried out in the autumn of 2018. The data collection for CE2 was carried out in waves throughout the summer and early autumn of 2019.

Table 1 displays descriptive statistics for the four survey samples (CE1-cyc, CE1-ped, CE2-cyc, CE2-ped).

Comparing the two cycling samples to the corresponding walking samples, we see that the female share is lower and the average age higher in the cycling samples. The share of respondents with university degree and the average income is somewhat higher in the

[2] The surveys are described in more detail (in Norwegian) in Veisten et al. (2021)

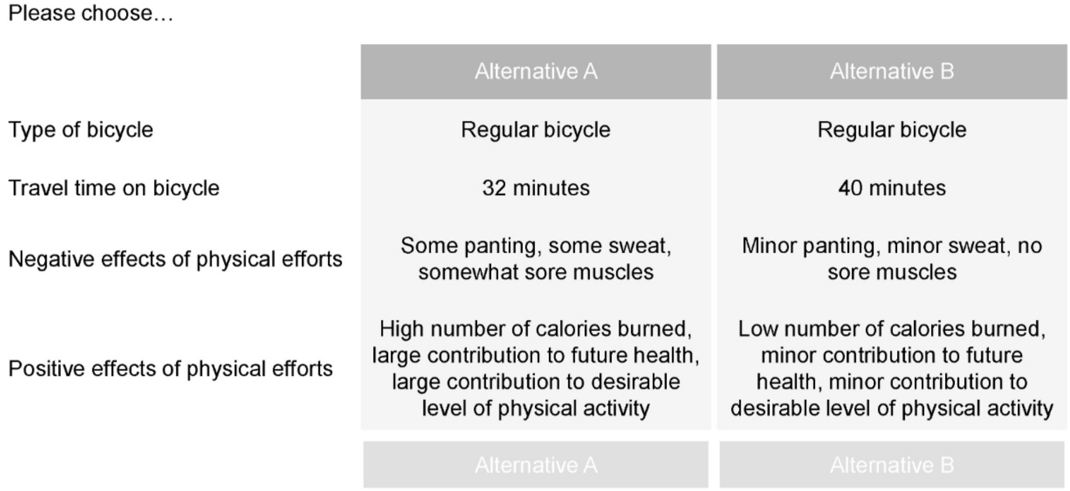


Fig. 2. Example of a choice card of CE2-cyc (translated from Norwegian).

cycling samples. The calculated response rate varied with the recruitment method. The response rate was particularly low for the email-register when calculated with respect to the number of dispatched survey invitations (by email); but a large share in the register may not have received any invitation, due to spam filters or obsolete/invalid email addresses.

3.2. *Descriptive statistics of health-related background variables*

3.2.1. *Question on motivation to cycle/walk and physical activity and health*

The questionnaires for all samples included several questions about physical activity and health. The question/statement which has closest relationship to internalization of health effects is: “I prefer to cycle/walk (versus other transport modes) as it gives me additional physical activity”. Respondents replied to the statement on a Likert-scale from 1 (absolutely disagree) to 7 (absolutely agree). Those respondents answering with 5–7, are coded as agreeing to the statement.

Table 2 shows the related shares for each subsample. In total, 65.5% agreed to the statement. While this share does not provide an estimate of the degree of internalization of health benefits in the VTTS, it indicates that a substantial share of respondents is motivated by additional physical activity (and presumably the related health benefits) when deciding to cycle/walk for transport.

Table 2 further reveals that cyclists are more inclined than pedestrians to agreeing to this statement. This may be expected given that cycling is associated with larger health benefits per time unit than walking (Ainsworth et al., 2000; Gojanovic et al., 2011).

Further descriptive statistics (not shown here) showed that the share of agreeing is increasing with age, and that this age effect is stronger for male than for female respondents.

Table 3 cross-tabulates the statement about active transport preference with agreement to other questions about physical activity.

The cross-tabulation of agreement to different statements indicates that the additional physical activity motivation correlates with agreement to cycling/walking requiring little effort, to increasing active travel time for the sake of exercise, and to active transport substituting other physical activity (Table 3).[3]

3.2.2. *Responses to screening questions about negative and positive features of active transport, prior to CE2*

Fig. 3a and b shows the distribution of responses to the screening questions about presumably negative and positive elements related to active transport.

Fig. 3a and b shows a lack of balance between perceived negative and perceived positive side effects. Most proposed negative effects of cycling/walking were not perceived as negative at all by the majority of the respondents, the exception being “sweating”. On the contrary, all proposed positive effects were indeed considered as positive by the majority of respondents.

3.3. *Data processing*

For the statistical analysis (see next section), we excluded the following observations from the data.

- Respondents completing the survey unreasonable fast[4]

[3] Veisten et al. (2011) presented an approach to the estimation of the share of cyclist/pedestrians that substitutes active transport for other physical exercise.

[4] The lowest acceptable time use is set to 3 min for the survey including CE1 and 5 min for the survey including CE2.

Table 1
Descriptive statistics of the four survey samples.

	CE1-cyc	CE1-ped	CE2-cyc	CE2-ped
No. of observations (completed surveys)	815	495	680	639
Response rate[a]	7%		3%	
Average age	40.4	38.3	44.7	42.8
Female share	47.6%	59.0%	50.1%	54.3%
University degree share	76.3%	63.1%	86.0%	67.9%
Average income (thousand NOK/year)	533	435	629	522

[a] Measured as share of the total number of invitations sent, including invitations to non-active email addresses. The response rate as share of those opening the email was 25.6% and 17.0%, respectively.

Table 2
Responses to statement about preference for active transport by subgroup.

Sample	I prefer to cycle/walk as it gives me additional physical activity					
	Neutral/disagree		Agree		Total	
	Count	Row %	Count	Row %	Count	Row %
Total	906	34.5%	1723	65.5%	2629	100.0%
CE1-cyc	214	26.3%	601	73.7%	815	100.0%
CE1-ped	166	33.5%	329	66.5%	495	100.0%
CE2-cyc	177	26.0%	503	74.0%	680	100.0%
CE2-ped	349	54.6%	290	45.4%	639	100.0%

Table 3
Responses to statements about the preference for active transport versus responses to related statements.

Statement		I prefer to cycle/walk as it gives me additional physical activity					
		Neutral/disagree		Agree		Total	
		Count	Row %	Count	Row %	Count	Row %
It takes little effort to use the "bike/feet" on my everyday travel	Neutral/ disagree	531	41.6%	744	58.4%	1275	100.0%
	Agree	375	27.7%	979	72.3%	1354	100.0%
Sometimes I deliberately take a detour when I "bike/walk" to get extra exercise	Neutral/ disagree	723	45.3%	873	54.7%	1596	100.0%
	Agree	183	17.7%	850	82.3%	1033	100.0%
Using the "bicycle/feet" as a transport mode will replace other physical activity/exercise	Neutral/ disagree	654	42.9%	869	57.1%	1523	100.0%
	Agree	252	22.8%	854	77.2%	1106	100.0%

- Reference travel time more than 90 min
- Some single observations with missing information about attribute values

With these exclusion rules, the samples were reduced by between 1.2% (CE1-cyc) and 5.0% (CE2-ped).

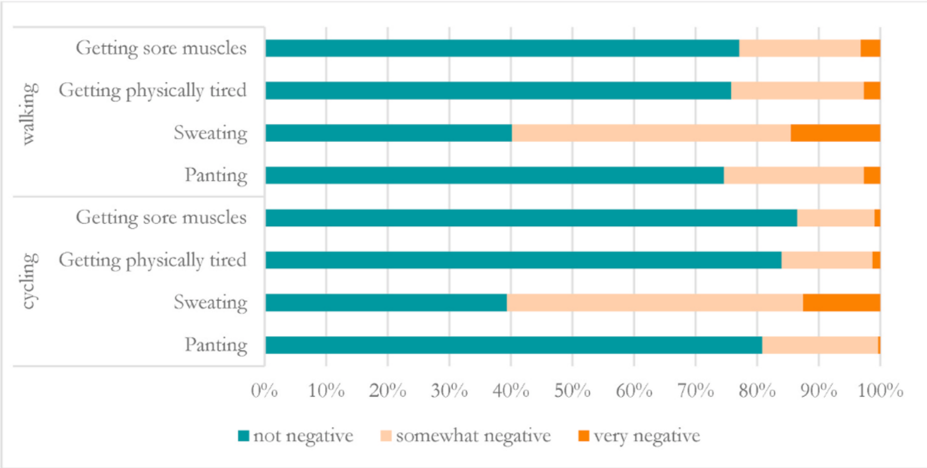
4. Estimation

We build mixed logit model for panel data (see e.g. Train 2009) to analyse the discrete choices from the different choice experiments. We apply normal distributions for central parameters, such as the marginal utility of travel time, to account for the taste heterogeneity in the sample.[5] The cost parameter is held constant over all respondents in CE1 (cost was not included in CE2). This assumption eases the calculation of mean values for VTTS as it avoids the need for simulation (Sillano and Ortúzar, 2005).

4.1. Estimation model and results for CE1

The observed alternative ranking from choice experiment t for respondent r are transformed into three discrete choices v. For $v = 1$,

[5] A normal distribution (opposed to e.g. a log-normal one) allows that some share of respondents prefer longer travel times. Allowing for this (opposed to restricting the sign a priori) seems reasonable in the case for cycling and walking, and initial tests showed that normal distributions fit our data better than lognormal ones.



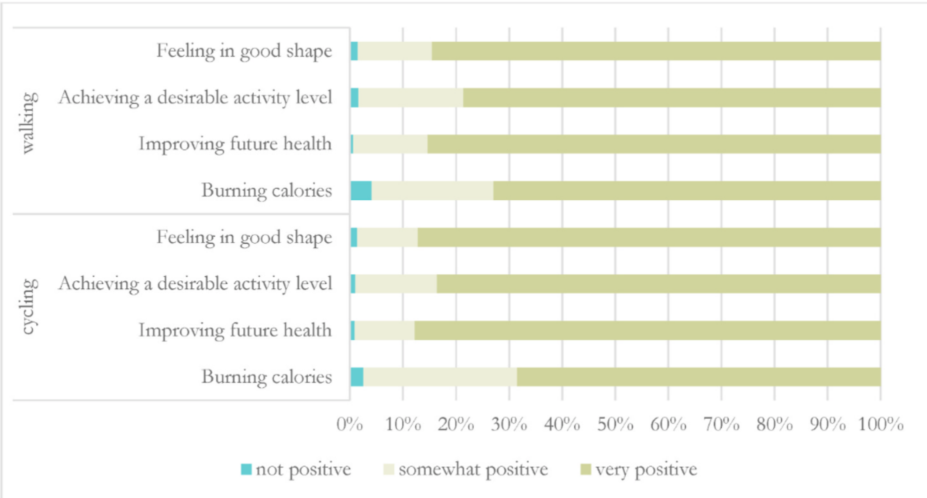


Fig. 3a. Response distribution to screening question about presumably "negative" side effects of physical activity, prior to CE2
Fig. 3b: Response distribution to screening question about presumably "positive" effects of physical activity, prior to CE2.

the choice set are all 4 alternatives, while for $v = 2$ and $v = 3$, the choice set has respectively 3 and 2 alternatives. The transformation is applied such that the chosen alternative can be interpreted as having the highest utility among all remaining alternatives.

As different attributes are used to describe the alternatives for cycling/walking and the paid mode, it is convenient to present the utility functions in separate equation.

For cycling:

$$U^{cyc}_{i,r,t,v} = \theta_{0,n} + \theta_{T,n} {}^*T_{i,\ r,t,v} + \beta_{LC} {}^*LC_{i,\ r,t,v} + \beta_{AC} {}^*AC_{i,\ r,t,v} + \varepsilon_{i,r,t,v} \tag{1}$$

With

$$\theta_{T,r} = \theta_{T0,r} + \sum_{k=1}^{5} \left(\beta_{T,k} * D_{k,\ i,r,t,v}\right) + \beta_A {}^*D_{A,r} \tag{2}$$

Where.

- i: index for choice alternative i = {«cycling route A», «cycle route B»}
- r: index for the respondent
- t: index for choice card experiment $t = \{1, 2, \ldots, 8\}$
- v: index for translated choice $v = \{1, 2, 3\}$
- k: index for cycle infrastructure k = {«"shared road with cars or pavement","on-road cycle lane", "shared off-road cycle/walk path", "off-road cycle path" or "off-road cycle highway"»}

- is a constant term for the cycling alternative with mean value β_0 and standard deviation σ_0. For the sake of normalization, $\beta_0$is set to zero.
- is the cycling time (in minutes)
- represent the marginal utility of cycling time
- β_{T0}; σ_{T0}) is a constant term in the vector that parameterizes $\theta_{T,r}$ with mean value β_{T0} and standard deviation σ_{T0}.
- is travel time for the cycle alternatives (in minutes)
- are dummy variables for infrastructure k.
- are corresponding time parameters for infrastructure k
- is a dummy that takes value 1 if the respondent replied « agree » to the question « I prefer to cycle/walk over other modes of transport as it gives me extra physical activity”
- represents the corresponding marginal effect of the utility of cycling time.
- $AC_{i,\ r,t,v}$ are the numbers of, respectively, signalised crossings and other crossings
- β_{AC} are the corresponding parameters.
- are iid-Gumbel distributed error terms («white noise»).

For walking:

In the estimation model for pedestrians (CE1-ped), the utility function for walking $U^{wa}_{i,n,t,v}$ is identical to the one for cycling, except that k is given as k = {“shared road with cars”, “shared off-road cycle/walk path”, “pavement”, “off-road pedestrian path”}.

For the paid travel mode (PM):

$$U^{PM}_{i,r,t,v} = \sum_{m=1}^{7} \left(\beta_{O,m} * D_{m,i,\ r,t,v}\right) + \beta_{TPM} * TPM_{i,\ r,t,v} + \beta_C * C_{i,\ r,t,v} + \varepsilon_{i,r,t,v} \tag{3}$$

Where.

- i: index for choice alternative i = {«route A with paid travel model», «route B with paid travel model»}
- r: index for the respondent
- t: index for choice card experiment $t = \{1, 2, \ldots, 8\}$
- v: index for translated choice $v = \{1, 2, 3\}$
- m: index for the type of paid mode m = {car driver, car passenger, bus, hypothetical bus, metro, train, tram}
- is the constant for travel mode m (it is measured relative to $\theta_{0,n}$ from equation 1, which is normalized to zero)
- $C_{i,\ r,t,v}$ are travel time (in minutes) and travel costs (in NOK), respectively
- β_C are corresponding parameters
- are iid-Gumbel distributed error term («white noise»).

The main parameter of interest is β_A. We expect it to have a value greater than 0, but lower than the absolute value of β_{T0} that represents the average marginal (dis-)utility of cycling.

From the estimation results, we can calculate the average VTTS on infrastructure k given the value of $D_{A,n}$ as:

$$\left(\overline{VTTS}_k | \left(D_{A,r} = 1\right)\right) = \frac{\left(\beta_{T0} + \beta_{T,k} + \beta_A\right)}{\beta_C} * 60 \tag{4}$$

$$\left(\overline{VTTS}_k | \left(D_{A,r} = 0\right)\right) = \frac{\left(\beta_{T0} + \beta_{T,k}\right)}{\beta_C} * 60 \tag{5}$$

Separate models are estimated for cyclists and pedestrians using Biogeme (Bierlaire 2003) with 500 Halton draws in each model. Table 4 below shows the estimation results.

All constant terms for the paid mode alternatives are negative, indicating that respondents prefer – other things being equal – to cycle (walk). The parameter for time (β_{TPM}) and cost (β_C) are as expected negative, and the implied VTTS for the paid mode is 82.6 NOK/hour[6] when assessed against cycling and 10.45 NOK/hour when assessed against walking. The former is within the expected range, while the latter is lower than expected.

The parameters for signalised crossings (β_{LC}) and other crossing (β_{AC}) are significantly negative in both CE1-cyc and CE1-ped.

Importantly, the estimated parameter related to health effect motivation (β_A) is as expected positive and statistically significant. It indicates that respondents agreeing to the statement (i.e. prefer active transport because of the additional physical activity) have lower marginal disutility of travel time in active transport.

Table 5 shows the implied VTTS based on equations 4 and 5.

Estimated VTTS.

[6] -0.119/-0.0869*60.

Table 4
Estimation results of CE1.

	cycling		walking	
# parameters		19		18
# observations		19320		11736
# persons		805		489
Adj. rho square		0.362		0.256
Parameter	Value	Robust t-stat	Value	Robust t-stat
$\beta_{O,car\ driver}$	−4.27	−10.18	−4.62	−11.46
$\beta_{O,car\ passanger}$	−2.25	−7.96	−3.79	−12.52
$\beta_{O,bus}$	−3.16	−8.57	−3.75	−6.68
$\beta_{O,hypothtic\ bus}$	−3.21	−10.67	−5.64	−12.62
$\beta_{O,metro}$	−3.63	−7.59	−4.99	−7.29
$\beta_{O,train}$	−3.37	−3.85	−0.642	−1.84
$\beta_{O,tram}$	−1.46	−2.78	−5.52	−9.22
β_C	−0.0869	−14.59	−0.0251	−1.92
β_{TPM}	−0.119	−11.65	−0.00437	−4.01
β_0	0	norm.	0	norm.
σ_0	3	16.23	2.76	10.63
β_{AC}	−0.134	−10.86	−0.102	−6.74
β_{LC}	−0.146	−7.1	−0.164	−6.58
β_{T0}	−0.228	−19.93	−0.216	−11.58
σ_{T0}	0.0561	11.32	0.0784	10.15
$\beta_{T,\ shared\ off-road\ cycle/walk\ path}$	0.0355	10.94	0.0434	6.73
$\beta_{T,\ shared\ road\ with\ cars\ or\ pavement}$	0	norm.		
$\beta_{T,\ off-road\ cycle\ highway}$	0.0372	9.39		
$\beta_{T,\ off-road\ cycle\ path}$	0.0505	13.31		
$\beta_{T,\ on-road\ cycle\ lane}$	0.0224	8.12		
$\beta_{T,\ pavement}$			0.045	6.62
$\beta_{T,\ off-road\ pedestrian\ path}$			0.0487	7.06
$\beta_{T,\ shared\ road\ with\ cars}$			0	norm.
β_A	0.0392	4.09	0.0669	7.99

- is in general higher for walking than for cycling
- varies with respect to the predominant infrastructure; it is highest in the case of "shared road with cars", for walking, and "shared road with cars or pavement", for cycling
- is lower for respondents agreeing to the physical activity motivation statement ($D_{A,n} = 1$)

Taking a simple average over infrastructure types, the reduction in VTTS for those agreeing to the physical activity motivation statement is about 20% in the case of cycling (CE1-cyc) and nearly 40% in the case of walking (CE1-ped).

4.2. Estimation model and results for CE2

For the cycling subsample, we specify the following utility function for alternative *i* (i = {A, B}), respondent *r* and choice task *t*:

$$U_{i,r,t} = \theta_{EL,r} * D_{EL,i,r,t} + \theta_{T,\ n,p,r} * T_{i,r,t} + \varepsilon_{i,r,t} \quad (6)$$

with

$$\theta_{T,\ n,p,r} = \theta_{0,r} + \sum_{n=1}^{3} \sum_{p=1}^{3} \left(\beta_{n,p} * D_{n,p}\right) \quad (7)$$

where.

- is a dummy which takes value 1 if alternative i in person *r*'s choice task *t* is an e-bike.
- is the corresponding parameter which is assumed to be normally distributed over respondent *r* (but fixed for choice task *t*) with mean value β_{EL} and standard deviation σ_{EL}. It measures the preferences for using an e-bike; it is here assumed to be independent of travel time.
- is the time attribute (in minutes).
- is the constant term of the vector representing the marginal disutility of the travel time attribute. It is assumed to be normally distributed over respondent *r* (but fixed for choice task *t*) with mean value β_0 and standard deviation σ_0.

Table 5
Implied value of travel time savings (NOK/hour) with respect to predominant cycle/walk infrastructure type and agreement to physical activity motivation, CE1.

VTTS (NOK/hour)	Cycling		Walking	
"Prefer active transport because of extra physical activity"	Agree	Do not agree	Agree	Do not agree
Shared off-road cycle/walk path	105.85	132.91	252.67	412.59
Shared road with cars or pavement	130.36	157.42		
Off-road cycle highway	104.67	131.74		
Off-road cycle path	95.49	122.55		
On-road cycle lane	114.89	141.96		
Pavement			248.84	408.76
Off-road pedestrian path			240.00	399.92
Shared road with cars			356.41	516.33
Average VTTS	*110.25*	*137.32*	*252.67*	*412.59*
"Agree" relative to "do not agree"	*80.29%*		*61.24%*	

- represent the set of dummies for the combination of attributes levels for negative effects n and positive effects p. For example, D_{13} takes the value 1 when the best level (level 1) is given for negative effects ("no/few") and the worst level (level 3) is given for positive effects ("no/few").
- are the corresponding parameters. Here we assume fixed effects for respondent r and choice task t. For identification, one parameter needs to be normalized. We apply $\beta_{3,3} \equiv 0$ (the parameter for dummy D_{33}, the worst combination of negative effects ("large") and positive effects ("no/few").
- are identically and independently (iid) Gumbel-distributed error terms.

Given the distributional assumptions of the error terms and the (two) random parameters, our model is a mixed logit model for (pseudo) panel data (e.g. Train 2009).

We are most interested in the marginal disutility of travel time given different levels of positive and negative effects ($\beta_{T,\ n,p,r}$). This is given by ($\theta_{0,r} + \beta_{n,p}$), an expression that is normally distributed with mean value ($\beta_0 + \beta_{n,p}$).

As the scale of utility is not interpretable in an economic sense, we need to look at relative values, e.g. ($\theta_{0,r} + \beta_{3,3}$)relative to ($\theta_{0,r} + \beta_{1,1}$).

Note that the mean of $((\theta_{0,r} + \beta_{3,3})/(\theta_{0,r} + \beta_{1,1}))$, i.e. the mean of the ratio of two normally distributed parameters is not mathematically identical to $(\beta_0 + \beta_{3,3})/(\beta_0 + \beta_{1,1})$, i.e. the ratio of the mean values. To avoid the need for simulation of the former expression, we also estimate models where we assume that θ_0 is fixed over all observations. In this case (referred to variant 2) taking ratios is mathematically valid.

The model for walking (CE2-ped) is identical to cycling except that the term $\theta_{EL,h}{}^{*}D_{EL,i,h,t}$ is omitted (as there was no analogy to e-bike vs. regular bicycle in the walking case). Note that model variant 2 (for walking) reduces to an MNL model[7] as it has no additional random term (only the iid term $\varepsilon_{i,r,t}$).

The models are estimated in Biogeme (Bierlaire, 2009) using 700 Halton draws to simulate the likelihood functions.

Table 6 shows the estimation results.

The goodness-of-fit in all CE2 model variants is rather low. One possible explanation is taste heterogeneity beyond what is captured by the normally distributed parameters. Including background variables in the parameterization of $\theta_{T,\ n,p,r}$ might have improved the goodness of fit, but it would have complicated the calculation of average differences between assumptions of positive and negative effects.

The mean value of the marginal utility of e-bike (β_{EL}) is negative, indicating that people on average prefer regular bikes over e-bikes, when we control for negative and positive effects of the physical activity (including sweating and perceiving an exercising/ fitness effect). Note also that the standard error (σ_{EL})is large compared to the mean indicating that the effects go in opposite direction for a large share of respondents.

The mean value of the constant term β_0 is estimated negative as expected; it represents the marginal (dis)utility of travel time given the worst levels of negative and positive effects ($\beta_{3,3}$), i.e., no/few positive effects and large negative effects.

The parameters for the $\beta_{n,p}$ are all positive. This is as expected; it indicates that the marginal disutility of travel time is reduced when negative effects are lower and/or positive effects higher. In some instances, the value of $\beta_{n,p}$ is larger in absolute value than β_0 indicating a positive marginal utility from more travel time. This is discussed further below.

The pattern of values across model variant 1 and model variant 2 are fairly consistent for the cycling and walking samples. Thus, we proceed with the results from the simpler model variant 2 only.

Table 7 shows the estimated marginal utility of travel time for different assumptions of negative and positive effects, in CE2. These effects are also monetized by use of information from CE1: It is assumed that the average VTTS would be the same in CE2 as estimated

[7] Technically this model is referred to as 'MNL model for panel data' in Biogeme. Standard errors are robustly calculated taking into account the panel structure.

Table 6
Estimation results for CE2.

	Cycling				Walking			
	Variant 1		Variant 2		Variant 1		Variant 2	
# parameters	12		11		10		9	
# observations	3978		3978		3642		3642	
# persons	663		663		607		607	
Adj. rho square	0.089		0.088		0.069		0.069	
	value	rob-T-value	value	rob-T-value	value	rob-T-value	value	rob-T-value
β_{EL}	−0.637	−7.94	−0.633	−7.98				
σ_{EL}	1.3	11.32	1.28	11.49				
$\beta_{1,1}$	0.084	8.95	0.081	8.88	0.0761	9.5	0.0752	9.27
$\beta_{1,2}$	0.0721	8.58	0.0702	8.55	0.0604	7.88	0.0597	7.83
$\beta_{1,3}$	0.0489	5.92	0.0474	5.83	0.0482	6.24	0.0479	6.18
$\beta_{2,1}$	0.0729	9.17	0.0713	9.07	0.0598	7.9	0.059	7.81
$\beta_{2,2}$	0.0554	6.94	0.0538	6.82	0.0537	7.12	0.0532	7
$\beta_{2,3}$	0.0342	4.01	0.0336	4.00	0.0421	5.49	0.042	5.48
$\beta_{3,1}$	0.0519	6.47	0.0504	6.33	0.0425	5.67	0.0424	5.65
$\beta_{3,2}$	0.0383	4.34	0.0373	4.3	0.0442	5.81	0.044	5.79
$\beta_{3,3}$	0	fixed	0	fixed	0	fixed	0	0
β_0	−0.0804	−7.92	−0.0784	−8.02	−0.0522	−6.31	−0.0522	−6.36
σ_0	0.0334	2.88			0.0221	1.71		

Note: The parameters $\beta_{1,1}$, …, $\beta_{3,3}$ represent the estimated impact from combinations of specific levels of negative and positive physical activity effects ($\beta_{n,p}$) on VTTS, such that, e.g., $\beta_{1,2}$ is the estimated impact when negative effects for the given cycle or walk trip obtain level "low/few" (best level) and positive effects the level "some" (medium level).

for CE1 (for cycling 137.32 NOK/h and for walking 412.59 NOK/h).

The estimated marginal disutility per travel minute and estimated VTTS are highest for the worst combination of large negative effects and no/few positive effects from the physical effort. VTTS will decrease with decreasing negative effects and with increasing positive effects.

The absolute values for the walking sample are rather extreme; this is a consequence of the high absolute VTTS from CE1 (412.59 NOK/hour) combined with the large relative differences in the marginal disutility of walking from CE2. The absolute VTTS values for cycling seem reasonable.

Focussing on cycling only and holding the negative level constant at "some" negative effects (mostly corresponding to "a bit sweating"), Table 7 shows that the VTTS is substantially lower in the case of "large" positive effects than in the case of "some" positive effects (33.7 NOK/hour versus 116.7 NOK/hour); and VTTS is substantially lower for "some" positive effects than for "no/few" positive effects (116.7 NOK/hour versus 212.5 NOK/hour). Taking an unweighted average of "some" and "large", at about 75 NOK/h, we derive that health benefits decrease the VTTS roughly from 213 NOK/hour to 75 NOK/hour, i.e. by about 65%. Holding the negative level constant at "large" negative effects, the reduction would be from 371.8 NOK/hour (no/few positive) to about 164 NOK/hour (the average of 132.8 and 194.9), i.e. about 56%. Thus, CE2-cyc yields substantially higher estimates of the implied health benefit impact on VTTS than the 20% estimate from CE1-cyc.

5. Discussion and practical implications

Our choice experiments were designed for the purpose of shedding more light on whether health benefits from active transport affect the valuation of travel time savings (VTTS), and if so, to what degree. Our results contribute to a small, but growing empirical literature on the economic interpretation of health effects from active transport.

Post-choice questions about active transport motivations (section 3.2.1) yielded more evidence about physical activity being a major motivation for active transport. By itself it supports the intuition that cyclists/pedestrians value and factor in ("internalize") health benefits in their transport decisions. Moreover, we find a significant difference in the VTTS between respondents motivated by additional physical activity and those who are not. These results head in the same direction as those reported by Björklund and Mortazavi (2013).[8]

[8] Standen (2018) proposed an interpretation of why such a result was not found by Börjesson and Eliasson (2012), who compared those who stated physical activity as main motivation versus those who stated "other" reason as the main motivation: that negative health impacts from increased injury risk and air pollution exposure could be perceived as approximately equal in magnitude to the positive health impacts, thus cancelling each other out, by both groups. We believe, however, that there is not such a cancelling-out effect; that there are positive health effects that are perceived to a various extent by different active transport users. Seemingly, the comparison based on degree of physical-activity (or health) motivation, like our approach and the one by Björklund and Mortazavi (2013), represents a better way of identifying the relationship with VTTS (than using main motivation only).

Table 7
Implied marginal (dis)utilities of travel minutes from CE2 and implied VTTS when scaled to average values obtained in CE1.

	Cycling			Walking		
Side effects of physical motion	marginal (dis) utility (minutes)	Relative to "large" neg./"no/few" pos.	scaled VTTS (NOK/h)[a]	marginal (dis) utility (minutes)	Relative to large" neg./ "no/few" pos.	scaled VTTS (NOK/h)[b]
no/few negative - large positive	0.0026	−3.32%	−12.3	0.023	−44.06%	−1840.6
no/few negative - some positive	−0.0082	10.46%	38.9	0.0075	−14.37%	−600.2
no/few negative - no/few positive	−0.031	39.54%	147.0	−0.0043	8.24%	344.1
some negative - large positive	−0.0071	9.06%	33.7	0.0068	−13.03%	−544.2
some negative - some positive	−0.0246	31.38%	116.7	0.001	−1.92%	−80.0
some negative - no/ few positive	−0.0448	57.14%	212.5	−0.0102	19.54%	816.3
large negative - large positive	−0.028	35.71%	132.8	−0.0098	18.77%	784.3
large negative - some positive	−0.0411	52.42%	194.9	−0.0082	15.71%	656.2
large negative - no/ few positive	−0.0784		371.8	−0.0522		4177.5

[a] Scaled such that the average value corresponds to the estimated value of 137.32 NOK/hour from CE1-cyc.
[b] Scaled such that the average value corresponds to the estimated value of 412.59 NOK/hour from CE1-ped.

Our cross-sectional (split-sample) comparison has methodological weaknesses in that it may be prone to self-selection, i.e., the differences in VTTS could be explained by other differences between the two groups that were compared. That was one of the reasons behind the novel "intra-sample" approach, where we systematically varied health benefits (presented as positive effects of cycling/ walking) for a given respondent. By also including negative effects, like sweating, we can estimate the effects of health benefits on VTTS controlled for the comfort element that relates to the physical effort. Notwithstanding, some elements of our approach can be tested and developed further in new applications. One issue is how respondents really perceive the "positive effect" and "negative effect" attribute levels in the choice sets, e.g., the realism in the changes from "no"/"few" to "much"/"very" with respect to travel time. Still, we obtained estimates that varied monotonically and substantially in the expected directions. [9]

We estimate a reduction in VTTS due to health benefits of between 20% and 65%. For pedestrians, CE1 indicates a reduction of roughly 40%; results for CE2 (for walking) indicated an even greater variation in VTTS but are regarded as less reliable/reasonable.

One pertinent question is what such a downscaling of VTTS would imply in actual project appraisal?

The current approach to economic appraisal in Norway, as in several other countries, is to treat all health benefits as external, disregarding internalization entirely (Vegdirektoratet, 2018; van Wee and Börjesson, 2015). That is, the benefits that the individuals themselves control and will enjoy themselves (better fitness, reduced illness risk, etc.) are also included as external. All monetized health effects are added to the benefits of a project alongside the benefits from time savings.

When considering the VTTS for active transport in handbooks for project appraisal, it is typically estimated without controlling for health benefits. Thus, we can expect the "official" VTTS actually being downscaled somewhat due to respondents' internalized health benefits in the CE survey that official VTTS for cycling/walking was based on. If respondents perceived health benefits as purely external, no perceived/known relationship between their active transport and short and long term health effects, the VTTS would have been higher. For an assessment of the possible "double counting" of health benefits in projects affecting active transport when health benefits are treated as external, as proposed by, e.g., Börjesson and Eliasson (2012), we list several possible outcomes of project appraisals that treat health benefits as external. Health effects in cost-benefit analysis are typically estimated from a unit value multiplied by the change in *kilometres* cycled (or walked), comparing the amount of active transport in the policy scenario to a reference scenario. The change in distance travelled (and thereby the sign of the health benefits) depend on the induced changes in route choice and the overall demand for active transport, as illustrated in Table 8.

Departing from Table 8, we can discuss what the use of "official" VTTS (being not controlled for health benefits) and full health benefits (i.e. unaccounted for internalization) implies for the economic benefits of projects.

For project types that yield travel time savings, primarily due to reduced transport distance, and subsequently negative health benefits per trip (indexed 1 and 6 in Table 8), the use of "official" VTTS and treating health benefits as external would overestimate the

[9] Götschi and Hintermann (2014) apply a revealed preference approach instead of survey-based stated preference in their assessment of the extent to which cyclists internalize health benefits. Based on Swiss travel survey data, they compare estimates of the generalized cost of transport between bicycling and motorized transport. "By including monetary savings of bicycling relative to other modes of transportation" in their generalized cost estimation, they could "monetize these costs and compare them with the health benefits of bicycling". The monetized health benefits were based on "estimates for the reduction in mortality risk due to exercise" and the value of statistic life (VSL). They estimated "that Swiss bicyclists internalize around half of the health benefits when making transportation choices, although the results are sensitive to the VSL estimate employed (the higher the VSL, the lower the degree of internalization)" (p. 298).

Table 8
Economic benefits of different improvements in cycling/walking infrastructure if health benefits are measured as a function of kilometres cycled/walked and are treated as external.

Assumed impact of the project/policy measure			Contribution of health benefits to economic benefits		Economic benefits as sum of time savings and health benefits
Example	Demand for active transport	Travel time given route choice	Per trip	In total	
1	Unchanged	Savings due to shortcuts	Negative	Negative	Depends on relative effects
2	Unchanged	Savings due to faster speed	Neutral	None	Positive due to time savings
3	Unchanged	No effect	Neutral	None	Neutral
4	Unchanged	Increases due to detours	Positive	Positive	Depends on relative effects
5	Unchanged	Increases due to slower speed	Neutral	None	Negative due to time increases
6	Increased	Savings due to shortcuts	Negative	Depends on size of demand effect	Depends on relative effects (likely positive)
7	Increased	Savings due to faster speed	Neutral	Positive	Positive due to time savings and health benefits
8	Increased	No effect	Neutral	Positive	Positive due to health effects
9	Increased	Increases due to detours	Positive	Positive	Depends on relative effects
10	Increased	Increases due to slower speed	Neutral	Positive	Depends on relative effects (likely negative)

loss in health benefits and therefore underestimate the overall benefits of such projects. That is, if internalization is really taking place, then the negative change in health effects per trip would upscale VTTS; and a higher VTTS (than the official) would change the overall benefit estimate (upwards).

In contrast, when a project induces cyclists to make detours (indexed 4 and 9)[10], in which higher health benefits are generated, using the recommended VTTS and treating health benefits as an external impact implies an overestimation of the benefits of such projects. Then the "true" relationship, given internalization, would be downscaling of VTTS (and subsequently the overall benefit estimate).

Two alternative changes of current appraisal practice could reduce the current potential "double counting" problem: (a) increasing the "official" VTTS to the level which corresponds to the VTTS controlled for health benefits (while still treating all health benefits as external); or (b) reducing the health benefits (removing the individual part, retaining only the true external part) while retaining the "official" VTTS values.[11] Based on our empirical results, yielding evidence for health benefits being internalized, with a downscaling effect on the VTTS, approach (b) is clearly preferable over approach (a). Economic principles suggest that one should not account for impacts that are already factored in ("internalized") by travellers. Furthermore, the VTTS that most likely includes a health effect (like the "official") is also the VTTS that is most relevant for explaining travel behaviour. The latter point is especially important when the same VTTS value is used in demand and route choice prediction.

With a back-of-the-envelope calculation, we apply our empirical results for cyclists from the previous section (a reduction of VTTS by 20–65%) to the current values found in the appraisal guidelines of the Norwegian Public Roads Administration (Vegdirektoratet 2018). The calculation shows[12] that the individual health benefits for cyclists (of currently 18.7 NOK/km) may be reduced by a value within the range of 2.5 and 18.6 NOK/km to account for that cyclists have factored in health benefits in their travel choices. In the case of the upper bound (18.6 NOK/km), this would imply that almost the entire individual health benefits are treated as being internalized. In case of the conservative lower bound, only a limited reduction (from 18.7 NOK/km to 16.2 NOK/km) would be proposed.

6. Conclusions

Overall, our empirical results yield additional evidence for the viewpoint that health benefits play a role in the decision to cycle and walk, and that cyclists and pedestrians factor in health benefits in their valuation of travel time savings. Applying two different choice experiments, we find a significant reduction in the of value of travel time saving due to health benefits; likely lying in the range of

[10] Note that this is not that uncommon, as improvements in cycling infrastructure (increasing cycling comfort and safety) may induce changes in route choice that may lead to an overall increase in cycle travel times (Hulleberg et al., 2018).

[11] Note that the expected effects of (a) and (b) vary across project types. For example, for project type 8 (in Table 8), (a) would make no difference (as there are no time savings) while (b) would lead to reductions in health benefits and overall benefits of the project.

[12] In the handbook, the current official VTTS for cycling is 154 NOK/h and the individual health benefits (based on ex-ante illness-risk reduction) are valued at 18.7 NOK/km (Vegdirektoratet, 2018). Compared to external illness costs to society (health sector, employers, etc.), the welfare-related health benefits (i.e., the part prone to internalization) make up for close to 90% of total health benefits. From the official VTTS and an assumed average cycling speed of 15 km/h, we can calculate a time cost of roughly 10 NOK/km. Assuming this value results from a 20–65% reduction in the VTTS for cycling that would have been obtained if controlling for health benefits, one would adjust up to a value for time costs of between 12.5 and 28.6 NOK/km, that is: $10/(1–0.2) = 12.5$ and $10/(1–0.65) \approx 28.6$. Taking the differences yields $(12.5–10 =)$ 2.5 NOK (for the lower bound) and $(28.6–10 =)$ 18.6 NOK (for the upper bound).

20–65%.

CRediT authorship contribution statement

Stefan Flügel: Conceptualization, Methodology, Formal analysis, Writing – original draft. **Knut Veisten:** Conceptualization, Writing – original draft. **Hanne Beate Sundfør:** Investigation, Resources. **Guri Natalie Jordbakke:** Software, Data curation. **Nina Hulleberg:** Software, Data curation. **Askill H. Halse:** Project administration, Writing – review & editing.

Attachment

The theoretical model combines elements from models proposed by Jara-Díaz and Guevara (2003) and Cawley (2004). It is given as an optimization problem of a representative agent who aims to maximize utility by allocating time to activities over the spend of one representative day.

$$U\big(E(S,\ L,\ O,\ T^{Ac}, T^{Pa},\ I,\ Y) + H(S,\ L,\ O, T^{Ac}, T^{Pa},\ I)\big) \tag{A1}$$

Subject to

$$w * O - Y - T^{Pa} * P_{T^{Pa}} = 0 \quad \rightarrow \lambda \tag{A2}$$

$$\left(S + L + O + T^{Ac} + T^{Pa} + I\right) - 24 = 0 \ \rightarrow \mu \tag{A3}$$

$$\left(T^{Ac} + T^{Pa}\right) - T^{min} \geq 0 \ \rightarrow \kappa_{T^{Ac}},\ \kappa_{T^{Pa}} \tag{A4}$$

$$N_i - N_i^{min} \geq 0 \ \rightarrow \kappa_i \text{ for i} = \{\mathrm{S, O, I}\} \tag{A5}$$

$$\mathrm{L} - \mathrm{h(Y)}^3 0 \ \rightarrow \kappa_\mathrm{L} \tag{A6}$$

With.

U(.): utility
E (.): the "enjoyment" function
S: daily hours used for sleeping
L: daily hours used for leisure activities
O: daily hours used for occupation (paid work)
T: daily hours used for transportation, transport is subdivided in active transport (T^{Ac}) and passive transport (T^{Pa})
I: daily hours used for unpaid work (housework)
Y: goods (prices are normalized to 1)
W: wage rate
$P_{T^{Pa}}$: price for passive transport (car, public transport)
H(.): the health function
T^{min}: minimum duration of transport
N_i^{min}: minimum duration of necessary activities i, with i $= \{S, O, I\}$
h(Y): a function of goods needed to sustain a leisure activity (equipment, tickets to movies etc.)

Lagrange multipliers are given as respectively. $\lambda, \mu,\ \kappa_{T^{Ac}},\ \kappa_{T^{Pa}}, \kappa_i, \kappa_L$
The Lagrange function is given as:

$$\mathscr{L} = E(S,\ L,\ O,\ T^{Ac}, T^{Pa},\ I,\ Y) + H(S,\ L,\ O, T^{Ac}, T^{Pa},\ I) - \lambda(w * O - Y - T^{Pa} * P_{T^{Pa}}) - \mu\big((S + L + O + T^{Ac} + T^{Pa} + I) - 24\big) - \kappa_{T^{Ac}}\left(T^{Ac} + T^{Pa}\right) - T^{min}\big) - \kappa_i\left(N_i - N_i^{min}\right) - \kappa_L(\mathrm{L} - \mathrm{h(Y)}) \tag{7A}$$

Taking the first derivative of the Lagrange function w.r.t. time spend in active transport gives:

$$\frac{\partial \mathscr{L}}{\partial T^{Ac}} = \frac{\partial E}{\partial T^{Ac}} + \frac{\partial H}{\partial T^{Ac}} - \mu - \kappa_{T^{Ac}} \tag{8}$$

The optimal point is found where this derivative is zero:

$$\kappa_{T^{Ac}} = \frac{\partial E}{\partial T^{Ac}} + \frac{\partial H}{\partial T^{Ac}} - \mu \tag{9}$$

Dividing by λ and multiplying with -1 to make $\frac{\kappa_{T^{Ac}}}{\lambda}$ positive we get:

$$\left|\frac{\kappa_{T^{Ac}}}{\lambda}\right| = \frac{\mu}{\lambda} - \frac{\frac{\partial E}{\partial T^{Ac}}}{\lambda} - \frac{\frac{\partial H}{\partial T^{Ac}}}{\lambda} \tag{10}$$

where.

$\left|\frac{\kappa_{T^{Ac}}}{\lambda}\right|$: represents value of travel time saving for active transport

$\frac{\mu}{\lambda}$: represents the opportunity cost

$\frac{\frac{\partial E}{\partial T^{Ac}}}{\lambda}$: represents the marginal value of the enjoyment of active transport ("comfort")

$\frac{\frac{\partial H}{\partial T^{Ac}}}{\lambda}$: is the value of the health benefits

Final disclosure

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