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Working Paper**Author(s):**

Weis, Claude; [Axhausen, Kay W.](#) 

Publication date:

2009

Permanent link:

<https://doi.org/10.3929/ethz-a-005823562>

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Originally published in:

Arbeitsberichte Verkehrs- und Raumplanung 558

7Induced Travel Demand: Evidence from a Pseudo Panel Data Based Structural Equations Model

Claude Weis
Institute for Transport Planning and Systems (IVT)
ETH Zurich
HIL F 33.1
Wolfgang-Pauli-Str. 15
CH-8093 Zurich
Switzerland
Phone: +41-44-633 39 52
Fax: +41-44-633 10 57
Email: weis@ivt.baug.ethz.ch

Kay W. Axhausen
Institute for Transport Planning and Systems (IVT)
ETH Zurich
HIL F 32.3
Wolfgang-Pauli-Str. 15
CH-8093 Zurich
Switzerland
Phone: +41-44-633 39 43
Fax: +41-44-633 10 57
Email: axhausen@ivt.baug.ethz.ch

Abstract

Induced traffic, defined as additional demand generated by improvements in travel conditions, has been a topic of research for many years. While previous studies have focused on specific and localised changes, the research described in this paper deals with the aggregate effects of changed generalised costs of travel on traffic generation: the propensity of participating in out-of-home activities on a given day, the number of trips and journeys conducted, and the resulting total times out-of-home and distances travelled. The generalised cost and accessibility elasticities estimated with a structural equations model for a pseudo-panel constructed with the Swiss National Travel surveys since 1974 are surprisingly substantial even after correcting for age, cohort and other socio-demographic effects.

Key words (JEL): D120, R110, R220, R410

1.0 Introduction and motivation

Induced traffic, a phenomenon that is here defined as additional demand for transport services directly caused by improving travel conditions, has been a topic of ongoing research for many years, the main focus being the assessment of potentially undesirable side effects of measures bringing about such improvements. While previous studies have focused on specific and localised changes, such as the construction of new roads or rail lines in given corridors, and the assessment of their potentially negative side effects, the research described in this paper deals with the aggregate effects of changing generalised costs of travel on traffic generation: the propensity of participating in out-of-home activities, or being mobile on a given day, the number of trips and journeys conducted, and the resulting total times spent out-of-home and distances travelled. Generalised cost is understood as the risk- and comfort-weighted sum of resources consumed for travel: time and (decision-relevant) monetary expenditures. The hedonic, social and monetary benefits of the associated activities motivating the travel cannot be captured in detail here.

The objective of this paper is to overcome the limitations of the literature (see below) by addressing the issue over a longer time period and a wider spatial scale than usual and using accessibility as central explanatory variable, as it is equally central in the policy discussions around transport projects and policy making. Accessibility is measured as the log sum term of a suitable work location destination and mode choice model (Fröhlich, 2008a, 2008b; Ben-Akiva and Lerman, 1985) capturing both the changes in the generalised costs of travel (via the mode choice element), as well as the changes in the number and the spatial distribution of the (work) opportunities. It is therefore an overall measure of the quality of service offered by the transport system. We assume that travel in its various dimensions is a normal good, i.e. that travellers

respond to reductions in generalised costs of travel by increasing their consumption (Varian, 1992). We also assume, that the travel behaviour observed reflects equilibrium conditions both behaviourally, as well as the underlying network flows and travel times. Individuals can adapt their travel behaviour¹ after a change in the generalised costs on several levels:

- the decision to leave home, that is to participate in out-of-home activities on a given day;
- the adaptation of the number of out-of-home activities;
- the combination of activities and trips into tours (journeys) or trip chains;
- the scheduling (timing and duration) of activities;
- the choice of locations for carrying out activities (destination choice);
- the choice of an origin-destination connection (mode and route choice).

Given the large number of existing studies dealing with the latter two dimensions, which effectively constitute the second to fourth steps in the classic four step model (see Ortúzar and Willumsen, 2001), and the very locally specific and personal nature of the scheduling process, this paper focuses on an aggregate analysis of the upper levels of the demand generation process. The scheduling process and the intra-household interaction issue will be addressed in future work through a stated adaptation survey following in the tradition of the Household Activity Travel Survey (HATS) (see Jones *et al.*, 1980).

When generalised costs sink, both the time and the monetary resources for participating in travel and non-travel activities increase. It is reasonable to expect that this shift in resource availability will lead to a number of demand generation responses:

- the propensity of participating in out-of-home activities increases;
- the number and duration of out-of-home activities and trips increases;
- the demand for transport services (distances travelled) increases;

¹ For the classification of movement into consistent elements see Axhausen, 2008.

- the number of trips per journey (succession of trips starting and ending at home) may both decrease, as returning to the home location after carrying out each activity becomes cheaper (in terms of generalised costs), or increase, as the added trips are integrated into existing chains rather than generating new journeys.

Ideally, the analysis of the stipulated effects and of their mixture requires a longitudinal panel data set in association with a careful description of the level and changes in generalised costs covering both a long time period and a large area to obtain enough variation for the detection of the effects of any change. Such combined data sets are not available anywhere. The German Mobility Panel (1994 – 2009; see Zumkeller *et al.*, 2009) and the Puget Sound Panel (1990 – 2003; see Yee and Niemeier, 2000; Goulias *et al.*, 2003) would be suitable in terms of duration and with some reservation geographical spread, but both are missing the necessary panel of network models.

The paper adopts therefore a second-best approach employing a *pseudo panel* (Deaton, 1985; Mason and Wolfinger, 2004) approach which has seen common use in transport in recent years (e.g. Bush ,2003; Dargay, 2002, 2007; Huang, 2007). For a *pseudo panel* individuals of different cross-sectional surveys are aggregated into groups with a consistent definition. The mean members of these groups are treated as individuals, which are followed over time, thus constructing an artificial panel dataset from a series of cross section surveys. The modelling framework that was used for testing the hypotheses formulated above is a *structural equations model*, which allows to model the effects of all exogenous variables on all endogenous variables simultaneously, and also to account for both error correlations and direct effects between the endogenous variables.

A series of *general linear models* (GLM) is used to test the hypotheses mentioned above

separately for all relevant dimensions. Based on these models, the *structural equations* model is formulated. Demand elasticities are computed from the regression weights, thus providing a consistent measure for quantifying the abovementioned effects.

The paper is structured as follows. The next section provides an overview of literature covering subjects treated in this paper. The subsequent sections describe the construction of the *pseudo panel* dataset and the variables it contains, the descriptive characteristics of the *pseudo panel* and its variation over time, and the model formulation and estimation steps, followed by conclusions and an outlook on further work.

2.0 Literature review

Goodwin (1992, 1996), Noland and Levinson (2000), Graham and Glaister (2004) and Goodwin *et al.* (2004) provide overviews of known income, price and supply elasticities of car ownership and demand for transport services, measured in vehicle miles travelled. Similar analyses can be found in the works of Oum (1992), Cerwenka and Hauger (1996), Cairns *et al.* (1998) de Corla-Souza and Cohen (1999), Lee *et al.* (1999), Barr (2000), Fulton *et al.* (2000), Noland and Cowart (2000), Noland (2001) and Cervero and Hansen (2002). Fröhlich (2003) provides a literature review of models treating the effects of increased road supply. All of these studies deal with the standard definition of induced traffic, that is the reaction of demand for transport services (travel times and distances) to the improvement of the capacities of the transport system and the implied drops in generalised travel costs.

Analogous Swiss studies dealing with traffic induced by localised changes to the transport system and the according accessibility changes include Sommer *et al.* (2004), Güller *et al.* (2004) Giacomazzi *et al.* (2004) and Aliesch *et al.* (2006), providing ex-post analyses of the effects of the construction of the A7 highway, the implementation of suburban rail lines in the Zurich metropolitan area, new transport infrastructures in the canton of Ticino and the opening of a shuttle train tunnel linking a previously remote Swiss mountain valley to the inland, respectively. However, all the mentioned analyses remain vague in their conclusions. Like all ex-post analyses, they suffer from the enormous challenges imposed by the empirical data requirements. In fact, in order to provide a detailed assessment of induced travel effects, all re-routed trips would have to be recorded before and after the implementation of the measure under study. Rudel and Maggi (2007) present current results based on the analysis of potential mobility pricing schemes.

The effects of the structural changes of the aggregate system are the subject of three recently finished dissertations at the Institute for Transport Planning and Systems (IVT, ETH Zurich). The studies are partly based on the same data employed here – the Swiss network models for private and public transport (Fröhlich *et al.*, 2005), updated once a decade since 1950, and a detailed database of Swiss municipalities since 1950 which was enriched with spatial and welfare data (Tschopp *et al.*, 2003). Fröhlich (2008a) uses the data for modelling the development of commuting behaviour since 1970. Tschopp *et al.* (2005) (as well as Tschopp, 2007) analyse the influence of changes in the transport system and the corresponding accessibilities on the numbers of residents and workers in the municipalities. Bodenmann (2007) provides an analysis of the interaction of firm locations and the transport system since 1970.

Literature dealing with the demand dimensions that are discussed in this paper is quite sparse, indicating that the generation side of transport demand has been neglected during the past 30 years. A few examples that draw on the concepts that are employed here include Kumar and Levinson (1992), the investigation of a generation model for work and non-work trips; Madre *et al.* (2004), a meta analysis of immobility in travel diary surveys; Mokhtarian and Chen (2004), a literature review of studies discussing the concept of constant travel time budget; van Wee *et al.* (2006), a quest for an explanation of increasing total daily travel times; Primerano *et al.* (2008), where definitions for trip chaining behaviour are provided.

Meier (1989) is an early attempt at explaining general induced travel demand effects in Switzerland, among others by analysing the variation of mobility (expressed by the share of mobiles and number of trips) by accessibility (in classes) and showing higher mobility for regions with superior accessibility.

3.0 Construction of the pseudo panel dataset

The concept of *pseudo panel* data was first introduced by Deaton (1985). It consists in grouping individuals from cross sectional observations into cohorts, the averages of which are then treated as individual observations in an artificial panel. These data can be used in the absence of actual panel data to approximate the latter by following virtual persons (created by the aggregation into cohorts; Mason and Wolfinger, 2004) over time and test for individual as well as dynamic effects. Examples for the application of the method in the transport planning field are Bush (2003), an effort to forecast future travel demand of baby boomers (see also Goulias *et al.*, 2007); Dargay (2002, 2007) and Huang (2007), where evidence for the substantial influence of cohort effects on household car ownership is provided.

3.1 Cross-sectional datasets used

The *pseudo panel* dataset was constructed with the Swiss National Travel Survey (named *Microcensus*) data, a person-based survey. In general only one person is interviewed in any one household. Large households, where a second person is interviewed, form a rare exception. The survey has been carried out approximately every 5 years since 1974. Over the course of time, survey methods have changed several times, complicating the comparison of the resulting data. A brief overview of the various survey methods used is given in Table 1 (adapted from Simma, 2003).

As the different survey methods lead to discrepancies in the data, the various household, person and travel datasets had to undergo a thorough reformatting in order to obtain a uniform data format for all persons over the different years and a consistent coding for the relevant socio-demographic characteristics and especially for the key mobility indicators (trip numbers et

cetera).

For example, a severe decrease in reported mobility (as far as increased non-mobility as well as reduced trip numbers are concerned) is obvious in the 1989 dataset (Simma, 2003). This discrepancy appears not to be explicable merely by seasonal fluctuations, but rather related to an underreporting of trips in the corresponding trip diary. These effects, which are clearly artefacts of survey methods or the fieldwork in the relevant year, are taken into account and corrected for in the modelling procedures that will be discussed in the following sections. Lleras *et al.* (2003) present approaches to account for data inconsistencies across travel behaviour surveys in pooled analyses.

3.2 Variables in the dataset

The cohorts for the *pseudo panel* dataset ought to be constructed with characteristics that are (or can reasonably be assumed to be) time invariant. The most obvious example of such a discriminating variables is the year of birth (which has been used in multiple studies, such as Dargay, 2002, and Huang, 2007). Other criteria, such as gender, education level, or spatial characteristics, are also conceivable as grouping variables.

When constructing a pseudo panel, two conflicting aims ought to be met: on the one hand, the cohorts should be constructed in a way that provides sufficient variability in the panel and provides a sufficient number of observations in order to estimate robust models. Thus, the cohort definition should be as detailed as possible. On the other hand though, when the disaggregation level becomes too detailed, the number of observations per cohort will become small for certain time periods, leading to greater weights of potential outliers in computing the cohort averages and thus to biased estimates of the population means (Huang, 2007).

As a compromise between sufficient level of disaggregation and large enough cohort sizes, a cohort subdivision according to three criteria was chosen:

- year of birth (split up into 10 year bands ranging from 1896 through 1985);
- gender;
- region (one out of 7 Swiss regions; the aggregation corresponds to the EU NUTS 2 regions; Eurostat, 2008).

The latter was chosen over a spatial definition based on municipality types (urban, suburban, rural, et cetera). In fact, it can be argued that relocations to better accessible places of residence (to a different municipality type) take place because of a certain desired mobility behaviour. Such a classification would be teleological and would bias the results. The postulated direct causal effect of accessibility on trip generation would not be discernible from a confounding residential self selection effect (Boarnet and Crane, 2004; Mokhtarian and Cao, 2008).

The pseudo panel dataset contains 838 virtual observations for the seven considered survey years between 1974 and 2005. The distribution of the resulting cohort sizes is displayed in Figure 1. As can be seen, a large portion of the cohorts are quite small (50% of them have a cohort size of 25 or below). However, these small cohorts contain relatively few of the total observations, approximately 85% of the individual observations being in cohorts of acceptable sizes. Consequently, a large portion of the underlying observations will be considered in the analysis, thus leading to reliable modelling results given that the observations will be weighted.

The selection of exogenous (independent) variables was limited by the differences in the survey over the decades. The chosen set represents a common core, which is regularly used in models of travel behaviour (Dargay, 2002; Bush, 2003; Huang, 2007). The averages for those variables expected to have an impact on the mobility indicators to be modelled were computed:

- age;
- household size;
- employment status (as percentage of full or part time employed in cohort);
- monthly household income (in Swiss Francs of 2005);
- car and motorcycle driving license ownership (as percentage of owners in cohort);
- number of cars, motorcycles and bicycles in household;

The indicators for travel behaviour that are treated as endogenous variables are:

- out-of-home activity (as percentage of mobile persons);
- number of trips;
- number of trips per home-to-home tour (journey);
- total duration spent out of home;
- respondent estimated total trip distance, as geo-coded locations and network derived distance estimates are only available from 2000.

In order to account for the sampling method differences between the various surveys, only weekday mobility figures were considered, thus avoiding biased means due to an over- or underrepresentation of weekends.

Furthermore, the dataset was enriched with several variables that, individually or in combination, may be used as a proxy for generalised costs of mobility tool ownership, respectively travel:

- price indices for individual travel (Abay, 2000; values up to 2005 were extrapolated);
- fuel costs (Swiss Federal Office for Statistics);
- accessibility measures (Tschopp *et al.*, 2005, respectively Fröhlich, 2008).

4.0 Measures used as an approximation for generalised costs of travel

4.1 Accessibility

Accessibility to population is defined as (Tschopp *et al.*, 2005; Ben-Akiva and Lerman, 1985):

$$A_i = \ln \left[\sum_{j=1}^n X_j \cdot f(c_{ij}) \right] \quad (2)$$

where A_i is the accessibility measure for spatial unit i (the spatial unit here being Swiss municipalities), X_i is the number of inhabitants of spatial unit i , c_{ij} is the intercentroid travel time from spatial unit i to spatial unit j (n being the total number of municipalities), and f is a weighting function. Tschopp *et al.* (2005) use a negative exponential function for weighting, ensuring decreasing intercentroid accessibilities with rising travel times. The contribution of the zone to its own accessibility was considered using a calculated mean intrazonal travel distance; see for example Fröhlich *et al.*, 2005, for a computation method for the mean intrazonal distance).

Increasing accessibility serves as a proxy for decreasing generalised cost of travel and is a possible indicator for testing the hypotheses that travel behaviour reacts to changes in generalised costs.

The distributions of accessibility values of all Swiss municipalities from 1970 through 2005 are displayed in Figure 2. As can be seen, accessibility values have steadily increased over the 35 years under consideration. It should be noted that the observed increase of the median value from 9.13 in 1970 to 9.47 in 2005 reflects an increase in the Swiss population by 1.2 million persons, an additional 840 km of motorways and roughly 29 billion Swiss Francs investment. The accessibility values for the survey data reference years were obtained by interpolation from the available network model data displayed in Figure 2.

In another approach, Fröhlich (2008a, b) estimates a joint discrete choice model for mode

and work location choice. The resulting utility log sums for each municipality is a theoretically consistent accessibility indicator, albeit one that has an inherent behavioural component, which is limited to work and therefore underestimates the total accessibility gain and is limited to a particular type of travel. The mode choice sub-model considers travel time, transfers, transfer weighting times, headways, quality-adjusted cost of car-ownership, and inflation corrected distance-based costs.

4.2 Price index for individual travel

The simple measure of accessibility as described above measures generalised costs of travel as a function of travel time. In order to have an monetary indicator in addition, price indices for individual travel, as provided in Abay (2000) are used. The index, calculated for years reaching back to 1972 is based on the Swiss national consumer price index, and weighted to reflect inflation-adjusted prices (the base year being 1972, hence the index is set to 1 for this year). As such, it represents a measure of transport prices relative to the general consumer prices for all goods. Figure 3 shows the index' evolution from 1972 through 2005.

5.0 Explorative data analysis

This section deals with the characteristics of the pseudo panel cohorts and their variation over time, and shows the generation and life cycle effects of the representative indicators as well as the above mentioned biases of the different survey methods.

5.1 Household size

Figure 4 shows the average household sizes for members of the respective year of birth cohorts and their life cycle evolution. Here, both a life cycle and a generation effect can be made out. The life cycle effect for all cohorts shows the expected trends. Young adults tend to live in their parents' homes and thus in large households. As individuals approach their mid 20's, average household size decreases as a consequence of moving out of the family home and setting up their own households. Then, after turning 30, the trend again turns to an increase in household size, as the individuals settle down and have their own families. As the mid 40's pass, household sizes decrease again as an effect of children moving out, and later on of spouses passing away.

As for the generation effect, it can be seen that younger cohorts tend to live in smaller households. This can be explained by the larger share of single person households (especially for young adults) as well as by decreasing birth rates. Also, elderly people increasingly tend to live on their own rather than moving back in with their families or moving themselves to nursing homes.

5.2 Car driving license ownership

The cohort and age effects for car driving license ownership are depicted in Figure 5. The life cycle effects that are seen here are as expected. In fact, young adults nowadays tend to acquire a driving license at quite young age. In 2005, there is a practically constant, above 80 per cent,

share of car driving license owners throughout age groups, up to the age of around 60. Car driving license ownership decreases with age, and is much lower for cohorts born before the Second World War, when licence holding was uncommon for women in particular. Overall, the generation effect clearly tends towards higher car driving license ownership in younger cohorts, again pointing to an increased general availability of mobility tools over time.

5.3 Key mobility figures

Household size and car driving license ownership, two important characteristics of the household structure and possible indicators for mobility, exhibit expected and consistent trends over time, over the various age groups and for the different survey periods. The key mobility figures, which will be discussed in the following paragraphs and form the basis for the models estimated subsequently, do not to follow the same clear and consistent scheme.

In fact, the relevant figures exhibit significant fluctuations for the various survey periods. As has been discussed above, these effects are not due to seasonal effects in year-round surveys, but are artefacts of the survey methods employed. As can be seen in Figure 6, weekday mobility (as a percentage of those individuals that reported at least one trip or out-of-home activity) approximately reproduces the life cycle effect that one would expect, that is continuously decreasing mobility with increasing age. However, for each cohort, there is a slight drop in reported mobility around the middle of the curve. These decreases are confirmed by Figure 7, and coincide with the 1984 and 1989 surveys. No natural reason for this fluctuation being apparent, this suggests measurement errors present in these years.

The undesirable effect of mobility underreporting becomes even clearer when considering the average reported trip numbers displayed in Figure 7. In fact, even normalizing to number of

trips per mobile person does not remove the effect. Mobility underreporting in the trip based self-administered diary surveys of these years appears to have happened on two levels: an overrepresentation of non-mobile persons, and trip underreporting from those that reported mobility. This hints at both a lacking willingness to participate in the surveys, and a considerable attrition effect and a lack of attention of the field work firm in monitoring the surveys.

The estimated models, which will be discussed in the following sections, account for the described effects and attempt to reproduce life cycle effects that are smoothed to reflect the actual behaviour, as well as correct parameter values for the remaining variables.

6.0 Formulation and estimation of the general linear models

This section describes the individual models for the various mobility indicators based on the factors listed above: share of mobiles, number of journeys, number of trips, duration of out-of-home activities, trip duration and estimated distances travelled. Descriptive statistics of the continuous independent variables upon which these models were fitted are displayed in Table 2. The modelling framework is a linear-in-parameters regression model. The *general linear model* (GLM) is a generalization of the standard linear regression model allowing the inclusion of categorical variables. It is assumed that the various mobility indicators can be expressed as:

$$y_{i,m} = \mu + \alpha_i + \tau_m + \beta_j \cdot x_j, \quad (1)$$

where $y_{i,m}$ are the dependent variables, and μ is a mean intercept term. x_j are the independent variables and β_j the parameters associated to them. α_i are error terms the values of which vary across the behavioural units (the cohorts), yet are invariant over time for any given cohort. τ_m are error terms the value of which varies for the different survey methods, but not over the behavioural units. These error terms serve to cancel out the measurement errors produced by the data collection process. The components α_i and τ_m will be treated as constants rather than random variables, leading to cohort specific as well as survey method specific dummy variable coefficients incorporated in the model. Thus, the model is called a *fixed effects model* (Kitamura, 2000).

Table 3 summarises the estimation results for the weekday mobility model, thus $y_{i,m}$ is the number of trips for birth year cohort i in a survey period where method m was applied. Parameter values and t statistics are provided.

All variables were found to have a significant effect on cohort level trip generation. The estimated fixed effects for the survey methodologies confirm their above mentioned impact on

the dependent variable. The most significant negative effect on trip reporting results for the trip based diary surveys in the 1980's, which confirms the conclusion drawn from Figure 7.

Males throughout generations are slightly more mobile than females. The same holds for employed individuals as well as for car driving license owners, the latter being an indication of a direct effect of mobility tool ownership on reported mobility. Household size has a slight negative effect on the dependent variable, thus individuals from single households tend to be more mobile than those from family households. However, the significance of this influence is not significant at the 5 per cent level.

Perhaps the most interesting effect is observed for the generalised cost measures. In fact, all other influence factors being accounted for, accessibility (sum of the road and public transport accessibilities) to population has a significant positive effect on trip making. The inverse holds for the price index variable: the negative effect implies that higher transport price levels cause lower mobility and vice-versa. These findings suggest that reductions in generalised costs do indeed increase travel demand.

The effect of age on weekday mobility follows the trend present in Figure 8. The cohort effect on trip generation was found to be insignificant when included in the model alongside both the accessibility and price index variables and was therefore left out of the final model. Thus, all other effects taken into account, behaviour does not seem to vary much between birth year cohorts, the life cycle effect being clearly predominant vis-à-vis the generation effect. In other terms, the α_i in equation (1) are constant across cohorts and can be expressed as a unique intercept term. This is surprising given the wider literature on long term effects of the improved childhood nutrition of the post-war generations (See for example Fogel, 2004).

As can be seen, the expected life cycle effects are well reproduced by the model: mobility

decreases with age, the slightly S-shaped curve resulting from the functional form of the relationship (summation of a linear, squared and logarithmic term) that was assumed based on the descriptive analysis.

Analogous models were estimated for the other mobility indicators; the models yielded the expected results, which will be discussed in more detail in the following section describing the *structural equations* model, which is a combination of the individual models accounting for the error correlations of the endogenous variables.

7.0 Structural equations model

The formulation and estimation of the basic models described in the previous section yield the expected effects of the independent variables on the various mobility indicators (exemplified by the model for weekday mobility). Here, a *structural equations* model (SEM) shall be described, which models the effects of the independent (exogenous) variables on the indicators (endogenous variables) simultaneously. Furthermore, the model structure allows accounting for the error correlations between the endogenous variables.

The method has been widely applied in the travel behaviour research field (see Golob, 2003 for a description of its benefits to travel behaviour research). Applications include Lu and Pas (1999), an analysis of activity participation and travel behaviour as a function of individuals' sociodemographics; Kuppam and Pendyala (2001), a study of the relationships between commuters' activity participation, travel behaviour and trip chaining patterns; Simma and Axhausen (2004), who analyse the interactions of travel behaviour, accessibility and spatial characteristics in Upper Austria based on a cross sectional dataset; as well as de Abreu e Silva and Goulias (2009), where the influence of land use patterns on adult workers' travel behaviour is analysed.

7.1 Model formulation

The *structural equations* approach (Bollen, 1989) is a confirmatory method for testing and quantifying assumed causal relationships between various factors. The general formulation is as follows:

$$y = By + \Gamma x + \zeta , \quad (3)$$

where y is an $m \times 1$ vector of endogenous variables, B an $m \times m$ matrix of coefficients

associated with the right-hand-side endogenous variables, x an $n \times 1$ vector of exogenous variables, Γ an $m \times n$ matrix of coefficients associated with the exogenous variables, and ξ an $m \times 1$ vector of error terms associated with the endogenous variables.

It is expected that the SEM will confirm the trends exhibited by the basic models and allow the computation of demand elasticities for all relevant dimensions simultaneously. The chart in Figure 9 represents the causal effects implied by the basic models. The model assumes direct causal relationships between a number of dependent variables, and thus goes further than merely capturing these relationships via error correlations. The hypotheses on the direct relationships (which are added to the effects of the structural and socioeconomic variables described above) between the cohort-level endogenous variables are as follows:

- Increased weekday mobility will increase the number of conducted trips. This conclusion is quite straightforward.
- Increased mobility, respectively the increased trip numbers it brings about, will increase out-of-home-durations as well as distances travelled.
- As a corollary, the number of trips per tour will increase, under the assumption that the number of tours remains roughly the same (i.e., the additional trips are integrated into existing chains rather than generating new journeys).
- As trip chains become longer, the effect on travelled distances described above should be attenuated, as adding new trips to a chain likely produces less mileage than conducting an entirely new journey (as the return home trip is left out).

The effects mentioned above are shown in Figure 10 (highlighted by the expected sign for the relationship), along with the resulting coefficients from the model estimation. The results will be discussed in the next section.

7.2 Model estimation and results

The SEM was fitted using the AMOS 16.0 software package (Byrne, 2001). SEM fitting is done using a covariance based structural analysis, also referred to as method of moments, consisting in minimizing the difference between actual sample co-variances and those implied by the model parameters (Bollen, 1989). Various optimization techniques are available for estimating *structural equations* models. In the AMOS software package, computing intercepts for the endogenous variables is only feasible when using the *maximum likelihood* approach. As the literature (Kuppam and Pendyala, 2001) suggests only marginally changing values for the estimated coefficients from this method to the *asymptotically distribution-free* method (ADF) that one would ideally apply to such a problem, the *maximum likelihood* method is used for estimation.

Table 4 shows the estimated direct effects for the endogenous variables. As can be seen, all hypothesised effects except those on trip distance are significant at the 5 per cent level and have the expected sign (see above). The effect of trip chain complexity on travelled distance is contrary to the assumptions postulated in the last section. Thus, the addition of trips to existing chains appears to accentuate the increase of covered distances induced by the higher general mobility, instead of attenuating it by suppressing the return home trips.

The regression parameters of the SEM estimation are shown in Table 5. The results from the previous analysis are confirmed for the out-of-home share variable and can be extended to the other endogenous variables: the life cycle effects exhibit the expected trends for all the indicators: mobility, trip numbers, out-of-home activity durations, and travelled distances all decrease with age.

The parameter for household size remains negative for all but one of the indicators, which

again indicates that individuals from family households are less mobile than singles. Employed people are more mobile, again reflecting the trends described above.

As far as the accessibility and price index variables are concerned, the results from the *general linear models* could also be confirmed. Accessibility has a significant positive influence, travel price a negative one on all endogenous variables. The only endogenous variable for which this does not hold is total out-of-home duration. However, as this variable is part of a succession of reciprocal effects between the other endogenous variables (see Figure 10), all influenced positively by the accessibility variable, the total effect of increasing accessibility on out-of-home duration is positive in turn, as shown in the next section.

As far as trip chaining, defined here as the average number of trips in a home-to-home tour, is concerned, the trend that was hypothesised in the introductory section could not be confirmed. In fact, the model shows that, with decreasing generalised travel costs, the tendency to chain trips seems to increase, as contrary to the postulated effect of the cheaper home trip between two activities. Thus, additional trips are integrated into existing chains rather than generating new tours. An argument for this observation is that the increased distances (see below) place the travellers at location, from which a return home is not reasonably possible anymore.

The relative valuations for the generalised cost variables in the various sub-models, as well as the total effects induced by the generalised costs and the interrelations between the endogenous variables, will be discussed in the next section.

In an alternative formulation, the price index and the accessibility values were replaced by the accessibilities of Fröhlich's (2008b) work. The results were inconsistent and will not be reported here. A detailed analysis of this rather surprising result will be undertaken in further

work.

8.0 Demand elasticities

A mean for comparing models which is better suited than the consideration of raw parameter values are the elasticities for the various demand variables. The values are computed at the sample means for all variables and reflect the estimated effect of a 1 per cent increase in accessibility on the endogenous variables. The results reported here for the SEM include both the effects of accessibility and price index on all dependent variables and the direct influences of the endogenous variables on one another, resulting from the coefficients shown in Table 4 and Figure 10. As can be seen in Table 6, the resulting values differ slightly from the individual GLM estimations to the simultaneous SEM, confirming the non-negligible influence of including indirect effects. The values from the SEM imply that, as a consequence accessibility rising by 1 per cent:

- the share of mobiles per day will increase by 0.6 per cent;
- the number of trips conducted will increase by 0.4 per cent;
- the number of trips per journey will increase by 0.2 per cent, thus people will trip chain slightly more.

The very high elasticities for travelled distances are rather surprising, as they imply that a one per cent increase in accessibility will generate roughly the equivalent relative increase in daily mileage. The historical data confirm this trend (mileage increased over time, from 26 kilometres per day in 1974 up to 40 in 2005). Thus, as a result of a 10 per cent increase in accessibility, the daily distance travelled by an average individual would increase by roughly 4 kilometres (that is, from 40 to 44 kilometres per day), but remember the investment needed to increase it by about 3% since 1970.

The efforts (for example in terms of added motorway lane miles and the according

monetary investments on the part of the public authorities) that would be necessary to bring about such massive accessibility increases from the already high current levels are the subject of ongoing work. It is expected that even large projects will induce only slight effects on global accessibility values (orders of magnitude of less than 5 per cent) and thus the induced effects on travelled distances should remain minor. However, the effects on the local scale could be quite large.

As far as changes to the travel price index are concerned, the changes in demand implied by the model correspond to the matching values in Table 6.

The most interesting finding, at least in the setting of the present study, is the substantial positive influence of lower generalised costs of travel (as implied by the rising accessibility and decreasing price index) on individual mobility and trip generation. Thus, accounting for relevant socioeconomic influences, an induced travel effect for demand generation of substantial size has been found.

9.0 Conclusion and outlook

The results obtained confirm the hypotheses postulated in the introduction. Decreases in generalised costs of travel are found to induce higher mobility at the cohort level, as the significant effects of the accessibility measure and price index, used as approximations for generalised costs, on mobility behaviour confirm. The substantial induced travel effect on the upper levels of travel demand generation is certainly a policy relevant finding and has, to our best knowledge, so far not been shown in the literature.

Equally interesting and also unexpected is the absence of cohort effects. The Swiss results imply that the price changes and accessibility improvements are causing the increasing mobility levels of the older population, which will shift the planning discussion in new directions, as the older population is increasingly interested in return to highly accessible and lower travel cost urban locations.

The surprising absence of significant income and car ownership effects will be investigated further, especially with mode specific models.

Further work on the topic will test the trends exhibited by these first results on a disaggregated level. A one week household travel diary survey will be conducted. Based on the resulting data, the general conditions for a given day of the household will be altered (for example, by moving the children's school further away, closing down the local corner shop, or providing additional mobility tools to the household), thus leading to changes in generalised costs for the planned activity schedule. The household will then be asked to adapt their schedule to the hypothetical new situation by the means of an interactive software tool.

It is hoped that this experiment will lead to further estimates of the elasticities of the relevant travel demand dimensions and help to validate the results that were obtained on an aggregate

scale and described in this paper. The results will help to improve the modelling of demand induced by changing the generalised costs in agent-based travel demand micro-simulations, such as MATSim (Balmer, 2008), which will also be used for the validation and an application of the obtained results, especially as far as feedbacks from the transport system (again modifying the generalised costs) are concerned.

10.0 Acknowledgements

The authors gratefully acknowledge the financial support of SBT-Fonds administered by the Swiss Association of Transport Engineers (SVI 2004/012) and the advice of the steering committee chaired by Michel Simon, also including Helmut Honermann, René Zbinden, Samuel Waldvogel and Stefan Dasen.

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Table 1 **Key Characteristics of Swiss Microcensus Travel Surveys Since 1974**

Year	Survey method	Number of households in sample
1974	Time use surveys; combination of pen-and-paper and personal interview	2'114
1979		2'000
1984	Trip based diary; pen-and-paper survey	3'513
1989		20'472
1994		16'570
2000	Stage based diary; CATI	28'054
2005		31'950

Source: Simma (2003)

Table 2 Cohort-level descriptive statistics of variables used in the models

Variable	Mean	Median	Std. Dev.	Minimum	Maximum
Age	54	54	22	17	99
Household size	2.56	2.59	0.82	1.00	6.00
Employed	0.48	0.51	0.37	0.00	1.00
Index corrected household income	5888	6238	1499	1471	9253
Car driving license ownership	0.61	0.73	0.32	0.00	1.00
Number of cars in household	1.00	1.09	0.46	.00	3.02
Accessibility	10.15	10.10	0.46	7.70	11.64
Individual travel price index	0.90	0.89	0.04	0.84	1.00

Table 3 Parameter estimates and model fit for weekday mobility model

Variable	β	t stat.
Intercept	1.483	2.70
Survey method		
Time budget (1974, 1979)	-0.004	-0.14
Trip based diary (1984, 1989)	-0.086	-6.55
Stage based diary (1994, 2000, 2005) (reference category)	-	-
Gender		
Male	0.075	4.96
Female (reference category)	-	-
Age		
Linear (*1/10)	0.260	2.70
Squared (*1/100)	-0.020	-4.70
Natural logarithm	-0.450	-1.94
Household size	-0.021	-1.96
Employed	-0.006	-0.19
Car driving license ownership	0.091	2.50
Accessibility	0.048	4.19
Individual travel price index	-0.144	-0.63

Values in **bold** are significant at the 5 per cent level (as indicated by the t statistics).

Adjusted $R^2 = 0.596$

Table 4 SEM estimation results – direct effects

	(1)	(2)	(3)	(4)	(5)
(1) Weekday mobility		2.61		240.85	
(2) Number of trips			0.27		1.76
(3) Number of trips per tour					0.93
(4) Total out-of-home duration					
(5) Total trip distance				0.97	

Values in **bold** are significant at the 5 per cent level.

Table 5 SEM estimation results – regression parameters

Exogenous variables	Endogenous variables				
	(1)	(2)	(3)	(4)	(5)
Intercept	0.776	2.586	3.045	1472.779	-63.133
Survey method					
Time budget ('74, '79)	-0.031	-0.224	-0.143	8.224	5.171
Trip diary ('84, '89)	-0.108	-0.357	0.019	-9.940	-3.294
Gender					
Male	0.099	0.255	-0.056	57.917	18.924
Age					
Linear (*1/10)	0.169	0.503	-0.303	170.078	-17.212
Squared (*1/100)	-0.017	-0.043	0.021	-7.108	0.262
Natural logarithm	-0.185	-0.760	0.487	-521.245	47.444
Household size	-0.019	0.094	-0.012	-22.454	-3.649
Employed	0.013	0.473	0.103	284.508	4.915
Accessibility	0.051	0.012	0.040	-11.526	2.811
Individual travel price index	-0.061	-0.539	-3.186	-271.231	-51.075
Squared multiple correlation (R^2)	0.587	0.766	0.493	0.768	0.596

Values in **bold** are significant at the 5 per cent level (as indicated by the C ratio test)

Table 6 Accessibility and price index elasticities for GLM and SEM models

Demand elasticity		GLM	SEM
Accessibility	Weekday mobility	0.56	0.61
	Number of trips	0.44	0.44
	Number of trips per tour	0.20	0.24
	Total out-of-home duration	0.24	0.10
	Total trip distance	0.89	1.14

Price index	Weekday mobility	-0.02	-0.06
	Number of trips	-0.24	-0.19
	Number of trips per tour	-1.96	-1.66
	Total out-of-home duration	-1.19	-1.95
	Total trip distance	-1.47	-0.84

Figure 1 **Distribution of cohort sizes**

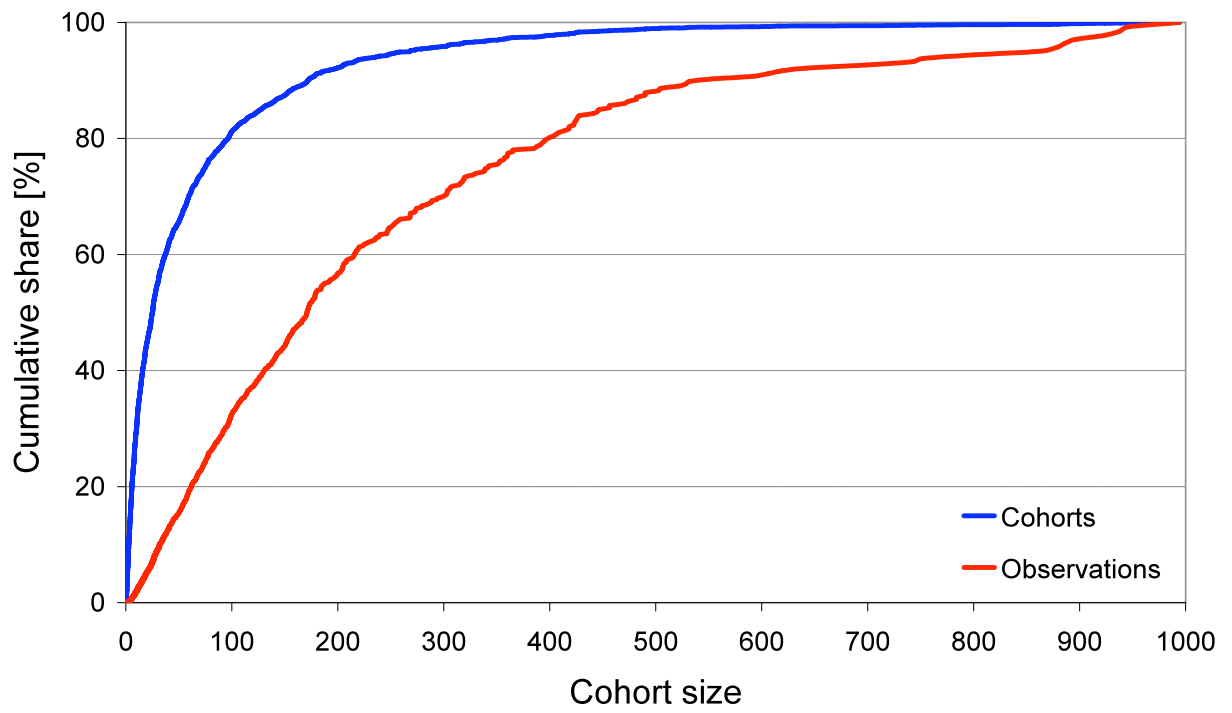


Figure 2 **Distribution of municipal accessibility values, 1970 - 2005**

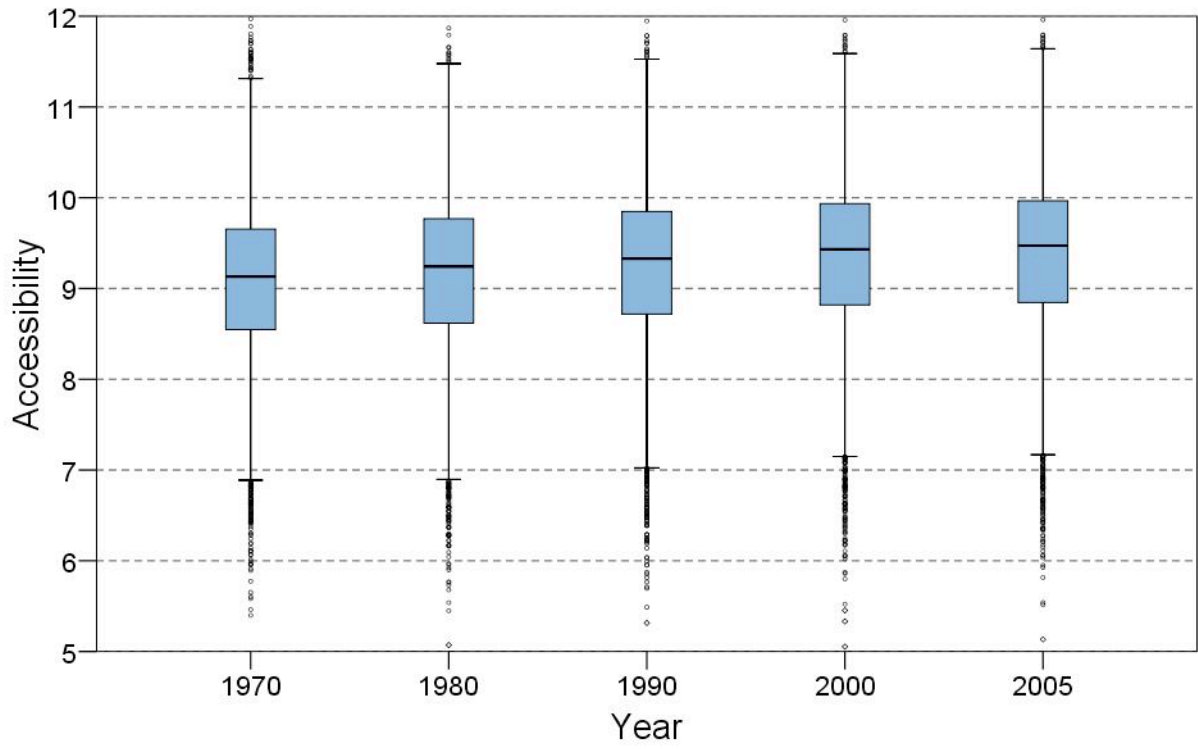


Figure 3 Evolution of inflation-adjusted individual travel price index, 1970 – 2005

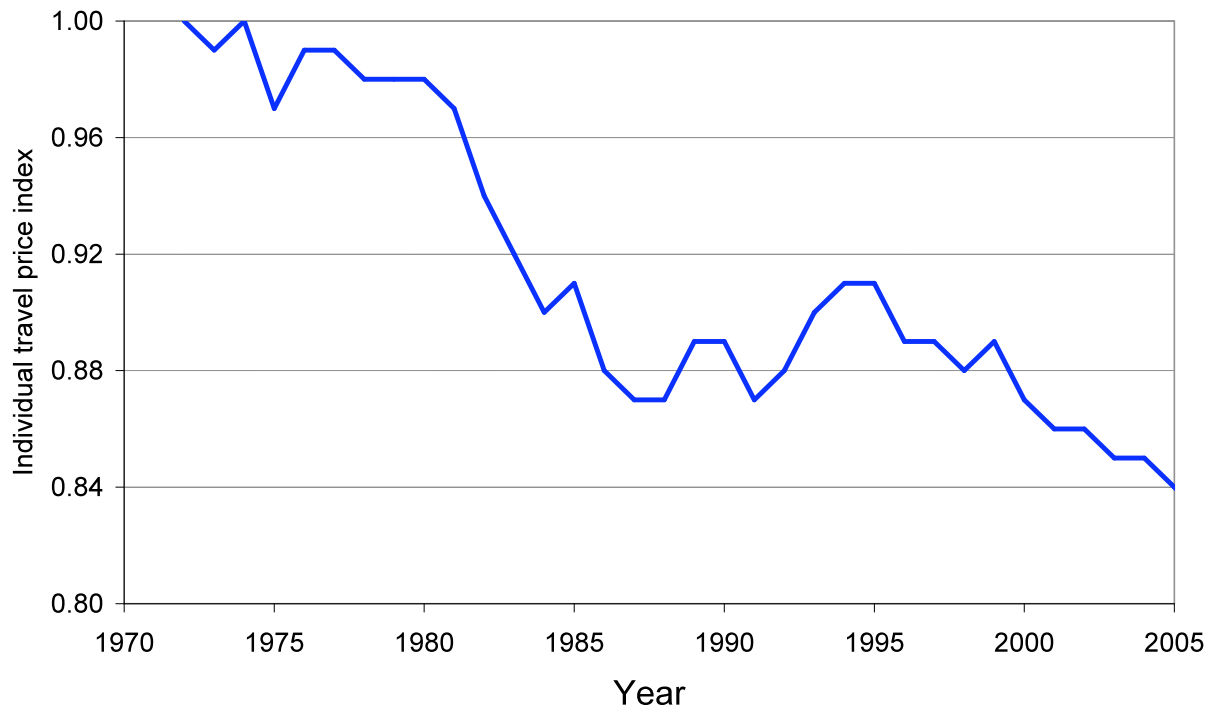


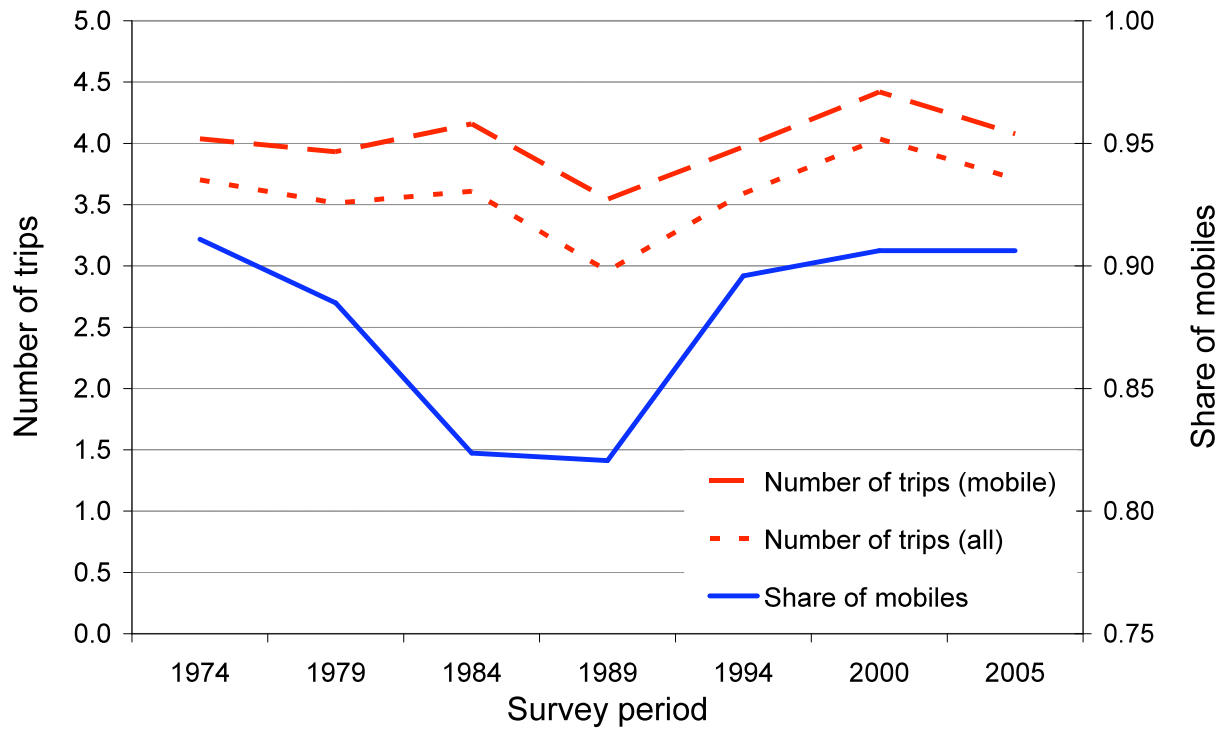
Figure 7 Reported mobility indicators for different survey years

Figure 8 Modelled age effect on weekday mobility

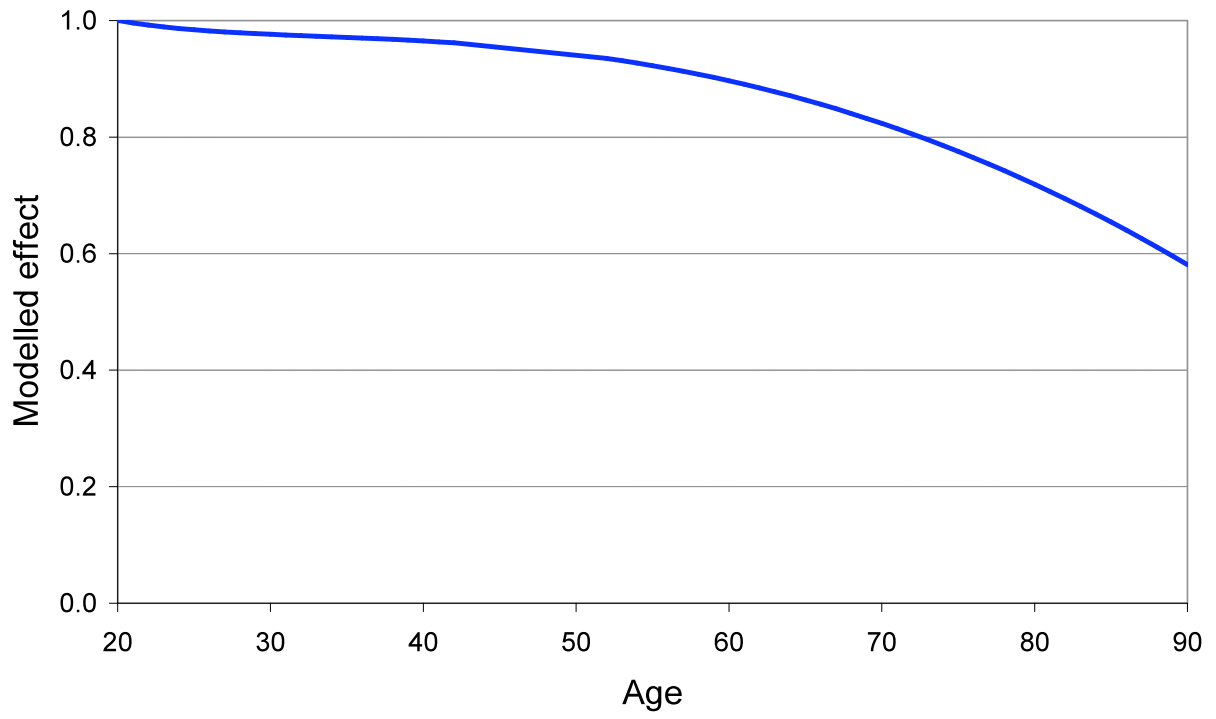


Figure 9 **Structure of the structural equations model**

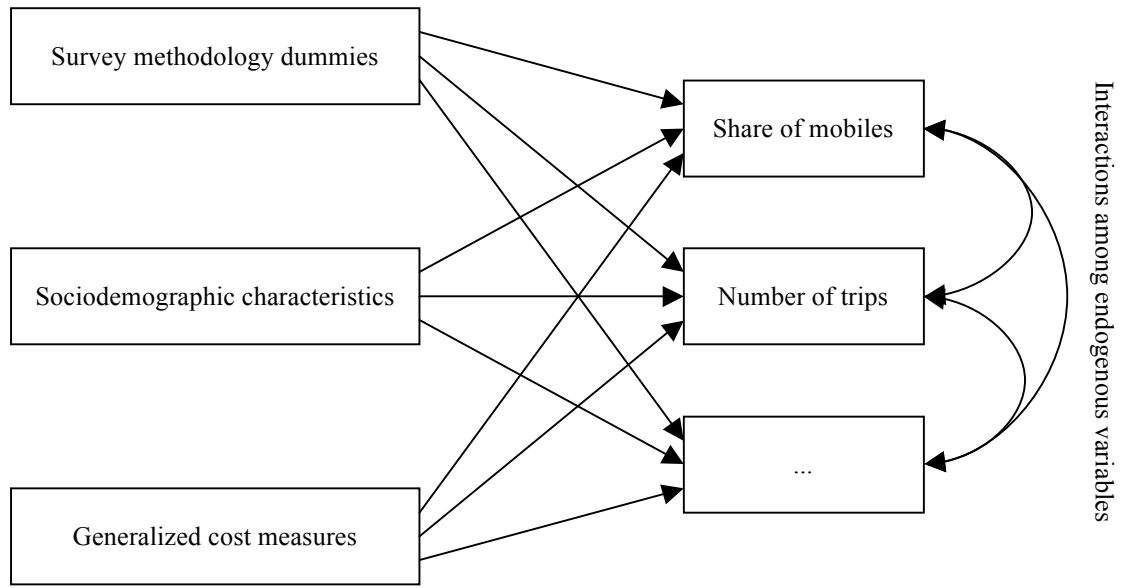


Figure 10 A-priori assumptions on direct effects vs. model results

Signs in circles are a-priori expectations on the direct effects

Numbers on arrows are coefficients resulting from model estimation

Numbers above boxes are regression coefficients for: Accessibility / Price index

