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The impacts of road pricing on route and mode choice behaviour

Milenko Vrtic[1*] Nadine Schuessler[2†] Alexander Erath[2‡]
Kay W. Axhausen[2§]

[1]IVS (Centre of Transportation System Planning), Vienna University of Technology, A-1040

[2]IVT, ETH Zurich, CH-8093 Zurich

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Abstract

This paper summarises the results of an extensive stated preference (SP) survey, conducted in Switzerland in order to obtain detailed information for the evaluation of road pricing schemes. Four different SP experiments were included: one about the political acceptability of road pricing and the other three about route, mode and departure time choice behaviour in the presence of road pricing. The questionnaires of 1005 respondents were used in a multinomial logit analysis of the latter three experiments. The values of travel time savings (VTTS) depended nonlinearly on the individual's income, travel time and overall travel costs. The respondents' evaluation of the cost components of fuel, tolls and parking differed significantly. Shifts in departure time depended on the choice situation were negatively valued. Furthermore, the importance of political preferences, as measured in the SP survey on acceptability, could be demonstrated, as the inclusion improved the model fit significantly as well as the reliability of the results.

Keywords: GPS data, postprocessing, trip detection, activity detection, mode detection, fuzzy logic, map matching

1 Introduction and motivation

In Switzerland, as in most European countries, infrastructure resources are getting scarcer. Therefore, new instruments have to be found to manage travel

*T: +43 1 58801 26901, F: +43 1 58801 26999, milenko.vrtic@tuwien.ac.at
†T: +41 44 633 30 85 , F: +41 44 633 10 57 , schuessler@ivt.baug.ethz.ch
‡T: +41 44 633 30 92, F: +41 44 633 10 57 , erath@ivt.baug.ethz.ch
§T: +41 44 633 39 43, F: +41 44 633 10 57, axhausen@ivt.baug.ethz.ch

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demand and to fund the transport system. Various examples indicate that new pricing regimes can be used to control travel behaviour more efficiently. Given the results already presented by Olszewski and Litian (2005), Santos and Shaffer (2004), Nielsen (2004), Evans et al. (2003), Committee for the Study of Long-Term Viability of Fuel Taxes for Transportation Finance (2006) and Transport for London (2003) the paper will not include a detailed review of the previous evidence. However, in Switzerland the findings of these and other studies led to a broad political discussion about an integrated and coherent system for all types of mobility pricing, for example, fuel taxes, parking costs, public transport charges, and certainly road pricing. The aim is to achieve a more efficient utilisation of the existing transport infrastructure and to safeguard the necessary funding in the long term.

For the evaluation of different road pricing schemes, transport models have to include road pricing as an element of the generalised cost of travel. Previous experiences abroad indicate that the predominant effects of such pricing are changes in route, mode and departure time choice. However, these effects have not yet been sufficiently studied for Switzerland. Several important questions have to be answered, including: What is the willingness to pay with regard to road pricing? How does it differ from the already known willingness to pay with regard to fuel prices or public transport fares? What would be the impacts of new road pricing schemes on route, mode and departure time choice?

Therefore, the Swiss federal government asked the Institute for Transport Planning and Systems (IVT), ETH Zurich, in collaboration with the Transport and Mobility Laboratory (TRANSP-OR), EPF Lausanne and the Institute for Economic Research (IRE), USI Lugano, to provide the knowledge base for the on-going discussion. The work relies in the main on a series of stated preference (SP) experiments, which have been constructed around an actual trip reported by the respondents in a previous revealed preference (RP) survey conducted by Swiss Federal Railways (SBB). Furthermore, an experiment was included that allowed participants to state their political preferences with regard to such pricing schemes. This additional experiment, which mimicked a referendum, was intended to shield the behavioural SP experiments from politically motivated strategic behaviour. The details of this experiment are described in Vrtic et al. (2007a). The complete project is presented in Vrtic et al. (2007b).

This paper describes the survey methodology and summarises its findings. The focus is laid on the perception of four different cost components: fuel price, tolls, parking costs and public transport fares. The results reveal that there are two major behavioural processes which have so far been rarely appreciated in the literature and never combined with each other. First, it is shown that the different cost components are indeed valued differently with higher elasticities for costs that are avoidable by changes in route or mode. Second, the perception of these cost components is not linear as commonly assumed but depends on household income, overall travel cost and specific travel time. Other important issues that are addressed here are the evaluation of departure times that are earlier or later

than the respondent's preferred departure time and the account for the political preference of the participant in behavioural models. While the former has been analysed in various studies before, the latter has achieved little attention so far even though it is generally acknowledged that participants' attitude towards road pricing strongly influences their behaviour in hypothetical experiments such as stated preference surveys.

The remainder of the paper is organised as follows: After a short overview of the survey design and the data collected, the modelling approach will be presented. Subsequently, the results of the combined route, mode and departure time choice model are described, including the derived values of travel time savings. Finally, the conclusions are presented.

2 SP study and data description

Since a road pricing system has yet to be introduced in Switzerland, a stated preference (SP) survey had to be conducted to derive the willingness to pay for the Swiss population in the presence of road pricing. To increase the realism of the hypothetical choice situations, the SP surveys were based on the answers to a nationally representative revealed preference (RP) telephone survey carried out by Swiss Railways (Swiss Railways, 2005). In this study, the respondents were asked to report all the trips they had made during the last 5 days that were over 1.5 km distance and across a municipal boundary. Furthermore, the respondents gave particulars about the trip's purpose, transport mode, departure and travel time as well as their socio-demographic characteristics. One of these reported trips was chosen for the construction of the SP experiments. To remind the participants of the details of their reported trips, it was included at the top of the questionnaire. This ensured that the respondent could imagine the choice situation even when supplementary pricing components were added. After agreeing to participate in the SP experiments during the SBB telephone survey, the respondents received the written SP experiments by mail.

For the SP survey, a total of four binary choice experiments were developed: one acceptability SP and three behavioural SPs. The acceptability experiment was essentially a set of political referenda about different pricing systems, containing changes in all types of mobility pricing (e.g. road pricing, taxation, public transport fares). Since referenda of this kind are part of the everyday life in Switzerland and a broad public discussion about new pricing schemes for mobility was already taken place, the authors had no indication to suspect that imposing the acceptability SP would trigger strategic behaviour in the subsequent behavioural experiments which was not present beforehand. Instead, the aim was test whether it is possible to deter respondents from such strategically behaviour by giving them the opportunity to explicitly state their political preferences. Additionally, the results could be used as an intertia variable in the route, mode and departure time model.

	Car	Rail, Bus Tram
Travel time (min)	10 min	25 min
Fuel / ticket cost	0,40 CHF	1,60 CHF
Number of Transfers		2
Access time public transport		10 min
Interval		10 min
Toll	0,40 CHF	
Parking fee	2,00 CHF	

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Figure 1: Example for a choice situation in the mode and route choice experiment

The behavioural experiments themselves were concerned with changes in route, mode and departure time choice in the presence of road pricing. One experiment was a joint car route and departure time choice (RDC) experiment for private transport. The second experiment dealt with mode and departure time choice (MDC) and the third with mode and route choice (MRC). An example for a binary choice situation in the MRC experiment is given in Figure 1.

To reduce the workload, each participant received only two out of the three behavioural experiments in addition to the acceptability experiment. The assignment of the two experiments to the participants was done randomly within predefined socio-demographic groups to make sure that all experiments were answered by a representative sample. A total of 1005 respondents from a sample of 2290 returned their questionnaires; with 566 respondents participating in RDC experiment, 702 in the MDC experiment and 725 in the MRC experiment. The resulting overall response rate of 44% is in line with expectations for the anticipated workload of this extensive and complex survey and the recruitment of the participants in the course of the Swiss Railways study.

The variables used in the route, mode and departure time choice experiments and their specifications are presented in Table 1. The set of variables was based on the experience gained in earlier Swiss SP and RP studies (e.g. Axhausen et al., 2004; Vrtic et al., 2003). A couple of assumptions had to be made for the specifications. In general, it was assumed that the road pricing scheme was not primarily introduced to earn more revenue but to regulate transport demand and to achieve a shift towards public transport. Consequently, it was assumed that public transport services would remain unchanged or be improved. However, for

Table 1: Variables in the SP experiments and their specifications

Variable	Specification (with respect to the reported trip)	Choice situation*
Departure time	30 min, 15 min earlier, unchanged, 15 min, 30 min later	rdc, mdc
Travel time car	40% less, 20% less, unchanged, 20% more, 40% more	rdc, mdc, mrc
Travel time PuT	20% less, 10% less, unchanged	mdc, mrc
Fuel costs car (without pricing)	0.12 CHF/km **	rdc
Fuel costs car (with pricing)	0.048, 0.06, 0.072 CHF/km **	rdc, mdc, mrc
Tolls	0.045, 0.06, 0.075, 0.105, 0.15 CHF/km **	rdc, mdc, mrc
Parking costs	0.00, 2.00, 5.00 CHF **	mrc
PuT costs	0.072, 0.092, 0.104 CHF/km** (GA holder) 0.135, 0.173, 0.195 CHF/km** (HT holder) 0.252, 0.322, 0.364 CHF/km** (no subscription)	mdc, mrc
Reliability car***	every 20th trip, every 5th trip, every 3rd trip	rdc
Reliability PuT***	null, every 20th trip, every 10th trip	mdc
Number of transfers	1 less, unchanged, 1 more	mdc, mrc
Headway****	1 level worse, unchanged, 1 level better	mdc, mrc
Access time to public transport	15% less, 15% more, 30% more	mrc

(*) rdc: route and departure time choice, mdc: mode and departure time choice, mrc: mode and route choice
(**) Currency exchange rate: 1 CHF = 0.80 USD (11/15/2006)
(***) Proportion of trips with a delay of at least 10 minutes
(****) Interval levels: 10 min, 20 min, 30 min, 50 min, 60 min, 120 min.

public transport fares, several scenarios were created with decreasing, current and increasing fares, relative to fares implied by the annual or discount tickets owned by the respondents. The General Abonnement (GA) is a network card that allows its holder to travel on all public transport services in Switzerland, except a few mountain railways, without extra charge and the owner of a Half-Fare Card (HT) can purchase his railway tickets at half price and other tickets at smaller discounts.

Fuel costs were based on Swiss fuel prices in September 2005 and the average fuel consumption of the Swiss car fleet in 2004. Other variable costs, e.g., amortisation or wear and tear, have not been accounted for. For the road pricing scenarios, it was assumed that the fuel tax is reduced when a road toll is introduced. Currently, the fuel tax makes up half of the fuel cost. Still, different levels were chosen to estimate the fuel price effect independently. Though all cost components are here presented in CHF/km, the respondents received estimates of the costs for their specific trip. Furthermore, it was assumed that all priced

private transport routes are 100% reliable, i.e., no delays of 10 minutes or more occurred compared to the average trip time for that time of the day.

Table 2 details the socio-demographic characteristics of the respondents and compares them to the overall sample of the SBB study, from which the sample was recruited. The comparison demonstrate that the adult Swiss population is as well represented here as it was in the SBB study, though there is a slight shift to male and to employed public transport users as already detected by Axhausen et al. (2004). Persons under 18 years of age were not included in the survey because this is the minimum age for a driver's licence in Switzerland. There was a slightly higher proportion of male respondents and of those belonging to higher income classes. Still, these proportions are so small that no re-weighting was necessary. However, 14.7% of the respondents did not answer the question regarding the household income. For those persons, an EM Missing Value analysis was conducted using the software SPSS to compute the missing income values. The analysis took into account the respondents' employment status, car ownership, age, household size, sex and other available characteristics, such as level of education or place of residence.

Another important characteristic is the ownership of mobility tools, since it has a prominent influence on transport behaviour. Mobility tools comprise all those things that reduce the marginal cost of use for one or more transport modes. Typical examples are the availability of a car or a public transport ticket. These figures show a slight shift towards people who own mobility tools and have a higher vmt (car km per year).

Regarding the spatial distribution, it can be seen that the different regions in Switzerland, represented by languages, have also been well represented, though the willingness to respond was slightly higher in the German-speaking part. All participants received the questionnaires in the primary language of their home location. The last interesting characteristic of the respondents was their respective place of residence, which was classified into four categories. Again, the figures show that the respondents match the overall Swiss pattern well, with 15.4% living in bigger cities and 25.0% in their agglomerations, 27.6% living in middle- and small-size towns including their agglomerations and 32.4% living in rural areas.

3 Modelling approach

Since the data used in this study was obtained from an SP survey, in which the respondents had to choose between discrete alternatives, the preferred modelling framework is discrete choice. The main assumption is that each decision-maker seeks to maximise his personal utility and chooses the alternative with the highest utility for him. The utility of an alternative i for decision maker n is defined by its utility function with a deterministic part V_i and a random part ε_i:

$$U_{in} = V_{in} + \varepsilon_{in} = \beta \cdot x_{in} + \varepsilon_{in} \tag{1}$$

Table 2: Socio-demographic characteristics of the respondents

Characteristic	Level	Frequency	Percentage	SBB study
Gender	Male	558	55.5	50.9
	Female	447	44.5	49.1
Age	Younger than 25 years	95	9.5	11.8
	Between 25 and 45 years	381	37.9	40.5
	Between 45 and 65 years	405	40.3	36.7
	Older than 65 years	124	12.3	11.1
Language	German	818	81.4	78.5
	French	141	14.0	17.5
	Italian	46	4.6	4.1
Persons in household	1	164	16.3	17.5
	2	358	35.6	34.8
	3	151	15.0	15.7
	4	232	23.1	21.9
	5 or more persons	100	10.3	9.9
Household income	Less than 36,000 CHF/year	37	3.7	4.4
	36,000 - 72,000 CHF/year	202	20.1	23.8
	72,000 - 108,000 CHF/year	327	32.5	30.1
	More than 108,000 CHF/year	327	32.5	30.1
	No answer	148	14.7	14.6
Employment	Full time	504	50.1	51.4
	Part time (less than 37 h/week)	209	20.9	20.7
	Not employed	292	29.1	27.9
Car availability	Always	672	66.9	64.4
	Occasionally	205	20.4	20.4
	Never	128	12.7	15.1
Annual car vmt	Less than 1,000 km/year	260	25.9	30.2
	1,000-5,000 km/year	317	31.5	32.6
	5,000-10,000 km/year	232	23.1	20.6
	10,000-15,000 km/year	232	23.1	21.9
	More than 15,000 km/year	260	25.9	30.2
Public Transport Subscription	General Abonnement (GA)	161	16.0	13.1
	Half-Fare Card (HT)	435	43.3	41.6
	No Subscription	409	40.7	45.3
Residential area	City	154	15.3	15.4
	Urban agglomeration	250	24.9	25.0
	Small/medium-sized town	277	27.6	27.4
	Rural area	324	32.4	32.2

The deterministic utility can be described by a vector β of unknown taste parameters to be estimated and a vector x_{in} containing the attributes of the alternative and the socio-demographic characteristics of the decision-maker. The assumed distribution of the random error term defines the model structure and thereby the functional form of the choice probabilities. The most commonly used formulation, also used here, is the multinomial logit (MNL) model, introduced by McFadden (1974) and extended by Ben-Akiva and Lerman (1985). In this formulation, the unobserved error terms are independently distributed type I extreme values (Gumbel).

As noted in Axhausen et al. (2004) the derivation of the appropriate utility function was carried out in a step-wise process. In the first instance, linear formulations of the parameters for each SP experiment were tested. In the next step, nonlinear specifications were examined and then combined models for all three SP experiments were estimated. The fitness function improved in each step and the combined model results in more robust parameters. All parameters of the joint model were also significant for the individual models and showed the expected sign. By means of scaling parameters for each individual data set, the differences in error distributions have been accounted for. The final utility formulation includes inertia variables, random parameter formulations of the attributes and a cost parameter that is elastic with respect to income and travel time and a travel time parameter that is elastic regarding overall travel costs. The software BIOGEME (Bierlaire, 2008) was used for the model estimation.

The formulation of the elasticity of the cost and the travel time parameters was adapted from the cost parameter elasticities of Axhausen et al. (2004), which was based on the study by Mackie et al. (2003). Mackie et al. (2003) analysed a number of UK value of time studies and showed that the cost parameter depends on the trip distance and the income of the respondent. They chose the following formulation for the cost parameter:

$$\beta_{cost}\left(\frac{income}{meanIncome}\right)^{\lambda_{income}}\left(\frac{distance}{meanDistance}\right)^{\lambda_{distance}} costs \tag{2}$$

This formulation was empirically confirmed by Axhausen et al. (2004). The elasticity parameter λ was estimated simultaneously with the other parameters. For the study at hand, this formulation was adapted slightly: instead of the trip distance, travel time is accounted for:

$$\beta_{cost}\left(\frac{income}{meanIncome}\right)^{\lambda_{income}}\left(\frac{travelTime}{meanTravelTime}\right)^{\lambda_{travelTime}} costs \tag{3}$$

In addition, it could be shown that the travel time parameter is elastic with respect to the overall travel cost. Thus, the nonlinear formulation of the travel time utility is:

$$\beta_{travelTime}\left(\frac{cost}{meanCost}\right)^{\lambda_{cost}} travelTime \tag{4}$$

The changes in departure time were simulated in the SP experiments by shifting the departure time reported by the participant for the actual trip, which was interpreted as the preferred departure time, to an earlier or later departure time. Based on the work of Vickrey (1969), Noland and Small (1995), and Hess et al. (2005), the changes in departure time were accounted for by introducing a parameter for the shift to an earlier departure time or a later departure time. The resulting time displacements were calculated with respect to the preferred departure time and introduced in the utility function as attributes of the alternative. The estimated parameters for these time displacements correspond to the penalties for early or late departure times.

Due to the political nature of the survey, it was assumed that the participants' responses in the experiments might be biased by their attitude towards road pricing. As explained in the introduction, the SP experiment about political acceptability, which preceded the behavioural experiments, was included to reduce this effect. Moreover, it was used to reflect the attitude of the respondents towards road pricing. Therefore, an additional person-specific inertia variable was derived by calculating for each respondent the share of situations in which he or she had chosen the scenario with road pricing over the one without. The resulting variable is introduced into the utility function of the toll route in the RDC experiment along with the socio-demographic characteristics of the respondents. It should be interpreted in a way similar to other inertia variables such as the ownership of public transport subscriptions, indicating a tendency to choose the route without toll depending on the attitude towards road pricing. The main difference is that this variable tries to capture strategic behaviour in the survey but not in real-live. The variable will therefore be left out in applications of the model results. The variable was not included in the mode choice models because there was no apparent possibility for strategic behaviour in these experiments.

The final utility functions for the combined model are summarised in Table 3. The elasticity of the travel time parameter is always calculated with respect to the total trip cost of an alternative. This includes, for example, for private transport, a mode choice alternative with parking cost the appropriate cost for fuel, tolls and parking. The inertia variables age and annual vmt (car km per year) are included as continuous variables and the remaining inertia variables as dummies. Since the error terms of the three data sets are likely to differ in their distribution, a scale parameter for each data set was introduced. Further tests were conducted to take into account that several observations were derived from the same individual (panel effect). Therefore, a random term was introduced that is invariant for the observations of a given individual for whom the variance is estimated. However, the models with this specification did not converge and therefore had to be omitted.

Table 4 reports the statistics of the variables describing the alternatives of the joint model. As described above, the SP experiments were constructed based on a trip reported by the respondent. The minimum distance was 3 km and longer trips were deliberately over-sampled. Consequently, the average trip length in the SP

Table 3: Utility functions of the route, mode and departure time choice models

Route and departure time choice model (R1: route without pricing; R2: route with pricing)	
$U_{r1} =$	$Constant_{r1} + \beta_{relCar} Reliabr1 + \beta_{earlyRC} EarlyDep_{r1} + \beta_{late} LateDep_{r1}$
	$+ \beta_{ttCar}(cost/meanCost)^{\lambda_{costCar}} TravelTime_{r1}$
	$+\beta_{fC}(income/meanIncome)^{\lambda_{incFC}}(travelTime/meanTravelTime)^{\lambda_{ttFC}} FuelCost_{r1}$
$U_{r2} =$	$\beta_{age} Age + \beta_{mileage} AnnualCarMileage + \beta att Attitude$
	$+ \beta_{earlyRC} EarlyDeparture_{r2} + \beta_{late} LateDepature_{r2}$
	$+ \beta_{ttCar}(cost/meanCost)^{\lambda_{costCar}} TravelTime_{r2}$
	$+\beta_{fC}(income/meanIncome)^{\lambda_{incFC}}(travelTime/meanTravelTime)^{\lambda_{ttFC}} FuelCost_{r2}$
Mode and route choice model (PuT: public transport)	
$U_{car} =$	$Constant_{car} + \beta_{carAv} CarAvailability + \beta_{mil} AnnualCarMileage$
	$+ \beta_{french} LangFrench + \beta_{german} LangGerman$
	$+ \beta_{earlyMC} EarlyDep_{car} + \beta_{late} LateDep_{car}$
	$+ \beta_{ttCar}(cost/meanCost)^{\lambda_{costCar}} TravelTime_{car}$
	$+\beta_{fC}(income/meanIncome)^{\lambda_{incFC}}(travelTime/meanTravelTime)^{\lambda_{ttFC}} FuelCost$
	$+ \beta_{to}(income/meanIncome)^{\lambda_{incTo}}(travelTime/meanTravelTime)^{\lambda_{ttTo}} Toll$
$U_{puT} =$	$\beta_{age} Age + \beta_{empl} Employed + \beta_{ga} GAOwner + \beta_{ht} HTOwner$
	$+ \beta_{earlyMC} EarlyDep_{puT} + \beta_{late} LateDep_{puT}$
	$+ \beta_{noT} NOfTransfers_{puT} + \beta_{hw} Headway_{puT} + \beta_{relPuT} Reliab_{puT}$
	$+ \beta_{ttPuT}(cost/meanCost)^{\lambda_{costPuT}} TravelTime_{puT}$
	$+\beta_{puTCo}(income/meanIncome)^{\lambda_{incPuT}}(travelTime/meanTravelTime)^{\lambda_{ttPuT}} PuTCost$
Mode and route choice model (PuT: public transport)	
$U_{car} =$	$Constant_{car} + \beta_{carAv} CarAvailability + \beta_{mil} AnnualCarMileage$
	$+ \beta_{french} LangFrench + \beta_{german} LangGerman$
	$+ \beta_{ttCar}(cost/meanCost)^{\lambda_{costCar}} TravelTime_{car}$
	$+\beta_{fC}(income/meanIncome)^{\lambda_{incFC}}(travelTime/meanTravelTime)^{\lambda_{ttFC}} FuelCost$
	$+ \beta_{to}(income/meanIncome)^{\lambda_{incTo}}(travelTime/meanTravelTime)^{\lambda_{ttTo}} Toll$
	$+\beta_{pC}(income/meanIncome)^{\lambda_{incPC}}(travelTime/meanTravelTime)^{\lambda_{ttPC}} ParkingCost$
$U_{puT} =$	$\beta_{age} Age + \beta_{empl} Employed + \beta_{ga} GAOwner + \beta_{ht} HTOwner$
	$+ \beta_{noT} NOTransfers_{puT} + \beta_{hw} Headway_{puT} + \beta_{relPuT} Reliab_{puT} +$
	$\beta_{accT} AccessTime$
	$+ \beta_{ttCar}(cost/meanCost)^{\lambda_{costCar}} TravelTime_{car}$
	$+\beta_{puTCo}(income/meanIncome)^{\lambda_{incPuT}}(travelTime/meanTravelTime)^{\lambda_{ttPuT}} PuTCost$

Table 4: Statistics of the variables describing the alternatives

Variable	Min	Mean	Max	Std. Dev.
Travel time car [h]	0.095	0.707	6.588	0.678
Travel time public transport [h]	0.167	1.009	6.588	0.974
Fuel costs [CHF]	0.115	3.608	29.996	4.185
Tolls [CHF]	0.100	4.899	60.600	6.370
Parking costs [CHF]	0.000	1.794	5.000	2.063
Public transport cost [CHF]	0.200	11.713	102.400	13.323
Reliability route choice (route without pricing)* [%]	3.300	5.902	20.400	9.526
Reliability mode choice (public transport)* [%]	0.000	7.480	10.000	8.285
Early departure mode choice [h]	0.000	0.203	12.500	0.471
Early departure route choice [h]	0.000	0.141	12.250	0.354
Late departure [h]	0.000	0.100	1.779	0.171
Number of transfers	0.000	0.861	5.000	1.053
Headway [h]	0.167	0.597	2.000	0.496

(*) Proportion of trips with a delay of at least 10 minutes

experiments was 55.6 km compared to 40.1 km in the SBB study. The resulting mean travel time of the SP trips was 41 min for private transport trips and 60 min for public transport trips. The mean value for the fuel cost was 3.61 CHF, for the tolls 4.90 CHF, and parking 1.79 CHF, the latter being calculated only for those experiments in which parking costs were included. For the public transport alternatives, the average ticket costs were 11.71 CHF, the mean headway was 36 min and the average number of transfers was 0.86.

4 Results of the combined route, mode and departure time model

The results of the combined route, mode and departure time choice model outlined in Table 3 are presented in Table 5. The model is based on the joint data sets from the RDC, MDC and MRC SP experiments described in Section 2. In the course of each SP experiment, the respondents answered six to seven choice situations. After removing unusable answers, 13,552 observations remained for parameter estimation: 3,927 of them originating from the RDC, 4,863 from the MDC and 4,762 from the MRC experiment. Most of the parameters were significant at the 95% confidence level and all had the correct sign. This also accounts for the λ parameters, which have the same negative sign as in Axhausen et al. (2004) and Vickrey (1969).

The travel time parameter was estimated as elastic with regard to the total trip cost. Individual travel time parameters and elasticities were estimated for private transport and public transport, respectively. On the whole, three different cost components for the private transport alternatives were included in the survey:

Table 5: Parameters of the combined route, mode and departure time model: separate cost components

Mode	Variable	Parameter	(t-test)
	Constant mode choice (car)	0.214	(1.19)
	Constant route choice (route without pricing)	4.798	(24.80)
	Travel time car [h]	-2.261	(-9.80)
	Fuel costs [CHF]	-0.081	(-3.43)
	Tolls [CHF]	-0.166	(-9.05)
	Parking Costs [CHF]	-0.209	(-7.25)
	Early departure mode choice [h]	-0.351	(-3.45)
	Early departure route choice [h]	0.300	(1.65)
	Late departure[h]	-0.783	(-6.71)
Private transport	Road reliability *	-0.036	(-8.11)
	Car availability	0.519	(6.77)
	Annual vmt [1000 km per year]	0.031	(11.09)
	Language French	-0.147	(-0.97)
	Language German	-0.521	(-3.50)
	Preference for road pricing in acceptability SP	6.497	(32.53)
	Lambda cost car	-0.103	(-4.26)
	Lambda income fuel cost	-0.024	(-0.07)
	Lambda income toll	-0.146	(-2.42)
	Lambda income parking cost	-0.284	(-3.26)
	Lambda travel time fuel cost	-0.328	(-2.13)
	Lambda travel time toll	-0.354	(-7.48)
	Lambda travel time parking cost	-0.271	(-4.45)
	Travel time PuT [h]	-1.897	(-8.98)
	Fare [CHF]	-0.097	(-7.53)
	Access time [h]	-2.608	(-7.63)
	Interval [h]	-0.557	(-7.42)
	Number of transfers	-0.258	(-6.78)
	Early departure mode choice [h]	-0.351	(-3.45)
	Late departure [h]	-0.783	(-6.71)
Car	PuT reliability *	-0.022	(-2.83)
	Age	0.013	(8.22)
	GA Holder	1.326	(8.43)
	HT Holder	0.620	(7.38)
	Employment	0.034	(0.68)
	Lambda cost PuT	-0.284	(-9.62)
	Lambda income PuT	-0.260	(-3.00)
	Lambda travel time PuT	-0.194	(-4.34)
Number of observations		13552	
Final log-likelihood		-6084.63	
Adjusted rho-square		0.35	
Scale parameter RDC model		1.00	(fixed)
Scale parameter MDC model		1.91	
Scale parameter MRC model		1.98	

(*) Proportion of trips with a delay of at least 10 minutes

fuel cost, tolls and parking. For each of these cost components, an separate β parameter was estimated, which was also estimated for public transport costs. In an analogous manner, separate β parameters were estimated for the elasticities with regard to income and travel time for each cost component. In addition, a model was estimated in which all cost components were aggregated to one total cost variable. This model is not presented here, but the parameters showed the same plausible results.

Regarding the penalties for shifts to earlier or later departure times, several variants were tested. The best model fit arose from a formulation with three penalty parameters, one for departing early in the RDC model, one for departing early in the MDC model and a joint parameter for departing late. Whereas, the parameter for being early in an RDC situation is positive, the parameters for being early in MDC situations and the parameter for being late have negative signs. This emphasises the different perceptions of an early departure time depending on the choice situation. If the decision-maker has to choose between driving by car or travelling by public transport, he favours the alternative with the smallest difference from his preferred departure time. However, the choice situation in the private transport route choice model is fundamentally different. In this case, the decision-maker not only has to account for the difference between his preferred departure time and the actual departure time, but also for the amount of time he spends in traffic congestion. If the decision-maker decides to take the congested route and thus avoid the toll, he prefers to depart earlier and perhaps arrive earlier at his destination than risk a delay. This aversion to delays is also expressed by the fact that the absolute value of the parameter for late departure is twice as high as the one for early departure.

Two constants have been included in the joint model, one for the unpriced alternative in the route choice model and one for the private transport alternative in the mode choice model. The constants account for the general preference for an alternative if the remaining utilities are equal for both alternatives. In the mode choice model, no significant value could be derived for the constant. However, in the route choice model, the constant showed a significant general preference for the alternative without road pricing. Concerning the socio-demographic characteristics of the respondents, the estimated model suggests that older persons are more likely to choose the route with road pricing in the route choice model and the public transport alternative in a mode choice situation. The same accounts for the holders of public transport cards. In contrast, the availability of a car and a high annual vmt decreases the probability of choosing the route with road pricing or the public transport alternative.

The variable indicating a preference for introducing new mobility pricing schemes, which was derived from the acceptability SP, had an important impact. People favouring new mobility pricing schemes have a very high probability of choosing the route with road pricing in the route choice experiment and vice versa. Obviously, including the acceptability experiment was not able to shield against this strategic behaviour in the travel behaviour experiments. However,

Table 6: Willingness to pay indicators

Willingness to pay at sample mean	
Car travel time / fuel costs [CHF/h]	27.8
Car travel time / tolls [CHF/h]	13.6
Car travel time / parking costs [CHF/h]	10.8
Public transport travel time / public transport cost [CHF/h]	19.5
Headway / public transport cost [CHF/h]	5.7
Number of transfers Public/ public transport cost [CHF/transfer]	2.7
Car reliability / fuel costs [CHF/prob%*]	0.4
Car reliability / tolls [CHF/prob%*]	0.2
Public transport reliability / public transport costs [CHF/prob%*]	0.2
Relative ratios of parameters	
Car travel time / public transport travel time	1.2
Number of transfers / public transport travel time [min./transfer]	17.6
Public transport access time / public transport travel time	1.4

(*) Probability of a delay of a minimum of 10 minutes

it did allow the respondents' political attitude to be taken into account and thus improved the model fit significantly.

Table 6 provides various relative ratios between the parameters, i.e. the comparison of their respective marginal utilities, at the sample means. For an application in project studies, they probably have to be re-weighted, as their value will be rather different at the respective population means. The ratios have been compared with previous studies in Switzerland (e.g. SBB, 2005) and found to be consistent with the prior evidence. The monetary values for reliability are slightly higher than in other studies. This is probably due to the special focus on reliability, which was immanently connected to the issue of road pricing. This conclusion is also supported by the somewhat lower monetary values for public transport headway and number of transfers and for the ratio between access time and travel time for public transport alternatives. The respondents did not attach the same importance to these attributes as they did in previous studies.

Certainly, the most important ratios in road pricing studies are the values of travel time savings (VTTS). Table 6 shows the willingness to pay at the sample mean for the four cost components. However, since the parameters of the cost attributes as well as for the time attributes have been determined to be elastic with respect to travel time and income or travel cost, respectively, the values of travel time savings have to reflect these elasticities. Figure 2 and Figure 3 illustrate the values of travel time savings with regard to the cost components fuel costs and tolls. Figure 2 depicts the dependence of the values of travel time savings on the corresponding cost components and travel time. It can be seen that the value of travel time savings decreases with increasing costs and increases with an increasing total travel time. This effect of the total costs reflects then overall budget constraints of the traveller. As the budget constraints become

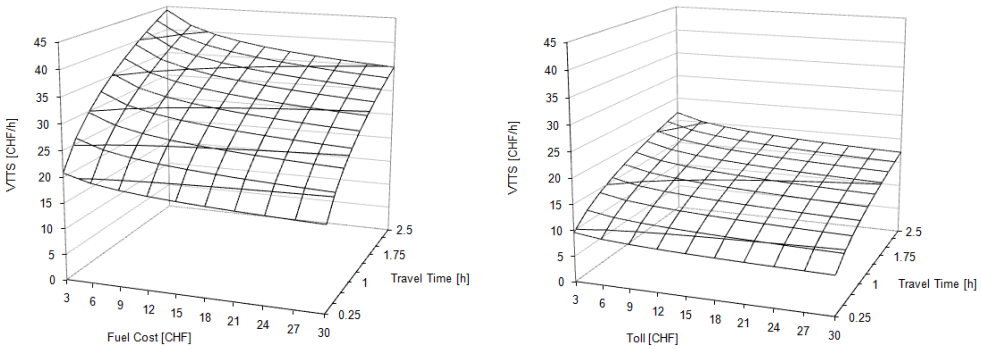

Figure 2: VTTS for fuel costs and tolls with respect to cost and travel time

binding, the travellers expect increasing payoffs in terms of travel time saved for the same payment.

As it was already indicated by the values of travel time savings at the sample mean, the level of the VTTS is considerably lower for costs caused by a toll than for those originating from fuel consumption. But, the increase with regard to travel time is slightly steeper for the former than the latter. It can be argued that the respondents are less responsive in the short term to changes in unavoidable fuel costs then to changes in the avoidable costs for tolls, which can be bypassed through longer trips. The same applies logic applies for parking costs. The even lower willingness to pay for parking indicates that Swiss respondents react strongest on increases in parking costs at their destination. Parking costs are even easier to avoid than tolls by longer search times or access walks or by choosing the public transport alternative. This finding is reasonable in the Swiss context where parking spaces are rare and the public transport network density is high and it is likely that the distance between the parking place and the destination is equal to or even higher than the distance between the public transport stop and the destination.

An equivalent pattern can be seen in Figure 3 where, in addition, the effect of income on the value of travel time savings is illustrated. As has been demonstrated in previous studies (e.g. Santos and Shaffer, 2004; Vickrey, 1969), an increasing income leads to an increasing value of travel time savings. Once again, the overall level of the VTTS is considerably lower for the costs arising from tolls than for those arising from fuel consumption. But here the increase of the VTTS with respect to income is significantly steeper for the toll costs than for the fuel costs.

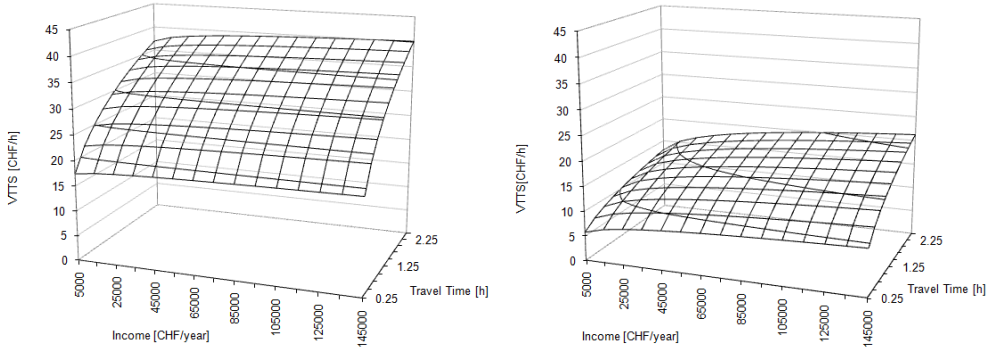

Figure 3: VTTS for fuel costs and tolls with respect to income and travel time

5 Conclusion

The major aim of the project described here is to support the Swiss policy discussion on new mobility pricing schemes and to inform later modelling efforts for cost-benefit analysis. The study is based on a substantial SP survey and examines the impact of road pricing on route, mode and departure time choices. Overall, the estimated models show realistic results that are in line with previous studies about road pricing impacts as well as studies about values of travel time savings for Switzerland.

The results emphasise traveller's nonlinear valuation of cost and travel time characteristics. The values of travel time savings strongly depend on household income, overall travel cost and specific travel time. Regarding the different cost components, the values of travel time savings have substantially different values. Respondent resent the more easily avoidable costs more, such as parking costs that can be reduced by longer walking times or toll costs that can be lessened by different route choices. In addition, parking and toll costs have to be paid in addition to the already familiar and accepted fuel cost. Thus, the respondents expect substantially larger time savings for the same payment.

It has been shown that a departure time earlier than the preferred one is priced differently depending on the choice situation. In general, Swiss travellers dislike earlier departure times. But if they choose to drive on a congested and non-toll route, they prefer to depart earlier to make sure that they arrive on time or earlier at their destination. This finding expresses a general attitude against delayed arrivals at the destination. A confirmation for that is also given by the penalty for late departure whose absolute value is twice as high as the ones for early departure.

Concerning the reliability of an SP survey on road pricing, one should note the strong impact of the respondents' attitude towards road pricing on their choices. The initial SP experiment about acceptability of new mobility pricing schemes

could not eliminate this effect. However, it was applied to take this attitude into account in the estimation of the behavioural parameters.

The estimated parameters will now be used to model scenarios of different road pricing schemes in Switzerland. These will be used with regard to changes in route, mode and departure time choices and, in combination with the parameters of the Swiss national model, destination choice. However, the results emphasised that traveller behaviour strongly depends on socio-demographic, trip and transport supply characteristics. Therefore, the effects of road pricing measures can be estimated only by a plausible and validated description of the transport service, the regional transport demand and the total trip costs.

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