

Weilenmann, Barbara; Schulz, Tobias

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Socio-economic explanation of urban sprawl: Evidence from Switzerland, 1970-2010

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Socio-economic explanation of urban sprawl: Evidence from Switzerland, 1970-2000

Barbara Weilenmann, WSL*

Tobias Schulz, WSL

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Abstract

This paper aims at analysing the major socio-economic drivers of land use changes towards urbanisation during the time span of 1980 to 2000 in Switzerland. We employ regression modelling of urban sprawl metrics (area of development, dispersion, utilisation density, and – made up of these three metrics – a composite sprawl index) for all 2495 Swiss municipalities, employing explanatory variables gathered and compiled from mostly public surveys and statistics that are available for the entire sample period.

The results of the empirical analysis a) confirm that basically the drivers suggested by the Monocentric City Model are relevant predictors of urban sprawl across time although the analysis is conducted at the municipal level which implies slightly different causal mechanisms than suggested by this theory. Correspondingly, we emphasize the need to differentiate between rural and urban municipalities, particularly since the analysis comprises the entirety of a country's municipalities b) highlight that different (additional) drivers can be identified as being important for different urban sprawl metrics, indicating that solely analysing composite, multi-dimensional indices of urban sprawl runs the risk of missing important insights.

Keywords: land Use, urban sprawl, urbanization drivers, Switzerland

JEL classifications: R14, R52, R58, C12, C30, O18

* Corresponding author. Economics and Social Science Unit. Swiss Federal Institute for Forest, Snow, and Landscape Research, WSL. Zürcherstrasse 111, 8903 Birmensdorf. E-mail: barbara.weilenmann@wsl.ch.
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1. Introduction

Since the 1970 suburban sprawl has been a matter of concern to the public and politics alike. It is one of the most important types of land-use changes affecting not only highly developed countries but urbanized areas all over the world: The built environment with its houses and infrastructure spreads further and further, penetrating into the rural. Urban areas, it is claimed, take up space, encroaching excessively on valuable agricultural land. Aesthetic benefits of open space are lost, natural ecosystems get disrupted and local communities change their structure (Lopez & Hynes 2003, Wissen 2010, Polyzos et al. 2013). This development is reflected also in the growing scientific literature on how to quantify sprawl in European countries (e.g. Drewett 1980 and more recently Mann 2009, Oueslati 2013).

Strong sentiments against urban sprawl have developed over the last few decades, also in Switzerland. At the root is the perception that the process of urban growth in Switzerland has gone awry (Müller et al. 2010, Wissen 2010, Jaeger 2014). The issue definitely was placed on the national agenda with unexpected high share, 63 percent, of the Swiss population endorsing a strengthening of the national law on spatial development in spring 2013.

The literature agrees about urban sprawl being an ambiguous concept that lacks both an accurate, generally accepted definition and respective measures (Galster et al. 2001, Ewing et al. 2002). Researchers working on urban sprawl usually define it depending on the context or the function of the term in (economic) models applied, while its operationalization critically hinges on the availability of appropriate data (Ewing 1997, Sutton 2003, Irwin et al. 2007, Paulsen 2013). As it is often the case when analysing social phenomena, moving from abstract conceptualization to the empirical operationalization has the consequence that analyses become rather data-driven (see also Mueller 2004). However, valid and reliable operationalizations are essential for improving the (quantitative) knowledge-base and thus for objectifying the discourse about urban sprawl (Burchfield 2006, Oueslati 2013).

Despite disagreements and contradictions in conceptualising and operationalising urban sprawl, it is generally agreed that not all spatial development is sprawl (Galster et. al. 2001, Cutsinger 2005), and that all sprawl is not the same. To capture quantitative and qualitative aspects of urban sprawl, multidimensional measurements are suggested (Torrens & Alberti 2000, Galster 2001, Cutsinger 2005, Torrens 2008) but also challenged (Wassmer 2008, Paulsen 2013). In our study, we use four sprawl metrics (area of development, dispersion, utilisation density) and their combination into a composite metric (Jaeger et al. 2010a, 2014) that together capture the multidimensional nature of urban sprawl as good as possible.

A theoretical model that is able to provide basic explanations of urban expansion is the Monocentric City Model (Kraus 2006), which has long been the standard economic approach to studying the development of urban areas (Anas et al. 1998, Burchfield 2006). We base our analysis on this model, which identifies population, income, transportation cost and the price of agricultural land as essential drivers of urban growth. Our assumption is that some common elements exist in the development process of urbanisation independent of time and space, which are captured by the Monocentric City Model. In addition, other socio-demographic and economic variables discussed in the literature will be considered in our analysis.

Most studies that are based on the Monocentric City Model work at the level of a metropolitan area (Burchfield 2006, Spivey 2008) or a city (Pirrotte & Madre 2011, Salvati & Carlucci 2014) and only more recently are they improved by observing across time (Paulsen 2013). We consider sprawl for the surface of an entire country (Switzerland) over three decades: 1980, 1990 and 2000. However, we measure urban sprawl at the level of municipalities.

In this paper, we test the explanatory power of ‘classical’ drivers taken into account by the Monocentric City Model, based on separate cross-sectional data for each period. We then extend the model with additional explanatory variables. Comparing the results of these cross-sectional analyses across time will allow us to better understand how the relative importance of these drivers developed. The analysis will be conducted for all four different sprawl metrics. Our goal is to understand to what extent the four different dimensions can be related to the same explanatory model or whether each dimension of urban sprawl should be explained with its particular set of variables (drivers).

In doing so, we enter new territory compared to earlier studies: (1) we use a multidimensional operationalization of sprawl that captures four different dimensions of the sprawl concept, measured consistently across space and for three points across time (2) our unit of analysis is the municipality which enables us to investigate the pervasiveness of sprawl and to analyse at the lowest political level, where the actual political and economic conflicts accrue and where the spatial planning policies have to be implemented (Wissen 2010, Jaeger et al. 2010b).

Following this introductory section, the article encompasses four main sections. The second section reviews both the conceptualisation of urban sprawl and the theoretical models that explain sprawl as well as our choice of explanatory variables we want to consider in this study. The third section presents the study area, the spatio-temporal scale of the analysis and the variables used in the model. The fourth section presents and discusses the results, and the final section - the conclusion - gives a synthesis as well as a future prospect.

2. Concepts of urban sprawl, theoretical models and previous research

2.1 Conceptualisation and operationalization of urban sprawl and metrics used in this study

Urban areas can grow in four directions: inwards (new buildings within existing buildings), upwards (higher buildings), downwards (metro, tunnels, underground levels), and outwards (outskirts of urban areas or on the green field). Growing outwards in an uncontrolled manner, i.e. an ‘overly’ space-consuming expansion of urban land area, is usually considered as urban sprawl. Although urban areas must grow spatially to accommodate an expanding population, the notion ‘sprawl’ should express that it is ‘too much’ of a boundless growth, ‘too discontinuous’ or lacking compactness (Brueckner & Fansler 1983, Brueckner 2000, Burchfield 2006, Spivey 2008). Yet, it appears as if in the public debate urban sprawl has become a catch phrase for everything that is bad about urban growth. While urban sprawl is thus a particular form of urban development that often bears a negative connotation, it is a matter of definition at which point of which scale the negative effects of urban growth outweigh its positive effects and which dimension of urban development (e.g. spatial growth, continuity) should be considered. Downs (1999) presents a comprehensive overview over suggested definitions and lists some 10 different conceptualisations and the corresponding characteristics of sprawl (see also Jaeger et al. 2010a).

When it comes to the operationalization of sprawl, most empirical studies use a single dimension of sprawl only. This dimension is very often an aggregate measure of density of some form¹ or the amount of built-up land measured via satellite data or aerial photographs (Burchfield 2006, Paulsen 2012). Yet, as Paulsen (2013) remarks, aggregate measures bear the danger of obscuring significant variation among the single variables (see also Burchfield 2006). Years before Paulsen's remark, Galster (2001) presented an approach about how to measure not only one but multiple characteristics of sprawl. This measurement was later refined by Cutsinger et al. (2005) who introduced metrics for twelve distinct dimensions of sprawl, e.g. including density, concentration, centrality, intra-use proximity and 'nuclearity'. Both Galster (2001) and Cutsinger et al. (2005) find that ordinal rankings of their study areas (U.S. metropolitan areas) vary notably across different sprawl metrics, which, they argue, is strong evidence for the possibility to meaningfully differentiate sprawl on different dimensions indeed (see Torrens 2008, Paulsen 2013).

In this paper we are able to work with spatial metrics developed by Jaeger et al. (2010a) that measure and quantify three distinct dimensions of sprawl: 1) developed area as a share of the total area of the municipality, 2) dispersion of settlements, 3) utility density, and 4) the composed sprawl index (WUP: weighted urban permeation), which integrates the three previous measures (Jaeger et al. 2010a, 2014). Some of these metrics – that will be explained further below – have specifically been developed for the case of Switzerland (Jaeger et al. 2010a, 2014), and particularly the composed index WUP integrates various conceptual considerations on the nature of sprawl in the Swiss context².

The next paragraph presents the different sprawl metrics used in this paper and discusses them in the light of alternative metrics used so far in the empirical literature.

a. Sprawl as spatial extend of build-up area: Area of development (S)

Sprawl increases land consumption and is visible as a transformation of land use (Kline 2000, Herold 2003, Loibl 2003, Burchfield 2006). Increased land consumption has often been quantified by using visual representations: maps in previous decades and satellite images or aerial photos more recently. Kline (2000) e.g., for his comparison of land growth management of different States in the U.S., uses an nationwide satellite-based assessment of land use that indicates the areas of land that are developed. The advantage is that measuring the built-up area this way does remain independent from an additional but closely related dimension of sprawl: the utilization density of the respective area (see also Cutsinger 2005, Burchfield 2006, Paulsen 2012).

Herold (2003) lists further arguments that prove the fitness of remote sensing data in analysing land cover changes and shows that the data are usually historically and spatially consistent. In Europe, Loibl (2003) e.g. uses satellite images to generate land use classifications for the suburban region of

¹ Density is focussed simply because the geographical boundaries of the study area are very often defined by population, housing-units or employment density. Thus the specification of the study area depends on a density measure (compare the studies using 'urban area' designation of the U.S. Census such as Fulton et al. 2001, Sutton 2003, Spivey 2008, Brueckner & Fansler 1983, McGrath 2005, Paulsen 2012, Wassmer 2008 or Nechyba & Walsh 2004).

² The weighting algorithm takes into account, for example, the special case of traditionally so-called 'scattered settlement areas' in some rural parts of Switzerland (see Jaeger et al. 2014). WUP does not identify them as strongly sprawled because the weights applied emasculate such extreme dispersion values.

Vienna, Jaeger et al. (2011) use remote sensing data (Corine Land Cover data) to identify sprawl in Europe.

The metric 'area of development' we use is derived from aerial photographs of Switzerland. It measures the spatial extent of settled area in each municipality independent of function, form, utilisation and position of the buildings.³ Jaeger et al. (2010a) calculate for each municipality the area of development as the actual area of development divided by the area that potentially can be developed⁴.

b. Geometry of scatter/discontinuity: Degree Urban Dispersion (DIS)

A further characteristic of sprawl refers to a more geometrical measurement of land use patterns. Here, sprawl describes a dispersed, irregular and discontinuous fragmentation of urban development (Galster et al. 2001, Cutsinger et al. 2005, Torrens 2008, Burchfield 2006). Galster et al. (2001) use two related measurements: one of concentration to give evidence of how evenly distributed housing units are across an urban landscape and one of clustering to say something about the area a housing unit takes up in an urban landscape. Cutsinger et al. (2005) define concentration as the percentage of units (housing/jobs) that would need to move in order to produce an even distribution within the observation area. Burchfield et al. (2006) address the question of scatter and compactness of development, respectively, taking leapfrogging (discontinuity of developments) into account. The index they develop is the percentage of undeveloped land in the square kilometre surrounding an average residential settlement of US metropolitan areas (see also Brueckner & Fansler 1993, Torrens & Alberti 2000).

The index we use (the degree of urban dispersion, DIS) characterises dispersion as a pattern of area of developments from a geometric perspective: The value of DIS is the highest within a certain area when the buildings are distributed evenly within this area and the lowest when the buildings are arranged close to each other. The calculation is done by determining the average value of the 'effort function' for any two randomly chosen points within the area (where the effort function describes the 'effort' required to connect two points as a function of their distance from each other). The value of DIS does not depend on the total amount of the area of development since the average effort of all pairs of points is considered (for details see Jaeger et al. 2010a, 2014).

c. People and job density: Utilisation Density (UD)

Often, sprawl refers to low density settlements (Ewing 1997, Lopez & Hynes 2003, Antony 2004, McGrath 2005, Burchfield 2006, Paulsen 2012). Ewing (1997) and later Torrens (2004) present a historical overview of characterisations of sprawl in the literature where a transition from an emphasis on 'scattered development' to one on 'low-density development' is evident and thus indicates the importance and general recognition of density measurements in the conceptualisation

³ The settlement area was calculated by Jaeger et al. (2010a). It does not include all individual buildings but partly includes (public) infrastructure such as railway marshalling yards and airports in enclosed settlement areas.

⁴ The concept 'developable land' excludes surfaces where construction is impossible. Excluding such areas is a topic repeatedly taken up (compare, e.g. Cutsinger et al. 2005). Such areas could be bodies of water, protected land, unstable soil, forests (which are absolutely protected in Switzerland) or steep slopes and thus are not meaningful if considering expansion of the built-up area. Paulsen (2013) includes a measurement of undevelopable land in his set of explanatory variables as does Anthony (2004).

of sprawl (see e.g. McGrath 2005, Huang et al. 2007, Wassmer 2008, Pirotte & Madre 2011, Paulsen 2012, who use density as a sprawl index). Two concrete examples of density indices provide Galster et al. (2001) who measure density as the total number of housing/employees units in a certain area, and Cutsinger et al. (2005) who measure density as the average number of housing/job units per square mile of developable land.

Along the lines of Galster et al. (2001) and Cutsinger et al. (2005), the data we use measures density in terms of utilisation of a built-up area. The more people and jobs are located in a built-up area, the better its utilisation. To calculate this utilisation density (UD), Jaeger et al. (2010a) count the number of habitants and work places of each municipality and divide it by the area of development.

d. Composite sprawl index: Index for Weighted Urban Proliferation (WUP)

Finally, the index for weighed urban proliferation (WUP) combines the three dimensions discussed so far. The algorithm established for this combination takes into account that the perception of sprawl is often non-linearly related to the level of land uptake per inhabitant or job (density) and to the level of dispersion of the built-up area. Hence, the two metrics, DIS and UD are weighted in a way that prevents them from increasing (or decreasing) towards the extreme sections of the scale (for the detailed explanations see Jaeger et al. 2010a, 2014). Intuitively, this means for both measures that the differences in perception are more pronounced at intermediary values of their corresponding scales compared to their extreme values (Jaeger et.al. 2014).

This translates into an index of sprawl (WUP) that is below average for both the inner cities where the utilisation density is very high and for the rural areas with traditionally scattered settlements but little urban development. In contrary, the index lies above average in the suburban regions in which urban sprawl is usually rather intense.

2.2. Monocentric City Model and Extensions

The economic view of urban expansion assumes that urban spatial size and location processes are regulated by a market process where land allocation is determined by opportunity costs (see e.g. Tiebout 1956, Brueckner & Fansler 1983). The resulting Monocentric City Model, originally developed by Muth (1969) and Mills (1972) and more completely elaborated by Wheaton (1974), captures the trade-off between higher income at the city centre on the one hand and commuting costs and lower prices for land at the fringe of the city on the other hand, in order to explain the urban spatial structure. The expectations are that, *ceteris paribus*, a growth in population and/or income increases the spatial extent of urban areas whereas a rise in agricultural land rent and increasing commuting costs inhibits the latter.

In their analysis of the Monocentric City Model, Brueckner and Fansler (1983) regress the size of urban areas (as defined in the U.S. census) on these classic four variables mentioned above. Brueckner and Fansler (1983) show that urban area is related to the explanatory variables as predicted by the model and conclude that urban development is not the result of an economic system out of control but underlies an orderly and predictable market process (see also Richardson & Gordon 1993). The robustness of the Muth-Mills Monocentric City Model is confirmed among others by McGrath (2005), Wassmer (2008) Spivey (2008) and more recently by Paulsen (2012, 2013). The validity of the model indicates that it captures the most important economic forces for urban growth and thus, as McMillen (2006) argues, in its simple form stays informative and useful.

Beginning with the contribution of Brueckner & Fansler (1983) and continuing among others with McGrath (2005), Wassmer (2008), Spivey (2008), Paulsen (2012, 2013) or Polyzos et al. (2013), a number of papers have extended and modified the Monocentric City Model. On the one hand, the proxies for the classical Monocentric City Model are being adjusted (e.g. Spivey 2008 who searches for new proxies for commuting costs). On the other hand, authors try to integrate the changing nature of urban patterns over recent decades (e.g. polycentricity) with additional variables that capture e.g. spatial accessibility, demographical characteristics, people's changing preferences and economic and/or regional structures (e.g. Cutsinger et al. 2005, Piroette & Madre 2011, Oueslati 2013).

2.3. Explaining urban sprawl at the municipal level

Most studies relying on the Monocentric City Model operate at the level of a metropolitan area, i.e. a larger area consisting of many municipalities that are built around one core area containing a substantial population and an economic nucleus. Contrary to that, our study, however, operates at the level of the municipalities. Our sample consists of municipalities belonging to or being centres of metropolitan areas (such as the biggest Swiss city Zurich with 360'000 inhabitants in 2000, being the core of a metropolitan area of 1.66 m inhabitants), belonging to suburbia, and even to isolated rural areas (such as the smallest Swiss municipality consisting of some 22 inhabitants in 2000).

We are aware that our unit of analysis (municipalities) does not allow testing the Monocentric City Model directly. However, we consider similar variables as have been applied in the literature cited above. We assume that for Switzerland, urban growth in rural areas is essentially driven by the same socio-economic factors as in metropolitan areas. Nonetheless, we try to identify the affiliation of single municipalities with metropolitan areas as well as the urban-rural differentiation to allow for possible differences as explained further in the model section of the paper.

In the remainder of this section, we present the explanatory variables and our expectations about their effects. These are summarized in Table 1, at the end of this section. The sprawl metrics we use imply that high urban sprawl corresponds to high values of the share of the settlement area (much land uptake of settlement area per municipality), of dispersion and – given its particular weighting algorithm – of the composite sprawl index (WUP). However a high level of sprawl corresponds to low values of utilisation density (less efficient use of space).

Population: number of inhabitants

Similar to the Monocentric City Model we expect more sprawl in more populous municipalities. The simple reasoning is that accommodating more people consumes space and creates pressure for more construction activities. While we expect the settlement area to be larger in municipalities with more inhabitants, we also expect a more dispersed area of development in these cases. Further, we expect utility density (number of people and jobs) to be negatively related to the size of the population. Although we thus expect comparatively higher values of the composite sprawl index (WUP) for more populated cities, it has to be noted that the weighting factors of WUP favour density and punish dispersion. Depending on how exactly density and dispersion relate to population, the effect might be less pronounced: if the utility density of a municipality would rise with population and there was no effect on dispersion, WUP could also be negatively related to the number of inhabitants (see Wissen et al. 2010).

Income

In the Monocentric City Model, the income of the core municipality drives the urban development of the entire metropolitan region. In our case, where we compare municipalities, we simply expect that for richer municipalities (in terms of per capita federal taxes collected), there will be more capacity for development and thus more sprawl. Hence, we expect a larger area of development and a higher composite sprawl index for richer municipalities. Since richer people can afford it, they tend to live in more spacious residential property (e.g. property surrounding). Therefore, we would expect a higher value in dispersion as well. Also, wealthier people can be expected to prefer low-density settlements, which adversely affects utilization density.

Commuting costs

The Monocentric City Model assumes that higher commuting costs prevent spatial extension. The question of how to operationalize commuting cost seems to be a fervent debate in the literature though. Brueckner and Fansler (1983), McGrath (2005), Wassmer (2008) and also Spivey (2008) and Paulsen (2012) have had difficulties in finding a consistent measurement of transport cost. Often, it is the percentage of commuters using public transport (as with Brueckner and Fansler 1983) or the average travel time to work that is used (Spivey 2008, Paulsen 2013). Although these variables do not express directly monetary costs, the hypothesis is that more and longer commutes are positively correlated with monetary (opportunity) costs.

We assume that higher observed numbers of commuters most likely point to lower commuting costs, since the number of commuters is also a function of the efficiency and density of the transport network. As a consequence, we expect that the more commuters a municipality hosts and attracts, the more it sprawls (higher area of development and higher composite sprawl index) since it has to provide housing and working opportunities. Similar to population pressure, we also expect that dispersion increases and density decreases with the number of in- and outbound commuters.

Agricultural land rent

In Switzerland, value of the land for construction can be assumed to be independent of the value of agricultural land: the agricultural land market is highly regulated and agricultural land cannot immediately be converted into construction land. Unfortunately, there are no data on the price of construction land or a suitable proxy on a municipal level. Therefore, we do not employ any variables reflecting land prices.

Additional variables: Share of single households, age distribution and homeowner rate

In addition to the factors mentioned above, we suggest to consider some control variables. Aero (2006), in an investigation on household preferences, emphasized the importance of deep-rooted and embedded, prevalent attitudes towards different types of residential areas. We take into account three variables to catch aspects of the change of lifestyle in the last decades and of demographic changes induced by migration: The homeowner rate, the rate of single households per municipality, and the age distribution.

Paulsen (2013) finds that a higher ratio of homeowners is correlated with a higher consumption of land per net new housing units and thus increases sprawl. Not considering net new housing units only but rather the entity of housing units, we expect that higher shares of residential property

(proportion of apartments and houses that are owned by their inhabitants) adversely affect urban sprawl since homeowners lobby against uncontrolled building activity in their neighbourhood. This expectation is consistent with Fischel's 'homevoter hypothesis' (areas with a higher percentage of housing units that are owner-occupied are more likely to receive zoning decisions that protect property values). Correspondingly, we expect a negative correlation of the homeowner rate with the area of development, dispersion and the composite sprawl index. In addition, the correlation with utility density is also expected to be negative since homeowners, despite fearing an extension of dispersed settlements, are sceptical with respect to an increased utilisation density, as this can also negatively affect the value of their property.

For the variable age distribution, we assume that elderly people consume more space. People tend not to reduce their living space even if preconditions change (e.g. children moving out, loss of partner) and therefore have also a negative leverage on utilisation density. Correspondingly, we expect a higher level of sprawl in municipalities with a greater share of retired people (see e.g. Mann 2009).

While the share of retired people per municipality has grown rather rapidly on average in the last decades, the same holds for the share of single households. Both are a sign of changing lifestyle and demography. By including the share of single households in our model, we account for the resulting increased need for more residential space. Both shares should thus be positively related to the area of development, the composite sprawl index and dispersion, while utility density should be negatively affected.

Table 1: Expected direction of the effects of the variables employed in the models for each dimension of urban sprawl as well as the composite Index (WUP)

	S	DIS	UD	WUP
Number of inhabitants (in 10'000)	+	+	-	+
Income (federal tax revenue) per capita	+	+	-	+
Outbound commuters (Wegpendlerquote)	+	+	-	+
Inbound commuters (Zupendlerquote)	+	+	-	+
Share of homeowners	-	-	-	-
Share of retired inhabitants	+	+	-	+
Share of single households	+	+	-	+

3. Structure of the Data and Econometric Model

Model specifications

The estimation models used in the literature fall into two categories: they either focus one city at a time and try to determine whether the model is valid for that case (e.g. McMillen 2006) or they test the model's comparative statistical predictions with a cross-section of cities or urbanised areas (e.g. Spivey 2008, Paulsen 2012). One of the big challenges, at least in a U.S. context, has been the gathering of temporally and spatially consistent land use data, which is able to match with socio-demographic and other variables (Paulsen 2013). If changes in land use patterns are examined, the empirical work requires data that are comparable across time and space at the relevant scale of the phenomenon being explained. In our case, since the resolution of the data and the underlying classification system of functional boundaries (Swiss municipalities with the boundaries of 2012) are

the same for all the decades that were measured, we can interpret all variables and indices consistently. Furthermore, concerning political and fiscal parameters for land-use planning and regulation, our unit of analysis is congruent with the lowest – and in Switzerland the most important when it comes to the implementation of land-use regulation – level of planning decision-making.

Despite having consistently measured and comparable repeated observations across time available, in this paper, we restrict ourselves to estimating cross-sectional regression models for the different decades 1980, 1990, 2000. We chose this rather simple model to become more familiar with the data and to first better understand correlations at the distinct points in time.

However, since we do not compare metropolitan areas but single municipalities, it is important that in our empirical model, we can control for membership of these municipalities in metropolitan regions as well as for the urban-rural distinction: it would not be appropriate to expect sprawl dynamics being the same across all functional types of municipalities. Further, because we are not considering a panel-data structure but estimate cross-sectional regression models for each decade, we crucially depend on the identification of differing 'preconditions for development' between municipalities, e.g. some information about historical development paths of the single municipalities.

Identification of Metropolitan Areas

The Monocentric City Model has usually been tested in the context of the USA by comparing metropolitan areas as the unit of analysis. More recently, functional criteria have been considered for the definition of these areas. Paulsen (2012), for example, differentiates between size and function of urban areas by using a dummy variable for regional size, and one for polycentricism respective in order to test different regimes of city structure. He compares small metropolitan areas with large metropolitan areas and concludes that there is a difference in growth pattern. Without explicitly testing for it, Spivey (2008) finds evidence for different casual mechanisms in large versus small regions as well. She reckons that in more populous cities with rising incomes the price effect of increased demand for housing outweighs the effects of the increasing aversion to time spend commuting.

We thus identify different metropolitan areas as to control for possible differences in urban sprawl between such regions. We would expect that the mean effect of metropolitan areas as compared to the 'rest' of Switzerland results in more sprawl since these regions have been major economic development clusters. A typology of the 5 Swiss metropolitan areas (with the four biggest Swiss cities and Milano (IT) as their respective centres) is provided by the Federal Office of Spatial Development. It has to be noted that these regions, except the metropolitan region of Zurich, are relatively small, only comprising a fraction of what is considered being the agglomeration or the 'peri-urban' regions.

Historical information about development paths: age of housing stock

A cross-sectional comparison of urban sprawl among spatial units is crucially dependent on a variable capturing historical information about development patterns in order to control for preconditions of urban development. One possibility is to measure the share of old buildings, e.g. those that had been built before 1945 (this data is taken from the Census). The variable implicitly measures how much new buildings have been constructed since 1945, without information, however, about the quality of this development. We expect that the higher the share of old buildings (less construction activity and urban development during the last decades), the less pressure there is and thus the less the

respective municipality sprawls. Paulsen (2013), who considers the percentage of housing units built before 1950 as to take into account the historical evolution of metropolitan structures, concludes that regions with a greater percentage of housing units built before 1950 experienced lower density development indeed.

One complication in our study is that with the weighted sprawl index (WUP) cities hardly turn up as sprawled. At the same time, for cities might have a higher proportion of old buildings than the surrounding sub-urban municipalities that usually experience more sprawl: city centres consist of a fairly big historical but compact core. The fact that cities have a comparatively high share of old buildings but also a low level of sprawl goes counter the expectations formulated in the previous paragraph. Hence, we have to reflect the differing conditions and development paths in rural and urban areas. We do so by combining a functional differentiation between urban and rural municipalities (based on a typology of the Federal Office of Spatial Development) with the age of the building stock. This allows for an interaction effect: while we expect a high share of old buildings to be associated negatively with sprawl this effect should be stronger for urban municipalities.

Operationalization of explanatory variables

The variables measuring the number of inhabitants, the share of retired people, the share of single households, and the share of residential property are taken from readily and publicly available official statistics provided by the Swiss Federal Office for Statistics and collected by the Census that took place every decade (between 1970, 1980, 1990 and 2000).

The measure used for estimating the wealth of a municipality is calculated by using the total amount of direct federal tax revenue per municipality and per head. The data is provided by the Federal Finance Administration. Since this tax is imposed in a unitary manner and rather consistently since 1947 at the national level, it allows to measure income or wealth consistently across municipalities and time.

As proxy for commuting costs, we decided to use the ratio of in- and outbound commuters in our analysis⁵. The ratio is calculated on the bases of census data and takes into account the heterogeneity of preferences of (in- and outbound) commuters as suggested by Spivey (2008).

Transformation of the dependent variable

Since we are applying a simple ordinary least squares regression model, we consider it as important that our dependent variables are approximately normally distributed. Heavily skewed dependent variables would most likely result in a violation of the assumption of normally distributed error terms, which is a precondition for the interpretation of the resulting point estimates and standard errors. All urban sprawl metrics employed in this study are strongly skewed (except dispersion), with the bulk of observations being positioned at the lower end of the scale. Correspondingly, we took the third root of the share of the area of development, utilization density and WUP to produce more evenly spread distributions. The downside is that the exact effect of an estimated coefficient cannot be readily understood without a re-transformation. However, for the current paper, we are less interested in the exact description of the effect of single variables, but rather in the differences

⁵ Alternatively, we could have applied the ratio of long distance commuters per municipality. Such an operationalization would largely follow Paulsen (2012) and Spivey (2008). However, we refrained from using this measure due to problems with multicollinearity.

between effects of different variables in magnitude and their significance. For the current paper, we thus refrain from re-transforming the point-estimates.

4. Results

Table 2: Regression Results for 1980

	S	DIS	UD	WUP
(Intercept)	0.34 (0.02)	43.32 (0.79)	8.80 (0.12)	0.96 (0.07)
Inhabitants (in 10'000)	0.01 (0.00)	0.46 (0.09)	0.18 (0.01)	-0.03 (0.01)
Per capita federal tax revenue (income)	0.01 (0.00)	-0.07 (0.03)	-0.03 (0.00)	0.02 (0.00)
Share of outbound commuters	0.21 (0.01)	7.52 (0.63)	-0.27 (0.09)	1.05 (0.05)
Share of inbound commuters	0.28 (0.01)	0.28 (0.66)	0.10 (0.10)	0.98 (0.06)
Share of condominiums owned by occupants (homeownership ratio)	-0.16 (0.02)	-1.91 (0.78)	-2.65 (0.12)	-0.42 (0.07)
Share of retired inhabitants (age > 65)	0.30 (0.06)	8.17 (2.63)	-0.74 (0.39)	1.48 (0.22)
Share of single-person households	0.19 (0.02)	-4.99 (1.12)	0.00 (0.17)	0.23 (0.09)
Buildings built before 1945 as a share of the number of buildings in 1980	-0.12 (0.02)	0.62 (0.84)	-1.18 (0.13)	-0.30 (0.07)
Rural municipality	-0.12 (0.01)	-1.49 (0.42)	-0.42 (0.06)	-0.47 (0.04)
Buildings built before 1945 as a share of the number of buildings in 1980 * Rural municipality	0.12 (0.02)	0.19 (0.82)	0.67 (0.12)	0.32 (0.07)
Metropolitan area Zurich	-0.04 (0.01)	-0.63 (0.38)	0.04 (0.06)	-0.17 (0.03)
Metropolitan area Geneva	-0.09 (0.01)	0.47 (0.42)	-0.27 (0.06)	-0.32 (0.04)
Metropolitan area Bâle	-0.02 (0.01)	-1.61 (0.56)	0.13 (0.08)	-0.15 (0.05)
Metropolitan area Berne	-0.08 (0.01)	-0.82 (0.71)	0.06 (0.11)	-0.33 (0.06)
Metropolitan area Ticino	0.09 (0.02)	-0.02 (1.18)	-0.13 (0.18)	0.31 (0.10)
R ²	0.68	0.12	0.58	0.60
Adj. R ²	0.68	0.12	0.58	0.60
Num. obs.	2495	2495	2495	2495

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Tables 2 to 4 list the results of the OLS-regression for each dependent variable (S: area of development; DIS: Dispersion; UD: Utilization density; WUP: Weighted urban permeation) and decade (Table 2: 1980; Table 3: 1990; Table 4: 2000).

For all three decades, the share of the area of development, dispersion and utilization density are all positively correlated with the number of inhabitants per municipality. Although this means that on average more population comes with a larger and more dispersed area of development (S), with respect to density (UD), we can conclude that larger municipalities (in terms of inhabitants) tend to be better utilized space and are thus able to accommodate more people in the same area. However, if we look at the composite sprawl index (WUP), it is always negatively correlated with the number of inhabitants. This most probably is consequence of the weighting algorithm applied: it rewards densely build and highly utilised areas but punishes dispersion; thus, the overall effect of population size results in a negative coefficient.

The results for income (federal tax revenue) of a municipality are not equally consistent across decades, although it is still apparent that higher income is associated with more sprawl, at least with a higher share of the area of development (S) and a higher weighted index (WUP). The impact of income on dispersion (DIS) and utility density (UD) is changing across decades but generally, utilization density (UD) is smaller in richer municipalities while dispersion (DIS) was actually lower in 1980 than afterwards. However, the respective effect does not remain significant.

As far as the ratio of commuters is concerned, the results are consistently supporting the expectation that commuting is favouring sprawl, at least for outbound commuters (the share of people living in the municipality but going elsewhere for work): the larger the ratio of outbound commuters the larger the share of the area of development (S), the more dispersed this area of development (DIS) is and the less densely it is utilized (UD). These effects are significant for all dependent variables and decades. Consequently, the corresponding coefficients are also always positive and significant in the case the dependent variable is the composite sprawl index (WUP). Inbound commuters, on the contrary, are not 'causing' sprawl with equal unambiguousness: while the area of development (S) and WUP increase with the share of inbound commuters, since the 1990s utilization density (UD) even increases significantly while the effect on dispersion (DIS) never becomes significant.

Another surprisingly consistent result across all decades we can find for the share of homeownership: as people that own property are more concerned about the value of their property and since sprawl can be expected to deteriorate the living environment and thus has an adverse effect on the value of property, all sprawl measures are negatively affected by the share of homeowners. It may thus be deduced, as hypothesized, that utilization density (UD) affects property values negatively.

Table 3: Regression Results for 1990

	S	DIS	du	WUP
(Intercept)	0.29 ^{***} (0.02)	42.10 ^{***} (0.87)	8.62 ^{***} (0.12)	0.73 ^{***} (0.08)
Inhabitants (in 10'000)	0.02 ^{***} (0.00)	0.49 ^{***} (0.09)	0.16 ^{***} (0.01)	-0.03 ^{***} (0.01)
Per capita federal tax revenue (income)	0.00 ^{***} (0.00)	0.01 (0.02)	-0.01 [*] (0.00)	0.02 ^{***} (0.00)
Share of outbound commuters	0.21 ^{***} (0.01)	7.97 ^{***} (0.65)	-0.42 ^{***} (0.09)	0.99 ^{***} (0.06)
Share of inbound commuters	0.27 ^{***} (0.01)	0.33 (0.59)	0.49 ^{***} (0.09)	0.98 ^{***} (0.05)
Share of condominiums owned by occupants (homeownership ratio)	-0.17 ^{***} (0.02)	-2.53 ^{**} (0.82)	-2.67 ^{***} (0.12)	-0.38 ^{***} (0.07)
Share of retired inhabitants (age > 65)	0.28 ^{***} (0.06)	3.17 (2.56)	-0.56 (0.37)	1.16 ^{***} (0.23)
Share of single-person households	0.22 ^{***} (0.02)	-4.57 ^{***} (1.03)	-0.04 (0.15)	0.34 ^{***} (0.09)
Buildings built before 1945 as a share of the number of buildings in 1990	-0.16 ^{***} (0.02)	1.03 (1.07)	-1.49 ^{***} (0.15)	-0.32 ^{***} (0.09)
Rural municipality	-0.13 ^{***} (0.01)	-1.24 ^{**} (0.41)	-0.59 ^{***} (0.06)	-0.45 ^{***} (0.04)
Buildings built before 1945 as a share of the number of buildings in 1990 * Rural municipality	0.15 ^{***} (0.02)	-0.27 (1.05)	0.95 ^{***} (0.15)	0.30 ^{**} (0.09)
Metropolitan area Zurich	-0.05 ^{***} (0.01)	-0.93 [*] (0.38)	0.05 (0.05)	-0.20 ^{***} (0.03)
Metropolitan area Geneva	-0.09 ^{***} (0.01)	-0.06 (0.42)	-0.23 ^{***} (0.06)	-0.37 ^{***} (0.04)
Metropolitan area Bâle	0.00 (0.01)	-1.85 ^{***} (0.55)	0.07 (0.08)	-0.12 [*] (0.05)
Metropolitan area Berne	-0.08 ^{***} (0.02)	-0.98 (0.70)	0.11 (0.10)	-0.35 ^{***} (0.06)
Metropolitan area Ticino	0.10 ^{***} (0.03)	0.29 (1.16)	0.24 (0.17)	0.31 ^{**} (0.10)
R ²	0.68	0.14	0.64	0.59
Adj. R ²	0.68	0.13	0.64	0.59
Num. obs.	2495	2495	2495	2495

p < 0.001, p < 0.01, p < 0.05

As far as the effect of a municipality's share of elderly and the share of single-person households is concerned, the results are only consistent for the share of the area of development (S) and the

composite index (WUP): as they rise, both shares increase the area of development (S) and the sprawl index (WUP) significantly. Curiously, however, the share of single-person households seems to be negatively correlated with dispersion (DIS) (and not related to utilization density, UD) in the 1980s and the 1990s, but not anymore in the new century (while it is then utilization density that seems to be negatively affected). The share of retired people seems to have a positive effect on dispersion in 1980 and a negative effect on utilization density in 2000 only.

An interesting result can also be found for the historical development variable (the share of buildings built before 1945) and its interaction with the 'rural municipality' indicator. The result is consistent with the expectation that the main effect of the share of old buildings (which applies for a zero value of the 'rural' indicator and thus for urban municipalities) is negative for the share of the area of development (S) and the composite sprawl index (WUP) but equally negative for utilization density (UK). This means that less developed urban areas (higher share of old buildings) have also sprawled less. This negative relationship is, however, less pronounced in rural areas, since the coefficient of the multiplicative term is positive. This pattern, although with the opposite consequence for sprawl, also holds for utilization density: in urban regions, the higher the share of old buildings, the less densely these regions are built, while this effect is less apparent in rural regions. The exception is dispersion (DIS): here, the effect of a rising share of old buildings (as well as of the interaction term) is never significant and we might simply conclude that dispersion is lower in rural regions.

Finally, the control variables for the various metropolitan regions in Switzerland reveal that these regions are usually less sprawled (at least with respect to the area of development and the composite sprawl index) than the municipalities not belonging to a metropolitan region. There is one big exception, though: in all decades, the metropolitan region of the canton of Ticino has sprawled more than the non-metropolitan municipalities.

Table 4: Regression Results for 2000

	S	DIS	UD	WUP
(Intercept)	0.29 ^{***} (0.02)	40.90 ^{***} (0.95)	8.80 ^{***} (0.14)	0.73 ^{***} (0.09)
Inhabitants (in 10'000)	0.02 ^{***} (0.00)	0.44 ^{***} (0.09)	0.16 ^{***} (0.01)	-0.02 ^{**} (0.01)
Per capita federal tax revenue (income)	0.00 ^{***} (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 ^{***} (0.00)
Share of outbound commuters	0.25 ^{***} (0.02)	9.31 ^{***} (0.72)	-0.45 ^{***} (0.10)	1.18 ^{***} (0.07)
Share of inbound commuters	0.29 ^{***} (0.01)	-0.49 (0.59)	0.37 ^{***} (0.09)	1.02 ^{***} (0.06)
Share of condominiums owned by occupants (homeownership ratio)	-0.16 ^{***} (0.02)	-1.84 [*] (0.82)	-2.54 ^{***} (0.12)	-0.33 ^{***} (0.08)
Share of retired inhabitants (age > 65)	0.44 ^{***} (0.06)	-1.73 (2.62)	-1.04 ^{**} (0.38)	1.63 ^{***} (0.25)
Share of single-person households	0.18 ^{***} (0.02)	-0.85 (0.84)	-0.38 ^{**} (0.12)	0.43 ^{***} (0.08)
Buildings built before 1945 as a share of the number of buildings in 2000	-0.19 ^{***} (0.03)	0.85 (1.27)	-1.44 ^{***} (0.18)	-0.43 ^{***} (0.12)
Rural municipality	-0.16 ^{***} (0.01)	-1.52 ^{***} (0.40)	-0.52 ^{***} (0.06)	-0.59 ^{***} (0.04)
Buildings built before 1945 as a share of the number of buildings in 2000 * Rural municipality	0.17 ^{***} (0.03)	-0.19 (1.26)	0.91 ^{***} (0.18)	0.37 ^{**} (0.12)
Metropolitan area Zurich	-0.04 ^{***} (0.01)	-1.00 ^{**} (0.37)	0.16 ^{**} (0.05)	-0.19 ^{***} (0.04)
Metropolitan area Geneva	-0.08 ^{***} (0.01)	-0.19 (0.41)	-0.09 (0.06)	-0.33 ^{***} (0.04)
Metropolitan area Bâle	0.01 (0.01)	-1.58 ^{**} (0.54)	0.08 (0.08)	-0.06 (0.05)
Metropolitan area Berne	-0.10 ^{***} (0.02)	-1.02 (0.69)	0.19 (0.10)	-0.46 ^{***} (0.07)
Metropolitan area Ticino	0.10 ^{***} (0.03)	0.36 (1.15)	0.06 (0.17)	0.36 ^{**} (0.11)
R ²	0.66	0.13	0.58	0.57
Adj. R ²	0.66	0.13	0.58	0.57
Num. obs.	2495	2495	2495	2495

^{***} p < 0.001, ^{**} p < 0.01, ^{*} p < 0.05

5. Discussion

We assumed that the variables associated with the Monocentric City Model would provide us with relatively solid explanations for spatial extension. The results led us to infer that the model can be applied to explain spatial development even at the municipal level indeed, particularly also because the effects are relatively stable over time. However, in the interpretation of the results, at least one qualification has to be made: The number of inhabitants is not related to sprawl in a straightforward way. Increases in population lead to increased and more dispersed settlement (S, DIS) but there seems also be enough pressure for more and thus more effective utility density (UD).

Wealth per capita is positively correlated with the extent of the area of development (S), dispersion (DIS) and negatively with density (UD); in short, high income causes sprawl. In Switzerland, big cities are usually not the richest municipalities but are surrounded by a certain type of agglomeration municipalities that swallow commuters and have developed low density, mostly single family dwellings (usually occupied by richer people) since the 1970s. This phenomenon of attracting single house owners could also be encouraged by the fact that Swiss municipalities can individually set tax multipliers which enables the municipalities to influence the type of growth they want to a certain extent (see e.g. Schaltegger et al. 2009). The high number of outbound commuters that is positively correlated with sprawl gives further support for this assumption since such villages are mainly dormitory towns. Inbound commuters, by contrast, are less clearly causing sprawl. This might be because the development of industry and service infrastructure (e.g. transportation industry) is not equally spatially distributed over the whole country.

Our findings, however, also show that changing social patterns (single household, age) have equally caused sprawl. Furthermore, we seemingly identify a political economy explanation: Interest groups seem to have influence on the development of their surroundings, particularly if they are strongly affected such as homeowners.

We originally assumed that metropolitan area would have distinctive characteristics of sprawl compared to the municipalities not belonging to a metropolitan area. We find that they, on average, have sprawled less (except for the most southern Swiss region, Ticino, which belongs to the area of influence of Milano (IT)). One possible conclusion is that this particular agglomeration has to response to changes originating in the metropolis Milano. Given the complexity and rapidness of the development, the interventions might be too weak and lagging behind the process (being responding instead of preventive).

Overall, our results also confirm that urban growth in the bigger Swiss cities leads to a slowdown or even a decrease of urban sprawl, since population growth gives incentives for densification, concentration and effective utilisation. The same effects are likely to already have occurred in the surrounding communities (metropolitan area). Sprawling areas could then be interpreted as kind of forefront of a dynamic urban growth. To capture this, longitudinal data⁶ seem extremely important.

⁶ We have also tested panel models and controlled for spatial dependence of error terms. In qualitative terms, the results do not change. This means that neither controlling for (random) intercepts nor taking into account
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The choice of measurement scale is a critical issue and depends upon the relevant scale at which the hypothesised socio-economic processes that drive or affect sprawl operate. We chose to investigate at the level of municipalities for which sound data is actually available for Switzerland. Nevertheless, the scale also raises some difficulties in the interpretation and validation of the results since the data consist of a rather heterogenic set of municipalities. Further research would have to take this heterogeneity of spatial metrics into account.

Conclusion

With this paper, our intention was to see, whether the basic drivers of the Monocentric City Model can also be applied for an analysis at the municipal level in Switzerland in order to explain spatial patterns of urban growth. We also aimed at identifying further variables that reflect contemporary demographic developments. For that matter, we use a set of metrics for quantifying attributes correlated with sprawl including extend of area of developments (S), degree of dispersion (DIS), utilisation density (UD) and a composite sprawl index (WUP).

For the most straightforward sprawl indicator (area of development), we were able to confirm the expected effects of the economic drivers associated with the Monocentric City Model (commuters, income) as well as of most of the demography variables. However, we sometimes found a deviating result for the combined sprawl index (WUP), depending on how the explanatory variable affected density and dispersion. In addition, our analysis has also revealed that it can be important for the explanation of sprawl to identify the strength of interest groups (in our case homeowners). Different interest groups might not be equally affected by all dimensions of sprawl, which can result in seemingly inconsistent effects across sprawl metrics. Similarly, not all dimensions of sprawl are equally affected by the demographic variables employed in the analysis. Hence, there certainly is a benefit from differentiating sprawl into different dimensions.

When quantifying the dynamic phenomenon of urban growth, it seems important to treat sprawl as a process and not a pattern. In future analyses we will thus put more emphasis on comparing the development of sprawl over time and to better exploit the panel structure of our data.

All in all, however, our results seem to confirm that sprawl takes merely place in relatively rich, “peri-urban” municipalities that accommodate a lot of outbound commuters and are not in the hands of strong homeowner interest groups. Whether or not such municipalities can influence these variables and whether the development has even been intentional is a different question that is beyond the scope of this paper.

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spatial dependence unveil hidden pattern that are crucial for the analysis. Most importantly, the results do not depend on characteristics that are fixed over time (such as natural, topographical conditions).

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