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Author(s):
Tschopp, Martin; Fröhlich, P.; Axhausen, Kay W.

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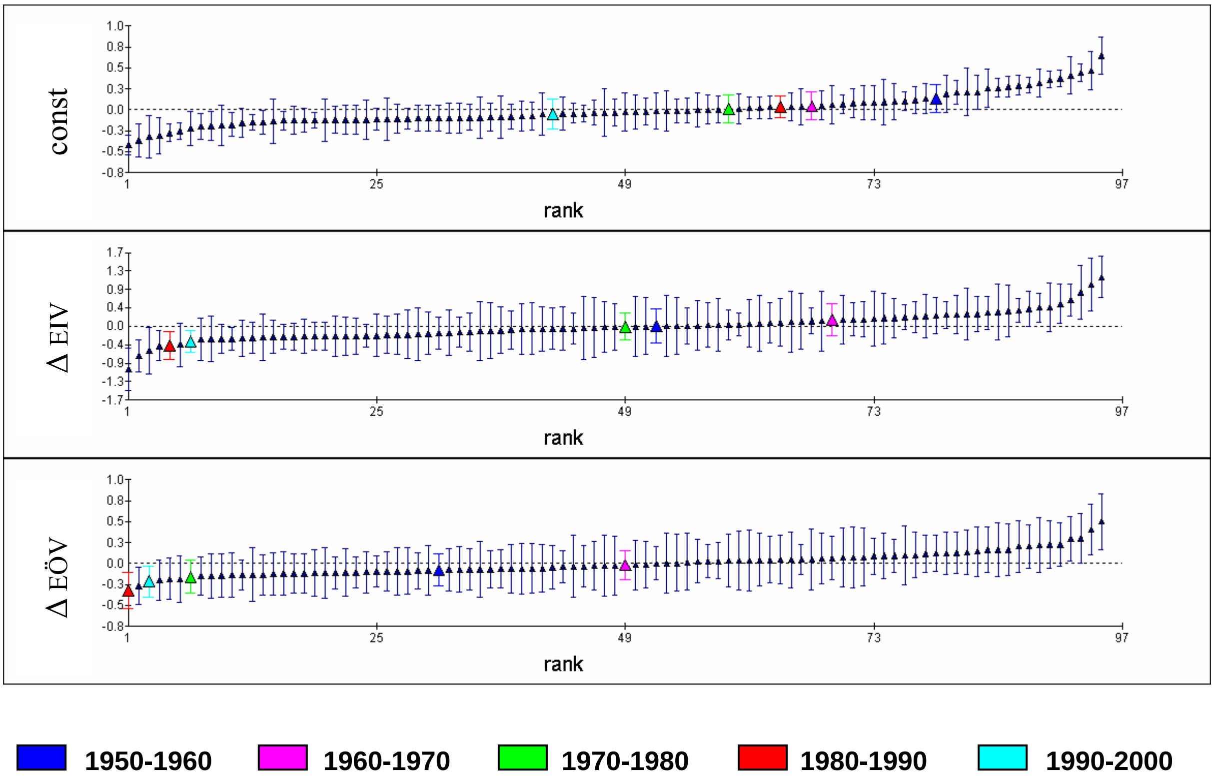

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M. Tschopp
P. Fröhlich
K. W. Axhausen

IVT Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Transport Infrastructure and Spatial Development

Martin Tschopp	K. W. Axhausen
IVT	IVT
ETH Hönggerberg	ETH Hönggerberg
8093 Zürich	8093 Zürich

Tel.:	01-633 27 19	Tel.:	01 633 39 43
Fax:	01-633 10 57	Fax:	01 633 10 57
email:		email:	
tschopp@ivt.baug.ethz.ch		axhausen@ivt.baug.ethz.ch	

Abstract

This paper focuses on the impact of transport infrastructure on demographic development of municipalities and regions. Accessibility is both the primary service provided by transport infrastructure and the link between transport infrastructure and land use. It can measure the spatial impact of newly built transport infrastructure and show the attractiveness of a region's location. A suitable approach for measuring its spatial impacts is the quantitative method of growth modelling accounting for spatial correlation. Multilevel growth models combine an individual level, which represents disaggregate behaviour with a contextual macro level. Following questions are of special interest: Where did accessibility change occur, when did these changes take place and how did accessibility change over time? First results indicate that the influence of accessibility on spatial development differs considerably over time and space.The paper is based on the research project "Accessibility and spatial disparities" and is funded by the Swiss National Science Foundation (SNF).

Keywords

Accessibility; Spatial disparities; Multilevel Modelling; IVT, ETH Zürich, STRC

1 Introduction

Transport systems have been built primarily to expand the reach of both people and industry. Frey, 1979, points out: „The main goal of transport infrastructure explicitly is to provide people and economy with public goods". Frey considers infrastructure, and especially transport infrastructure, as having spatial impacts, as an important mean for regional policies. Lendi and Elsasser (1985) are more specific: „A central – but not exclusive – function of regional policy and spatial planning is the diminishment of spatial disparities. Spatial disparities are to be understood as significant differences in socio-economic development". Also Kesselring et al., 1992 argue that transport infrastructure affects the extent to which location factors and decision makers can interact. Transport infrastructure and therefore accessibility is seen in regional science as highly important for spatial development.

One measure of the resulting change in the transport infrastructure services is the change in *accessibility*. For this, two components must be considered. First, what can be reached, and second, how much effort is necessary to get there? Accessibility is both the primary product of transport infrastructure and the link between transport infrastructure and land use. It can measure the spatial impact of newly built transport infrastructure and shows the attractiveness of a region's location.

While the rail road network was improved only punctually during the last decades (track extensions, improved tracks for higher average speeds) the construction of motorways was the main contribution to accessibility gain. Therefore this paper will mainly concentrate on the development of the motorway network.

The link between accessibility improvement and economic and population growth, at least change, is a key tenet of regional policies, even when it is acknowledged that networks are only a sufficient and not necessary condition for growth. The empirical work trying to document this link (see for example Aschauer, 1989; Fernald, 1998; Holtz-Eakin, 1994; Munnell, 1990; Nadiri, 1998; Shirley and Winston, 2004) suffers from a number of short comings: the use of large spatial units, such as US states or UK counties; the reliance on short study periods, typically ten to twenty years; omission of railway services and finally in many cases the approximation of the services of the transport system by the value of the public capital stock.

The goal of the paper is to analyse the development of spatial accessibility and its influence on spatial development. How did the impact of accessibility improvements develop over space and time? Following questions are of special interest: How much is spatial development influenced by accessibility. Does this influence vary over time and space? The timeframe of the analysis ranges from 1950 to the year 2000, we focus, as discussed, on the accessibility by individual transportation (IV) but we compare with public transport network (ÖV) and its resulting accessibility.

Methods used in this project are in a first part simple OLS regression models, which will be extended to hierarchical regression models with implemented two and three level models.

For this project both spatial data series at the municipal level and digital transport network models over an extended time frame (1950-2000) were constructed. The socio-economic data were collected from Swiss censuses and restructured to refer to the year 2000 geographies throughout (Switzerland in 2000 consists of 2896 municipalities which cover the whole territory of the country; in the last five decades more than 300 mergers have taken place). The network models were built by IVT, ETH Zürich (see Fröhlich, Frey, Reubi and Schiedt, 2003 and Tschopp, Frey, Reubi, Keller and Axhausen, 2003).

Accessibility is defined as in Geurs and Ritsema van Eck, 2001:

“...the extent to which the land-use transport system enables [groups of] individuals or goods to reach activities or destinations by means of a [combination of] transport mode[s].”

In other words accessibility gives an answer for the question: What can be reached and how much effort is necessary to get there? We can measure accessibility as:

$$A_i = \sum_j O_j f(C_{ij})$$

where

A_j	is the accessibility at point *i*
O_j	is the number of opportunities at point *j*
$f(C_{ij})$	= exp ($-ß * c_{ij}$), where $ß$ is the distance weight, c_{ij} travel time (generalised costs) between municipality *i* and municipality *j*

2 Estimations with OLS Regression models

In a first attempt the analysis of the impacts that transport infrastructure has on spatial development is made globally which means that Switzerland with all its 2896 municipalities as an entire country is examined. The methods used are multiple linear regressions.

For assigning the relevant influences and for excluding irrelevant variables the method of stepwise forward regression is chosen (Bender und Hoffmann, 2003): First all regressions between dependant and independent variables are calculated. Stepwise regression starts with one independent variable and adds step by step one more explaining variable. The variable with the highest correlation coefficient will be added first. The second implemented variable is the one with the second largest correlation coefficient and so on. A partial F-test decides over the intake of further variables. When a variable is not successful in improving the goodness of a model it will not be taken into the calculation. Thus the stepwise forward regression excludes all potential independent variables which do not affect the dependant variable by a given significance level.

As depending variables analysed is spatial development, here operationalised by population development. As independent variables serves variables of accessibility development, divided into total accessibility and accessibility of population. The modelling is made for accessibility for the networks for public (EÖV) and individual transport (EIV). Implemented are furthermore developments of spatial variables of the present (t) and the preceding decade (t-1), such as population development (BEV) and working places divided into the sectors 2 and 3 (AB2 and AB3).

2.1 Empirical results

In a first step the question of spatial relevance of how and to what extent accessibility comparing to other influencing factors is of interest. Spatially relevant means in this special case the influence on population. Thus population development is taken as depending variable in this first model. Independent variables are development of working places of the sector 2 and 3 for both the present and the preceding decade, as well as population development of the preceding time period. Table 1 gives an overview.

Table 1 Overview of the variables in the global model

Period (decade)		← t-1 →	← t →
Dependent variable	Population development		Δ BEV $_i$
Independent variable	Population development	Δ BEV $_{t-1}$	
	Work place development (sector 2)	Δ AB2 $_{t-1}$	Δ AB2 $_t$
	Work place development (sector 3)	Δ AB3 $_{t-1}$	Δ AB3 $_t$
	Accessibility development IV	Δ EIV $_{t-1}$	Δ EIV $_t$
	Accessibility development ÖV	Δ EÖV $_{t-1}$	Δ EÖV $_t$

t Observed decade; t = 1950-1960, 1960-1970, 1970-1980, 1980-1990, 1990-2000

In the following model 9 independent variables from two following decades are implemented. In this manner 4 models between 1950 and 2000 were estimated.

Tables 2 and 3 summarise the results of the stepwise forward regressions. In the decade t (1960-1970) population development is depending on eight of the tested variables. The variables with the highest impact are accessibility development of public transport of time period t, accessibility development of individual transport of time period t, as well as population development in time period t-1 (1950-1960). Those variables show the highest t statistics. However the variable accessibility development of the time period t-1 was excluded, the variables of individual transport for time period t-1 as well as working places of sector 2 for time period t are influencing the model negatively. For comparison reasons the model discussed is confronted with a similar one but closer to the present (here t stands for the 1990-2000 decade, t-1 for the 1980-1990 decade, see table 3). Again eight variables are accepted. The variables with the highest impacts are again accessibility development of public transport for the time period t, accessibility development for individual transport for the time period t as well as population development for the time period t-1. Excluded is the variable for working places for the sector 2 for time period t. Comparing with the first model this model show a distinct lower adjusted sum of squares of 0.292 what indicates that the goodness of the model has fallen considerably.

Table 2 Explanation of population development by all independent variables included (t = 1960-1970)

variables:		coefficients	t statistics	
constant		0.163	1.304	
Δ EÖV$_t$		0.662	43.433	
Δ BEV$_{t-1}$		0.248	14.696	
Δ AB3$_t$		0.047	7.283	
Δ EIV$_t$		0.122	8.191	
Δ EIV$_{t-1}$		-0.162	-5.677	
Δ AB2$_{t-1}$		0.040	5.818	
Δ AB2$_t$		-0.029	-6.163	
Δ AB3$_{t-1}$		0.026	2.618	
excluded variables: Δ EÖV$_{t-1}$				
ANOVA:	degrees of freedoms	mean sum of squares	F	sig
regression	8	11.905	743.089	0.000
residuals	2639	0.016		
total	2647			
regression statistics:				
adjusted sum of squares:	0.692	standard error:	0.127	

Table 3 Explanation of population development by all independent variables included (t = 1990-2000)

variables:		coefficients	t statistic	
constant		1.156	8.220	
Δ EÖV$_t$		0.221	19.904	
Δ BEV$_{t-1}$		0.092	5.216	
Δ AB3$_t$		0.016	3.475	
Δ EIV$_t$		0.228	9.349	
Δ EIV$_{t-1}$		0.077	4.409	
Δ AB2$_{t-1}$		0.025	4.258	
Δ AB3$_{t-1}$		0.042	3.658	
Δ EÖV$_{t-1}$		0.054	3.305	
excluded variables: Δ AB2$_t$				
ANOVA:	degrees of freedom	mean sum of squares	F	sig
regression	8	1.3	138.111	0.000
residuals	2653	0.009		
total	2661			
regression statistics:				
adjusted sum of squares:	0.292	standard error:	0.097	

According to the models in tables 2 and 3 similar models for all other decades between 1950 and 2000 were estimated. For summarising in table 4 all the explaining variables representing accessibility are listed. Two variables of public transport accessibility of time periods t-1 were not integrated into the models. Of interest is the large difference between the influence of individual transport and public transport in time period t, which will be discussed further down. The strength of the coherences between public transport accessibility of time period t and the dependent variables is declining consistently over time whereas a similar a trend can not be seen for the influence that public transport accessibility has on population development. Furthermore it is difficult to make conclusions to the variables of time periods t-1. The overall goodness of fit of the models (adjusted sum of squares) is also declining consistently over time towards present.

Table 4 Influence of accessibility of all models and goodness of models

Period (decade)	Δ EIV_t	Δ EIV_{t-1}	Δ $EÖV_t$	Δ $EÖV_{t-1}$	Adj. R Square
1960-1970	0.122	-0.162	0.662	excl.	0.692
1970-1980	0.041	0.099	0.659	excl.	0.594
1980-1990	0.136	0.070	0.514	0.147	0.441
1990-2000	0.228	0.070	0.221	0.054	0.292

Until now different variables were estimated on its influence on population in the global model. These models were able to detect impacts differing over time. The regression of the forward stepwise regression detects for all models total accessibility of public transport, total accessibility of individual transport (each in time period t), as well as population development in period t-1 for explaining as independent variables for population development in time period t as the most influencing in explaining land use development. These results encourage in focussing on accessibility as a landscape influencing variable in multilevel models as described in the following chapters.

3 Hierarchical regression models

In this second part the analysis will be extended with a spatial component whereas Switzerland will be divided by its political hierarchies to respond to the geographical relevance of the question raised. There is a variety of statistical applications for geographical data (see Tschopp, 2004). This work relies on the approach of multilevel modelling. It enables to find out where the impacts are how strong.

First the multilevel approach will be described and first estimations will be commented. In a second phase the models are extended by the component time.

3.1 Theoretical approach

Multilevel modelling tries to combine an individual level representing disaggregate behaviour with a macro-level model representing contextual (in our case: spatial) variations in behaviour. The point of multilevel modelling is that a statistical model should explicitly recognise a hierarchical structure where one is present (Fotheringham, 2000). By focusing attention on the levels of hierarchy in a dataset, multilevel modelling enables the researcher to understand where and how (and later: when) effects are occurring.

This approach has obvious appeal in our case, as the municipalities are grouped in cantons or can be classified by the location relative to the major centres. The formulation of the multilevel regression model is:

One often described multilevel model is the two level model. For an example one could imagine data of municipalities, which are embedded in Cantons (this model outline is used in the following). The model on the first level gives the relation of the data of each single municipality. The model on the second level in contrary describes the influence of the factors on a cantonal level. $i = 1,...,n_j$ are level 1 units (municipalities), which are allocated to $j = 1,...,J$ level 2 units (Cantons).

$y_{ij} = \beta_{0ij} x_0 + \beta_{1j} x_{1ij}$

where:

$$\beta_{0ij} = \overbrace{\beta_0}^{\text{fixed part}} + \overbrace{u_{0j} + e_{0ij}}^{\text{random part}}$$

and

$$\beta_{1ij} = \overbrace{\beta_1}^{\text{fixed part}} + \overbrace{u_{1j} + e_{1ij}}^{\text{random part}}$$

where:

y	relative population growth
$\beta_{0,1}$	parameter
x_0	constant
x_1	absolute change of accessibility
u	residual (departure of the *j*-th Canton's intercept (slope respectively) from the overall value)
e	residual (departure of the *i*-th municipality's actual score from the predicted score)
i	level 1 (municipality)
j	level 2 (Canton)

In effect instead of calculating one regression line 23 regression lines are calculated, one for each Canton. The models were estimated using MLwiN (Rasbash, Browne, Goldstein, Yang, Plewis, Healy and Woodhouse, 2000)

3.2 Hierarchical model estimations

Looking at the entire country in chapter 2 we noticed a strong link between accessibility and population growth. Nevertheless there are big differences between the Cantons concerning its impacts on the one hand and there seems to be differences in the strength of explanation over time.

In a first multilevel modelling attempt population change between 1950 and 2000 is explained by the change in accessibility in the same time span (see Figure 1). If we focus on the regression results an obvious pattern of intercepts and slopes can be seen. The intercepts of four Cantons (dark) are significantly above the average of all 23 Cantons, while five Cantons have a significant steeper slope (light). Interestingly the Cantons with steep slopes have small intercepts and vice versa. See figure 2 for the locations of these two groups: one urban group which is red dyed (Basle, Geneva and Zürich plus suburban Aargau) and another light blue dyed group with Cantons, covering the peripheral areas in the Alps and the Jura mountains (Graubünden, Glarus, Ticino, Wallis/Valais and Jura). For the urban areas there is not much evidence that accessibility change is associated with strong population growth. In rural and alpine areas the situation is completely different: Starting at a lower level, further accessibility growth is strongly associated with healthy population growth

Figure 1 Hierarchical model: regression and residuals different Cantons

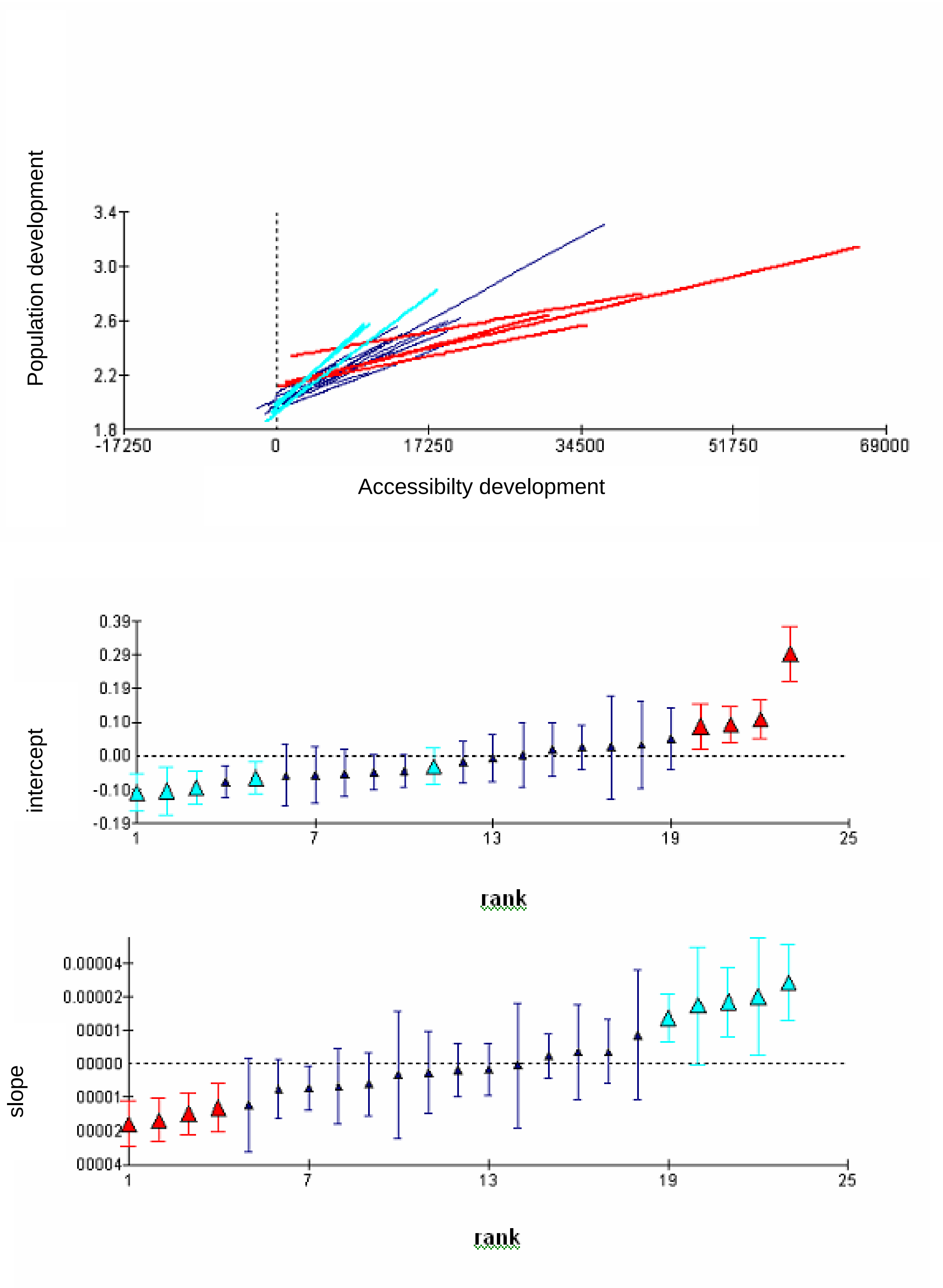
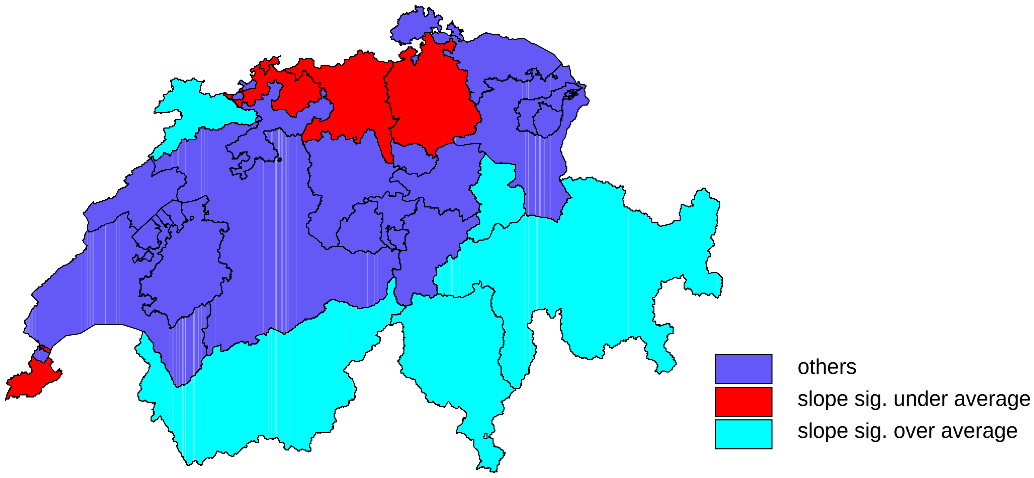


Figure 2 Hierarchical model: regression and residuals Cantons



3.3 Including time – a three level model

The two level hierarchical models seen in 3.2 are now extended by the component time for finding out when are the observed coherences between accessibility and spatial development how strong and if they underlie a trend. For this a third hierarchical level is implemented which consists not of geographical but time units. This model has the ability to analyse the panel data available (fine spatial allocation over different points in time) in all its depth.

The model described here varies from those models concerning its configuration. The third level stands for a temporal instead of a spatial grouping of the data. Additionally to a geographical grouping according to the Cantons the data of each municipality is nested into different periods of time (here decades). The independent variable in this model is the relative population development, independent variables are relative accessibility developments for public and individual transport (according to the global OLS models) for each decade. For all municipalities therefore the dependant variable was confronted with the independent variables five times (once for each decade). Thus the models are consisting now of 14450 municipalities (2890 for each decade). In this manner the model gives an answer on how the coherences of the variables in the model vary over time and space and to what extent this variation is significant.

Table 5 Impacts of total accessibility of individual and public transport on population development in a three level model

Δ BEV = $ß_{0ijk}$ cons + $ß_{1ijk}$ Δ EIV$_{ijk}$ + $ß_{2ijk}$ Δ EÖV$_{ijk}$

fixed part

Predictor	coefficient	Standard Error
$ß_{0ijk}$	0.094	0.024
$ß_{1ijk}$	0.549	0.070
$ß_{2ijk}$	0.497	0.089

random part

deviance (variance) third level (decade)		
v_{0k}	0.000	0.000
v_{1k}	0.011	0.016
v_{2k}	0.036	0.025
deviance (variance) second level (Canton)		
u_{0jk}	0.043	0.008
u_{1jk}	0.159	0.036
u_{2jk}	0.039	0.011
deviance (variance) first level (municipality)		
e_{0ijk}	0.568	0.009
e_{1ijk}	0.525	0.042
e_{1ijk}	0.172	0.016
log likelihood	36582.98	

The three level model (table 5) shows, not surprisingly, that the coefficients are positive and significant, thus accessibility development for public and individual transport has a positive impact on population development, as seen before. The values of the coefficients are comparable with the global models in chapter 2. The results of this kind of hierarchical regression models are well corresponding with those previous results and are plausible.

For the deviance over time the random part gives for the variable accessibility for individual transport a variance of 0.011, however with a standard error of 0.016 it is not significant. Also public transport with a variance of 0.036 and a standard error of 0.025 is not significant on a 5 percent confidence interval. The variances for the other two levels are significant for each variable.

Figure 3 Residuals for the variables for public and individual transport for the different decades (third level)

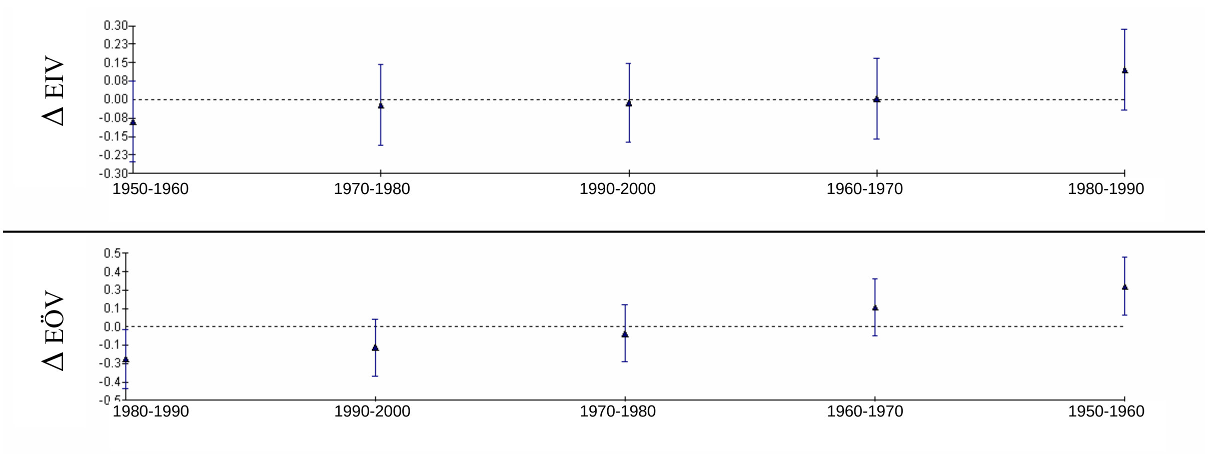
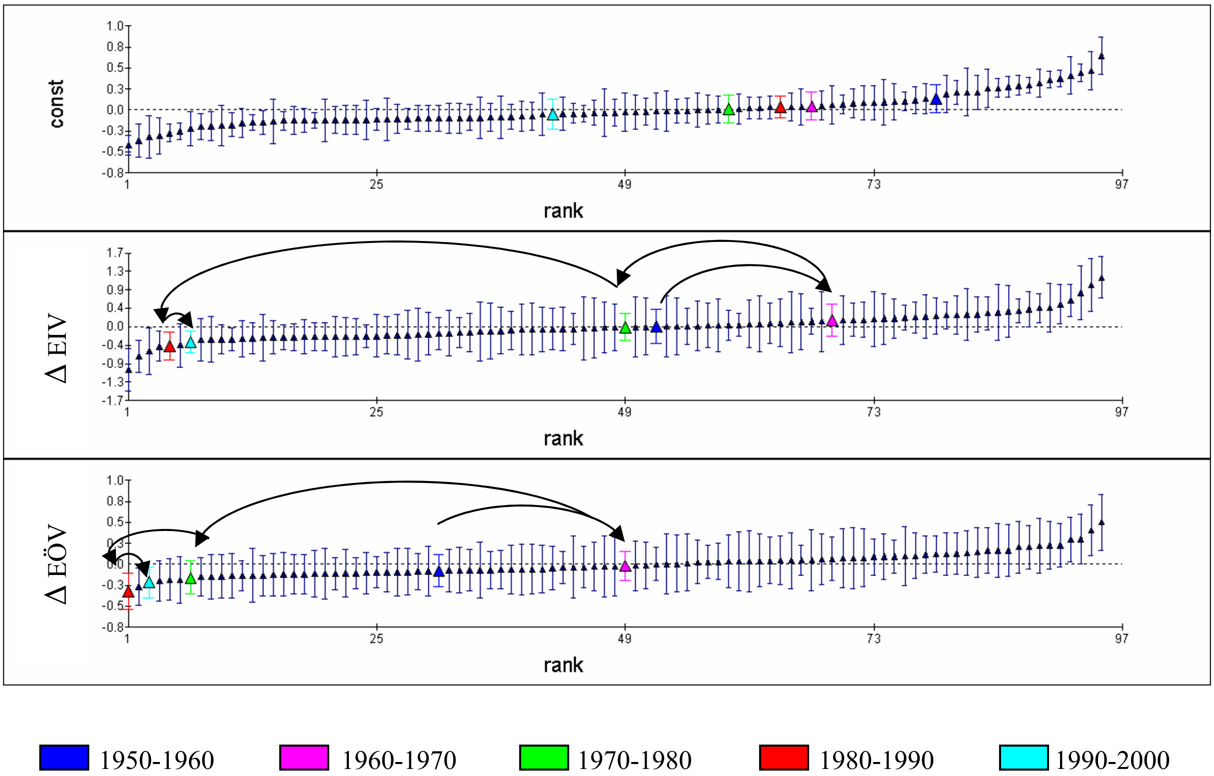


Figure 3 describes the random part of the third level of the model, the decades over time. The dots show the deviance from the fixed part of the model for every decade. Indicated is also the confidence interval. This figure indicates how the different decades are departing from the overall average represented by the dashed line. For the explaining variable individual transport accessibility no clear trend can be seen, whereas for the explaining variable public transport a clear trend from over average to under average can be observed. Over the decades the parameter of this variable is constantly declining.

In Figure 4, in analogy to Figure 3, the second level residuals for the same model can be seen. It describes the deviance for each single Canton from the overall average. In contrast to the simple two level hierarchical regression, here as explained above, every Canton appears five times, once in every decade included in the model.

Figure 4 Canton Zürich residuals (second level)

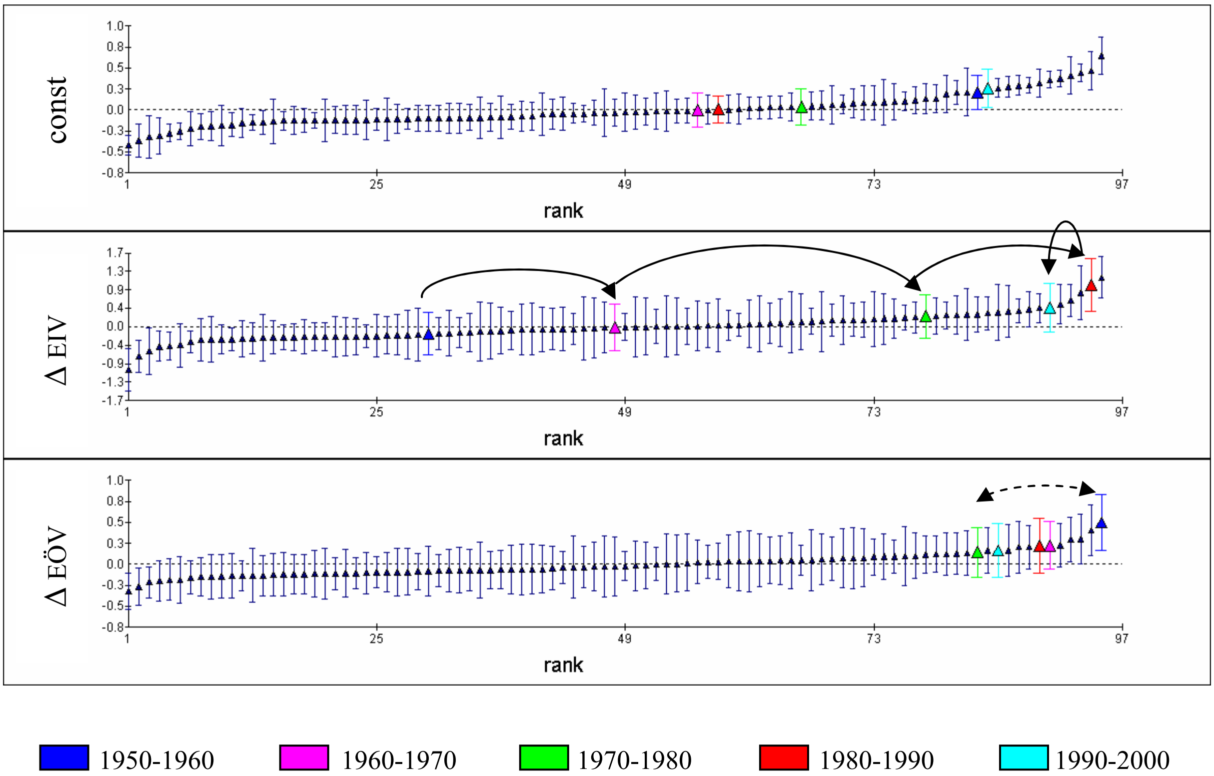


The display of the residuals on this second level of the hierarchical model enables to trace the development of the residuals of each Canton during time. Thus it is possible to find typical patterns for the development of the residuals for different types of Cantons. At first the Canton Zurich, an urban and highly industrialised Canton is on focus. The residuals are developing out of the midfield towards the higher ranks for declining continuously during the time period between 1970 and 1980 towards the period 1980-1990 and to level off on a low level towards the present. The same development can be stated for the residuals for the variable for public transport with a less high deflection though.

Comparing with the rural and alpine Canton Graubünden (figure 5) a completely contrary trend line can be stated. The explaining accessibility variable for individual transport is gaining importance consistently, whereas the explaining accessibility variable for public transport remains throughout the time span observed on a very high level.

Rural and urban Cantons seem to show completely different development patterns concerning the influence of accessibility on land use.

Figure 5 Canton Graubünden residuals (second level)



4 Conclusion

Coming from an ordinary least square regression, over a two level- we came to a three level hierarchical regression model which is able to analyse the whole bandwidth of panel data and to detect spatial and temporal variations which can not be seen in OLS models.

Nevertheless OLS regressions as well as more sophisticated two and three level hierarchical regressions show similar results. In urban, densely settled areas the influence of accessibility in explaining land use development is declining over time. In areas with high accessibility other variables as housing prices as well as general crowding-out effects are more important. In alpine areas similar effects can not be seen. In those rural regions spatial development still seems to be connected strongly with accessibility gains. The development of the population in space and time in the urban agglomerations in Switzerland is characterised by a continuous dispersion during the last five decades. Connected to this development is a big amount of land consumption, an increase of distances covered, spatial dispersion of traffic, and thus an increase of motorised individual traffic.

The mobility of people, the reduced impedance of space in the Swiss Mittelland led to more interactions. The short distances in Switzerland, the federal structures expedite those trends and led to an abolishment of the former division of town and countryside.

The paper reports for Switzerland the development of transport infrastructure and therefore accessibility and socio-economic variables consistent with a high spatial resolution and over a long span of time. Nevertheless the present work is only the beginning, as the causal relations between accessibility and spatial organisation are not trivial[1]. Useful models should be able to separate the following:

- The calculation of accessibility requires an estimate of the generalised cost of travel. Is the development of travel time or the development of travel costs (e. g. gas prices, car prices) more suitable to explain spatial development?

[1] See for example Aschauer, 1989; Banister and Berechman, 2000; Boarnet and Haughwout, 2000; Bökemann and Kramar, 2000; Kesselring, Halbherr and Maggi, 1982; Lutter, 1980; Seimetz, 1987; Vickerman, 1991).

- If accessibility follows the spatial and economical development or is the causal relation is reverse? Can both effects occur? Are they synchronous or time lagged?

- What influence have other variables (e. g. starting conditions of a region, structural changes of the economy, competition situation on the world market, amount of taxes, subsidies etc.)?

- What impacts has the vicinity in time and space on the developments of neighbouring settlements? (In modelling term: what impacts have spatial and temporal (error) correlations?)

5 Acknowledgements

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