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ABSTRACT

This paper focuses on the impact of transport infrastructure on the population change 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 be a measure of the spatial impact of newly-built transport infrastructure and it can enhance the attractiveness of a region's location. A suitable approach for measuring the spatial impact of accessibility is the quantitative method of growth modeling, which accounts for spatial correlation by using OLS models, OLS models corrected for spatial correlations, and multilevel growth models. Multilevel growth models combine an individual level, which represents disaggregate behavior, with a contextual macro level. The following questions were investigated: Where did accessibility change occur, when and how did these changes take place, and to what extent did accessibility change influence spatial development? First results indicate that the influence of accessibility on spatial development differs considerably over time and space: its strength declines the more developed a region becomes and the closer it approaches the present.

MOTIVATION

Transport systems have been built primarily to expand the reach of both people and industry. Frey (1979) pointed out that, “The main goal of transport infrastructure explicitly is to provide people and [the] economy with public goods.” According to Frey, infrastructure, and especially transport infrastructure, has spatial impact and is thus an important instrument of regional policy. Lendi and Elsasser (1985) were 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.” Kesselring, Halbherr and Maggi (1992) also argued 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 (see Banister 2000; Aschauer 1989).The link between accessibility improvement and economic and population growth, or at least change, is a key tenet of regional policy, even when it is acknowledged that networks are only a sufficient and not a necessary condition for growth.

Compare, for example, figure 1a, which depicts the waves of population growth by distance from the center of Zürich, with figure 1b, which shows the same waves by travel-time distance (on the road). Without an understanding of transport-system change, one would misinterpret the patterns.

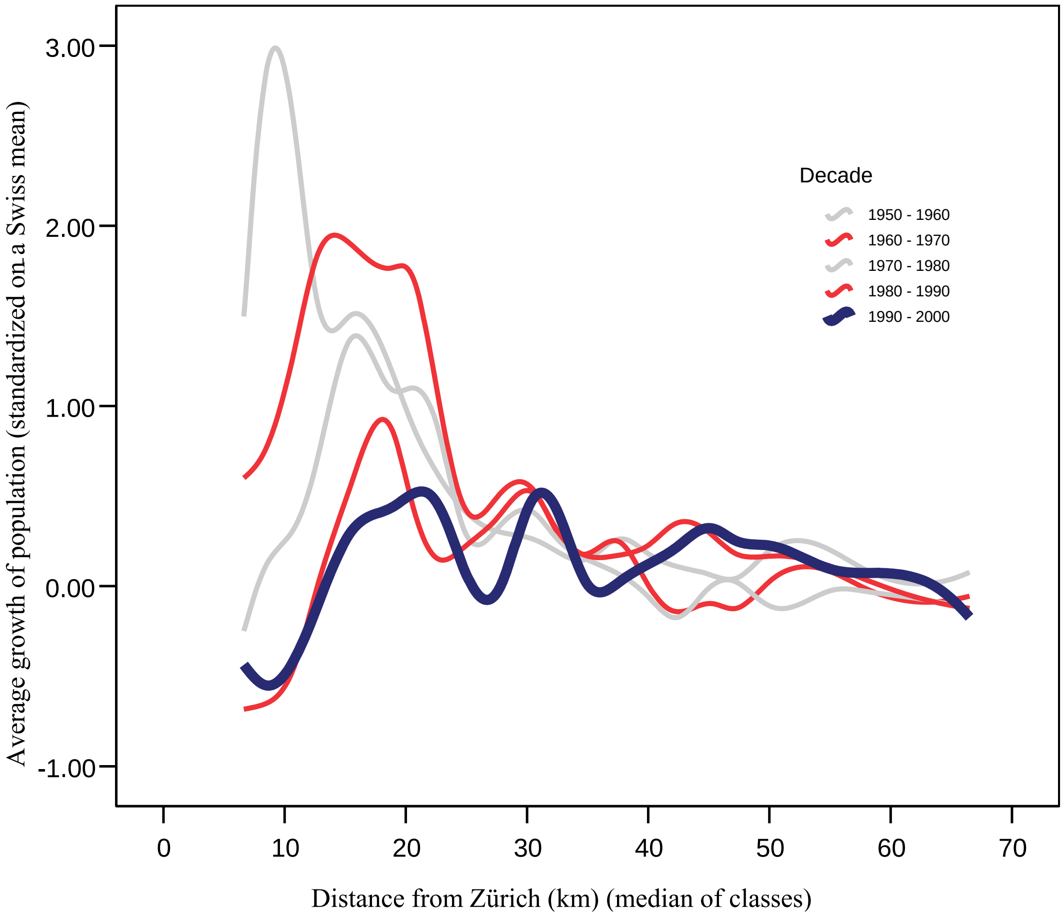

Figure 1a Population development in the Zürich area by distance over decades

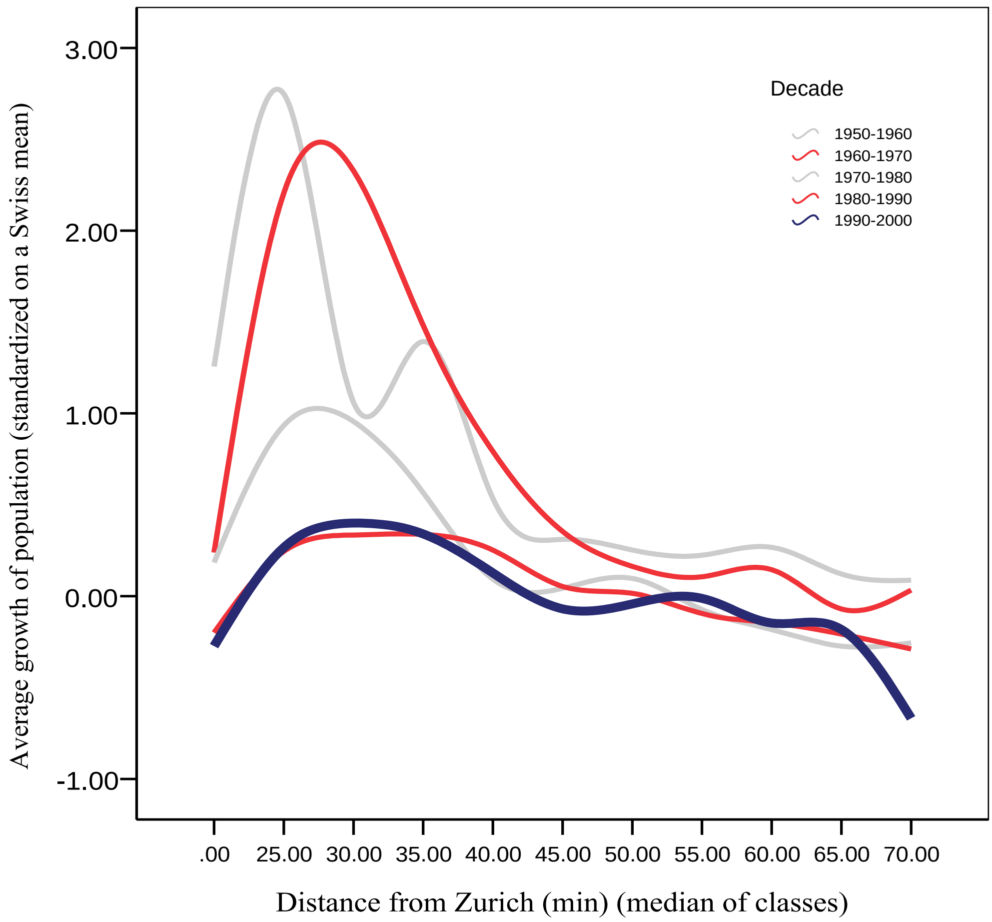

Figure 1b **Population development in the Zürich area by travel distance over decades**

A value of zero corresponds to the respective average decennial growth rate of Swiss municipalities. A value of one corresponds to a growth rate of plus one standard deviation of the distribution of the growth rates. The values were averaged over 5-km intervals. The front of growth has gradually spread out over time. In the years between 1950 and 1960 it was about 10 km away from the city center, whereas at present it is located about 45 km from downtown Zürich. Subcenters such as Winterthur or Bülach, which are about 30 km from Zürich, have their own dynamics. Although the waves of highest population growth have spread away from the center in spatial distance over the decades, the travel time has remained constant.

One way to measure the effects of infrastructure investment is to measure the change in *accessibility*. This allows us to disregard physical distances and to concentrate on the different levels of transport-system service available at a particular location. Accessibility is the product of the opportunities which can be reached from a certain location and the effort required to reach them. While the railroad network has only been improved in a few matters of detail over the last decades (including track extensions and improved tracks for higher average speeds), the construction of motorways has been the main motor of accessibility change. Therefore, this paper will concentrate primarily on the development of the motorway network.

Previous empirical work trying to link accessibility and population or employment change has often involved the approach of production-function modeling (see, for example, Aschauer 1989; Fernald 1998; Munnell 1990; Nadiri 1998; Shirley and Winston 2004). In most of these models the relationship between transportation-infrastructure development (infrastructure spending) and labor productivity or economic growth has been estimated. According to a summary by Banister (2000), the elasticity of those models ranges between 0 and 0.4. Elasticity decreases the more developed the study area becomes and the closer the study approaches the present. Holtz-Eakin confirmed these findings in his 1994 study of an aggregated level, but he did not find any significant impact of infrastructure investments on productivity gains in a more sophisticated model in which he included characteristics of federal US states. However, most such studies suffer from some shortcomings: the use of large spatial units, such as US states or UK counties; the reliance on short study periods, typically ten to twenty years; the omission of railway services, and finally, as previously mentioned, in many cases the approximation of the services of the transport system by the value of the local or regional public capital stock.

In this paper we seek to overcome these limitations by means of a unique Swiss data set. The timeframe of the analysis ranges from 1950 to 2000. Each of about 3,000 Swiss municipalities has been identified. We shall focus on accessibility by road, but shall compare this with public-transport accessibility. The socio-economic data were collected from Swiss censuses and restructured to refer to the year 2000 geographies throughout (Switzerland in the year 2000 consisted of 2896 municipalities which covered the whole territory of the country; in the last five decades more than 300 mergers have taken place; see Fröhlich et al. 2003; Tschopp et al. 2003). The corresponding network models were built by IVT, ETH Zürich (Axhausen, Fröhlich, and Tschopp 2006).

The methods used in this project were at first simple OLS-regression models which were corrected for spatial correlations by extending them to spatial-autoregressive and spatial-error models. Those models were completed with two- and three-level hierarchical regression models.

The preferred localized measure of road-network service is accessibility (Rietveld and Bruinsma 1998; Geurs and Ritsema van Eck 2001).

$$A_i = \ln \sum\nolimits_{\forall j} X_j f(c_{ij}),$$

where

A_j : the accessibility of location i;

X_j : the number of opportunities at location j, here the number of residents;

Cij : the generalized costs of travel between locations i and j, here travel time;

f( ) : the weighting function for the generalized costs of travel, here: $e^{-\lambda c_{ij}}$; and

λ : the parameter set to 0.2 in line with Schilling’s 1973 estimate.

This formulation can be shown to be an exact measure of consumer surplus (rent) in a destination and mode- or route-choice context (Williams 1977; Ben-Akiva and Lerman 1985) and therefore of the service offered by the road or public transport system. This formulation already highlights that the distribution of spatial opportunities and markets is essential to the service of the road network.

ESTIMATIONS WITH OLS-REGRESSION MODELS

In a first step the influence of accessibility change is tested by using a global linear regression of the decennial change in population for each of the 2,896 Swiss municipalities. The method of stepwise forward regression was chosen to exclude irrelevant variables (Bender and Hoffmann 2003). First, all regressions between dependant and independent variables were calculated. Stepwise regression starts with one independent variable and adds, step by step, one more explaining variable at a time. The variable with the highest correlation coefficient is added first. The second implemented variable is the one with the second largest correlation coefficient, and so on. A partial F-test determines the intake of further variables. If a variable does not significantly improve the goodness of a model, it will not be taken into the calculation. Thus, the stepwise forward regression method excludes all potential independent variables which do not affect the dependant variable by a given significance level.

The available independent variables were: the change of accessibility for the population as calculated for travel on the public transport system (ACT)ransit and on the road network (ACR)oad. The public-transport-network travel times were based on the relevant summer timetables of all the railway systems and of the important regional bus services. In addition, the lagged change in the population and the workplaces, distinguished between the second (industrial) and tertiary sectors (service sector), was available.

The four models for 1960/70, 1970/80, 1980/90 and 1990/2000 include the following (table 1):

Period (decade)		← t-1 →	← t →
Dependent variable	Population change		Δ BEV $_{i}$
Independent variables	Population change	Δ BEV $_{t-1}$	
	Employment change (sector 2)	Δ AB2 $_{t-1}$	Δ AB2 $_{t}$
	Employment change (sector 3)	Δ AB3 $_{t-1}$	Δ AB3 $_{t}$
	Accessibility change IV	Δ ACR $_{t-1}$	Δ ACR $_{t}$
	Accessibility change ÖV	Δ ACT $_{t-1}$	Δ ACT $_{t}$

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

Table 1 Overview of the variables in the global model

Tables 2 and 3 summarize the results of the stepwise forward regressions. In the decade t (1960-1970), population change depended on eight of the tested variables. The variables with the highest impact were: accessibility change of public transport for the time period t; accessibility change of individual transport for the time period t; as well as population change during the time period t-1 (1950-1960). Those variables also show the highest t statistics. However, the variable transit accessibility change for the time period t-1 was excluded, and the road accessibility for time period t-1 as well as the workplace change variable in sector 2 for time period t influenced the population change negatively. For the sake of comparison, the model discussed was confronted with a similar one for the period of 1990-2000. As before, eight variables were accepted. The variables with the highest impact again included: accessibility change of public transport for the time period t; accessibility change of individual transport for the time period t; as well as population change during the time period t-1. The change in workplaces for the sector 2 of the time period t was excluded. Compared with the first model, this model shows a distinctly lower adjusted sum of squares of 0.292, which indicates that the goodness of the model has fallen considerably.

t = 1960-1970

Variables:	Coefficients	t-statistics
Constant	0.163	1.304
Δ ACT_t	0.662	43.433
Δ BEV_{t-1}	0.248	14.696
Δ $AB3_t$	0.047	7.283
Δ ACR_t	0.122	8.191
Δ ACR_{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 ACT_{t-1}

F	sig
743.089	0.000

Regression statistics:

Adjusted sum of squares: 0.692 Standard error: 0.127

t = 1990-2000

Variables:	Coefficients	t-statistics
Constant	1.156	8.220
Δ ACT_t	0.221	19.904
Δ BEV_{t-1}	0.092	5.216
Δ $AB3_t$	0.016	3.475
Δ ACR_t	0.228	9.349
Δ ACR_{t-1}	0.077	4.409
Δ $AB2_{t-1}$	0.025	4.258
Δ $AB3_{t-1}$	0.042	3.658
Δ ACT_{t-1}	0.054	3.305

Excluded variables: Δ $AB2_t$

F	sig
138.111	0.000

Regression statistics:

Adjusted sum of squares: 0.292 Standard error: 0.097

Table 2 Explanation of population change by all independent variables included (1960-1970 and 1990-2000)

Table 3 compares the parameter estimates for accessibility change from all four models. The lagged-transit accessibility change was insignificant twice. Of interest is the large difference between the influence of road transport and public transport during the time period t, which will be discussed later. The strength of the influence of public-transport accessibility has declined consistently over time, whereas a similar trend can not be determined for road-transport accessibility. Furthermore, it is difficult to identify trends in the lagged variables. The overall goodness of fit of the models (the adjusted sum of squares) has also declined consistently over time towards the present.

Period (decade)	Δ ACR$_t$	Δ ACR$_{t-1}$	Δ ACT$_t$	Δ ACT$_{t-1}$	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

Table 3 Influence of accessibility of all models and integrity of the models

Spatial-error component of the OLS models

Given the network-induced accessibility change, it is likely that there are spatial autocorrelations which are further strengthened by the taxation and policy differences between the cantons, or regional governments of Switzerland. The OLS models can be corrected for spatial correlations by adding contiguity information to the model. The goal of spatial analysis is to explicitly account for correlations by fitting a parameter to the residuals or to the lagged independent variable of other contiguous observation in the data set. This paper uses LeSage's (2004) terminology. The spatial-error model (SEM) corrects for the spatial correlation of the error terms and is analogous to stationary correlated errors in time series data. The models were estimated using the MATLAB library according to LeSage (2005).

$$y = \beta X + u \,,$$

where $u = \lambda W_e u + \varepsilon \quad , \varepsilon \sim N(0, \sigma)$.

In the SEM model, the parameter λ corrects for spatially-correlated errors, whereby the neighbors are related to each other in Euclidean distances (direct airline distance) from one centroid of a municipality to another. The estimation of different models showed that the best overall goodness of fit (best R^2) could be achieved by including eight neighbors (eight municipalities) into the SEM model estimation. Those SEM-parameter estimates for 1990-2000 do not vary considerably from the OLS models; the accessibility variables again had the strongest impact. Nevertheless, there are some differences. The parameter for the public transport variable is constantly lower over the decades in the SEM model than in the OLS model. The SEM model estimations are considerably better than the normal OLS regressions, and the existence of residual spatial error is proved by a significant SEM parameter (see table 4); therefore, spatial varieties are existent.

		OLS Model			SEM (8 neighbors)		
Year	Variable	Parameter	Sig.	R^2	Parameter	z. prob.	R^2
1950-1960				0.261			0.383
	constant	0.000	0.994		0.190	0.563	
	$\Delta AB2_t$	-0.400	0.019		-0.025	0.105	
	$\Delta AB3_t$	0.127	0.000		0.089	0.000	
	ΔACR_t	0.270	0.000		0.246	0.000	
	ΔACT_t	0.348	0.000		0.267	0.000	
	lambda				0.555	0.000	
1970-1980				0.675			0.715
	constant	0.000	0.991		0.001	0.966	
	$\Delta AB2_t$	0.024	0.024		0.013	0.172	
	$\Delta AB3_t$	0.084	0.000		0.068	0.000	
	ΔACR_t	0.065	0.000		0.082	0.000	
	ΔACT_t	0.779	0.000		0.777	0.000	
	lambda				0.464	0.000	
1990-2000				0.238			0.309
	constant	0.000	0.979		-0.007	0.788	
	$\Delta AB2_t$	0.019	0.241		0.014	0.364	
	$\Delta AB3_t$	0.027	0.108		0.011	0.492	
	ΔACR_t	0.141	0.000		0.150	0.000	
	ΔACT_t	0.439	0.000		0.430	0.000	
	lambda				0.412	0.000	

Table 4 Explaining population change with SEM-model estimates (t = 1990-2000)

HIERARCHICAL REGRESSION MODELS

In this part we shall extend the analysis to include a different treatment of spatial effects: multilevel modeling (see Goldstein 1987; Raudenbush 2002). Multilevel models operate at more than one level or scale simultaneously. This effects a considerable improvement over the usual single-level model by allowing relationships to vary from place to place and according to context (see Jones 1991). Switzerland shall be divided by its political hierarchies to account for differences in policy, taxation, and location. This method, which was initially developed to capture organizational hierarchies, has often been applied to geographical data (see Tschopp 2004). First the multilevel approach will be described. An initial set of estimates will be followed by models which explicitly include time.

Modeling approach

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

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 centers. The formulation of the two-level multilevel regression model is as follows:
The model on the first level captures the structure at the level of each single municipality. The model on the second level, in contrast, describes the influence of the factors on a cantonal level. $i = 1,\ldots,n_j$ are level-1 units (municipalities) which are allocated to $j = 1,\ldots,J$ level-2 units (cantons).

Where:

$$y_{ij} = \underbrace{\beta_{0ij}x_0}_{\text{fixed part}} + \underbrace{\beta_{1j}x_{1ij}}_{\text{random part}}$$

and

$$\beta_{0ij} = \underbrace{\beta_0}_{\text{fixed part}} + \underbrace{u_{0j} + e_{0ij}}_{\text{random part,}}$$

$$\beta_{1ij} = \beta_1 + u_{1j} + e_{1ij}$$

Where:

y = e.g. relative population growth
$\beta_{0,1}$ = parameter
x_0 = constant
x_1 = e.g. absolute change of accessibility
u = residual (departure of the j-th canton's intercept and slope 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 cantons with small numbers of municipalities were grouped as follows: Appenzell Innerrhoden and Ausserrhoden; Basel city and Land; Ob- and Nidwalden). The models were estimated using MLwiN (Rasbash et al. 2000).

Hierarchical model estimations

Looking at the entire country, we noticed a strong link between accessibility and population growth. Nevertheless, there were big differences between the cantons, and there seem to be differences in the strength of the trends over time.

In a first multilevel model, population change between 1950 and 2000 was explained by the change in road accessibility during the same time span (see figure 2). If we focus on the regression results, an obvious pattern of intercepts and slopes can be seen. The intercepts of four cantons (red) are significantly higher than the average of all 23 cantons, while five cantons have a significantly steeper slope (light blue). 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 is marked in red (Basel, Geneva and Zürich plus suburban Aargau), and another light blue group comprises cantons covering the peripheral areas in the Alps and the Jura mountains (Graubünden, Glarus, Ticino, 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.

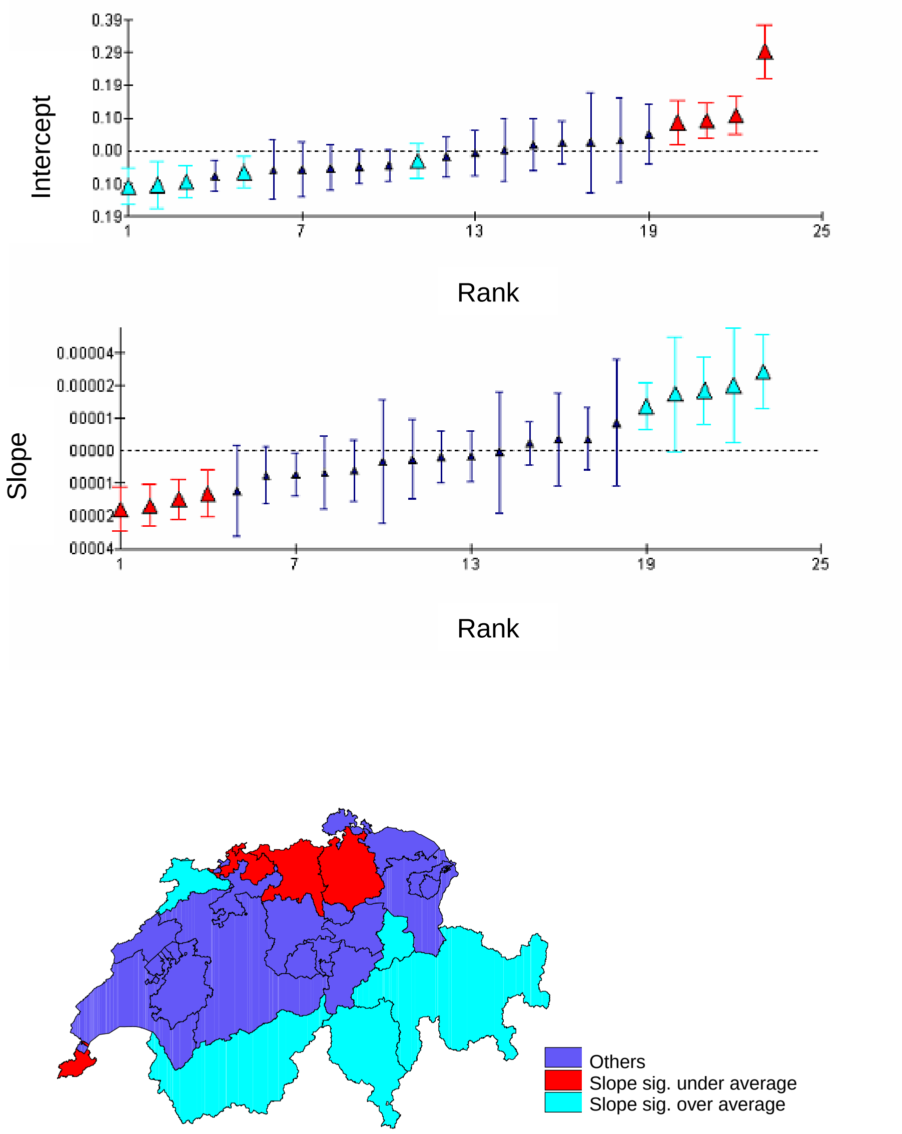

Figure 2 Hierarchical model 1950-2000: Cantonal differences in slope (accessibility impact) and intercept

Including time – a three-level model

The two-level hierarchical models shall now be extended by the time component to find out when there are links between accessibility and spatial change and whether they follow a trend. For this a third hierarchical level is implemented which consists not of geographical, but of time units. This model permits the analysis of the available panel data (fine spatial allocation over different points in time) in all its depth.

The model described here varies from the other models with respect to its configuration: the third level stands for a temporal rather than a spatial grouping of the data. In addition to a geographical grouping by canton, the data of each municipality is nested into different periods of time (here decades). The independent variable in this model is the relative population change, and dependent variables are relative accessibility changes in public and individual transport (according to the global OLS models) for each decade. For all municipalities, therefore, the dependant variable was regressed against the independent variables five times (once for each decade). The models now consist of 14,450 municipalities (2,890 for each decade). In this manner, the model provides an answer to how the variables vary over time and space and to what extent this variation is significant.

$$\Delta \text{ BEV} = \beta_{0ijk} \text{ cons} + \beta_{1ijk} \Delta \text{ ACR}_{ijk} + \beta_{2ijk} \Delta \text{ ACT}_{ijk}$$

Fixed part		
Predictor	Coefficient	Standard error
β_{0ijk}	0.094	0.024
β_{1ijk}	0.549	0.070
β_{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	

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

The three-level model (table 5) shows, not surprisingly, that the coefficients are positive and significant. Thus greater accessibility to public and individual transport has a positive impact on population change, as seen before. The values of the coefficients are comparable to the global models in section 2.
The random part gives for the variable accessibility for individual transport a variance of 0.011 for deviance over time. However, with a standard error of 0.016, it is not significant. The same is true for public transport accessibility with a variance of 0.036 and a standard error of 0.025. The variances for the other two levels are significant for each variable.

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. The confidence interval is also indicated. The dashed line in this figure depicts how the different decades depart from the overall average.

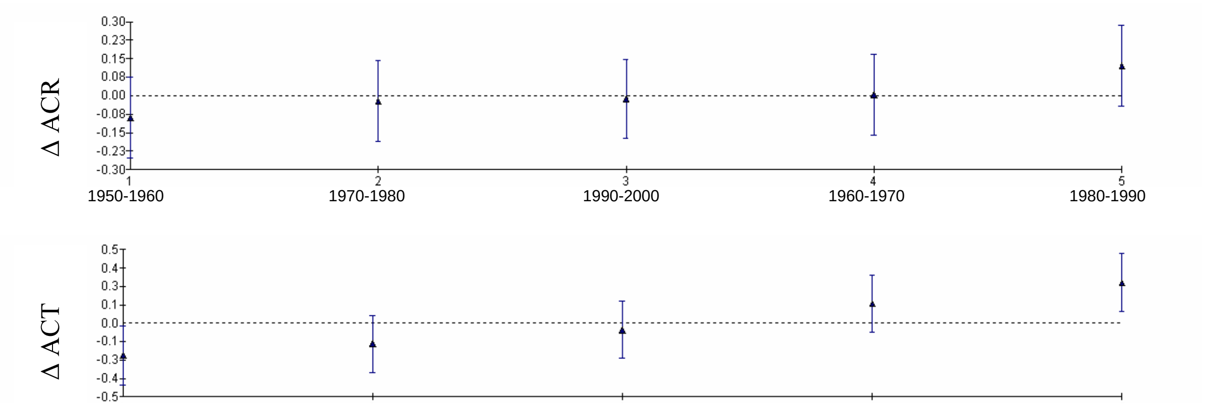

Figure 3 Residuals for variables of public and individual transport for the different decades (third level)

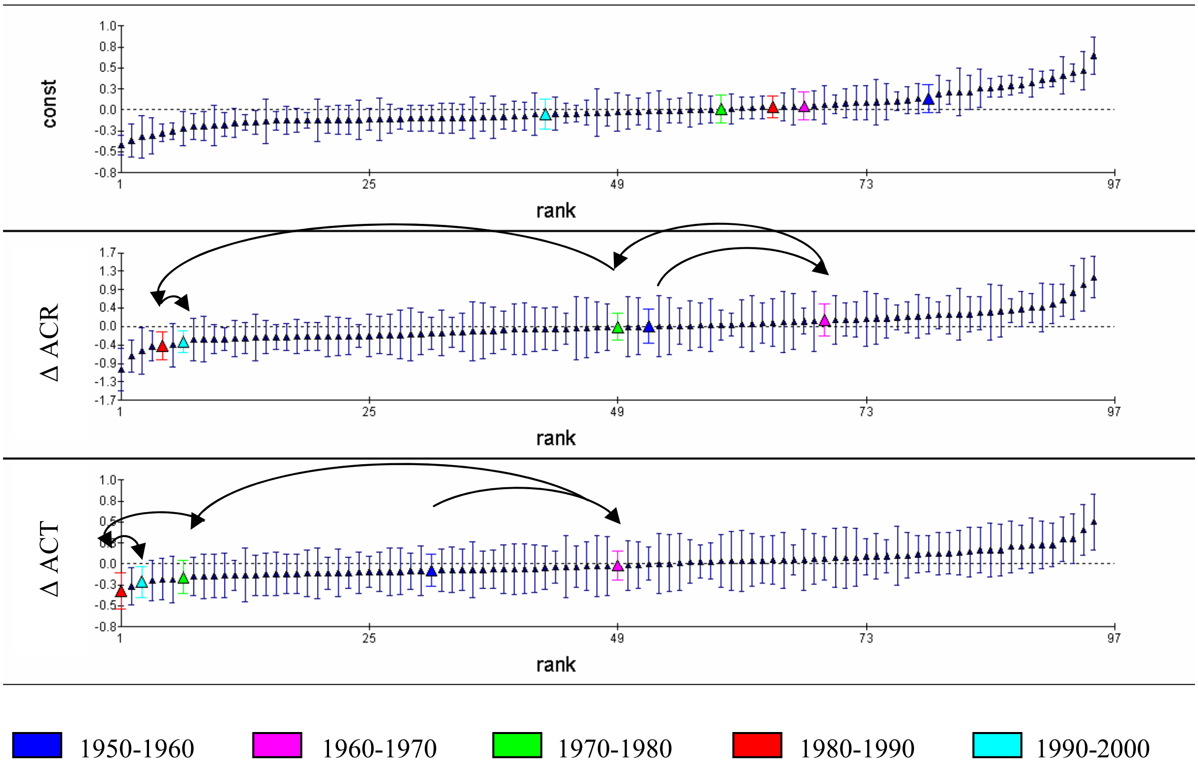

Figure 4 Canton Zürich residuals (second level)

No clear trend can be seen for road accessibility change, whereas a clear trend from above average to under average can be observed for public transport accessibility change. The parameter of this variable has constantly declined over the decades.
Figure 4 depicts the second-level residuals for the same model as in figure 3. It describes the deviance of each individual canton from the overall average. In contrast to the simple two-level hierarchical regression, every canton appears five times, once for every decade included in the model.

The display of the residuals at this second level of the hierarchical model enables us to trace the development of the residuals of each canton over time. It is thus possible to find typical patterns for the development of the residuals for different types of cantons. First the canton of Zürich, which is urban, very densely populated, and highly industrialized, is traced. The residuals developed out of the midfield towards the higher ranks, then declined continuously during the period of 1970-1980 towards the period of 1980-1990, and leveled off on a low

plane approaching the present. The same development can be observed for the residuals for public-transport accessibility, though less pronounced.
In contrast, there was a completely contrary trend in the rural and alpine canton of Graubünden (figure 5). Road-accessibility change consistently gained importance, whereas public transport accessibility change left a high impact throughout the time span observed. Rural and urban cantons show completely different developmental patterns regarding the influence of accessibility on population change.

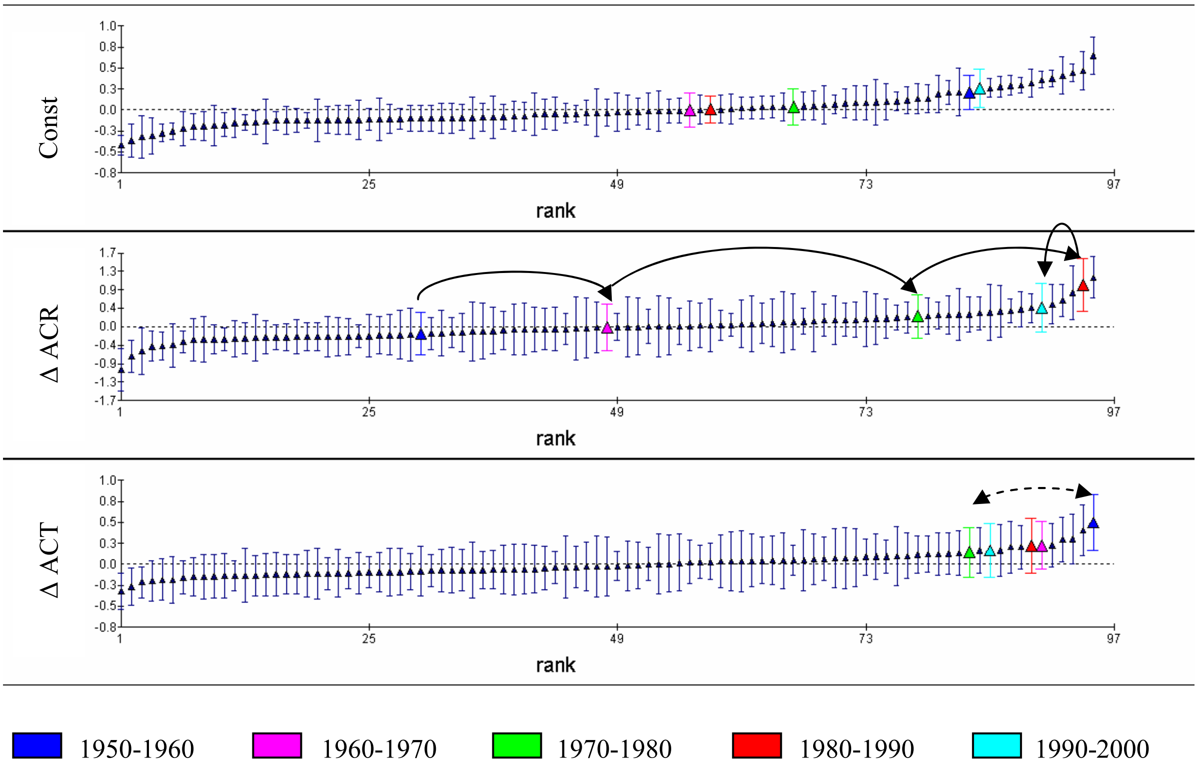

Figure 5 Canton Graubünden residuals (second level)

CONCLUSIONS

Starting with an ordinary least-square regression and then progressing through spatial-error models, we have arrived at a two- and three-level hierarchical regression model with which we can analyze the whole breadth of panel data and detect spatial and temporal variations which cannot be seen in OLS models.
Nevertheless, OLS regressions, SEM models, and more sophisticated two- and three-level hierarchical regressions all show similar results: a decline in both the goodness of fit in the model estimations and in the strength of the influence of accessibility parameters. In urban, densely settled areas the influence of accessibility in explaining population change declines over time. This process can be seen in figure 1: the “wave of suburbanization” which moved away from city centers during the early decades flattened continuously towards the present.
In areas with high accessibility, other variables such as housing prices as well as general crowding-out effects were more important. In alpine areas, similar effects could not be found. In rural regions spatial change still seems to be connected strongly with accessibility gains. Here only municipalities with high (increases of) accessibility values are able to attract both habitants and industry.
The development of the population in space and time in the urban agglomerations in Switzerland is characterized by a continuous dispersion over the last five decades. Connected to this development is a great amount of land consumption, an increase in distances covered, spatial dispersion of traffic, and thus an increase in individual motorized traffic. The mobility of people and the reduced impedance of space in the Swiss Mittelland have led to more interactions. The short distances in Switzerland and the federal structures expedite those trends and have led to an abolishment of the former division between town and countryside.

Our analysis has confirmed the trends reported using less spatially-detailed data over shorter time spans: accessibility gains are losing their power to shape the environment over time (see, e.g., the work of Krugman 1995).

The much larger spatial detail and temporal span of our data has enabled us to show that this trend varies by the starting position of the relevant unit. Further work will be required to disentangle the direction of causality between transport investment and population change, e. g., using structural equation models. Furthermore, it would be interesting to test non-linear transformations of the independent variables employed and to increase the range of variables tested.

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