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Spatial Analysis of the Urban-to-Rural Migration Determinants in the Viennese Metropolitan Area. A Transition from Suburbia to Postsuburbia?

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Abstract Currently urban spatial structures are affected by pervasive developments, which provoke a diversity and reorganization of population. This article examines the driving forces that cause urban-to-rural migration of population in the Austrian metropolitan area of Vienna using exploratory spatial analysis methods over the time period from 2001 to 2006. To model the qualitative changes between sub- and postsuburban processes, fuzzy sets are applied as variables. Because of significant concentration of high urban-to-rural migration along the main transportation corridors, a geographically weighted regression approach is used to determine whether suburban or postsuburban determinants are essential to predict urban-to-rural migration. The results show that the spatial variation of urban-to-rural migration can be statistically best modeled by using the two covariates "good accessibility to the core city by motorized individual transport" and a "high land price index". The article argues that this represents the prominence of classical hard location factors, which are interpreted as typical suburban. Accordingly, the metropolitan area is—concerning urban-to-rural migration—still under the influence of suburban processes.

Keywords Suburbanization · Postsuburbanization · Urban-to-rural migration · Driving forces · Geographically weighted regression · Vienna (Austria)

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Introduction

Since the last decades dramatic chances have occurred in European and US-American cities and altered their urban spatial patterns (Hall 1993). Almost any city has been shaped and reorganized by suburbanization processes, which have provoked population movement to urban fringes. Inhabitants profit from several advantages of these areas, including better air quality, living close to nature, enjoying the attractiveness of the landscape, less traffic, etc., while still having good accessibility to the core city (Gaebe 1987; Hall 1993). In contrast to these advantages, suburbanization processes increase commuter volumes, due to most inhabitants maintaining their place of employment in the core city. After a certain time lag, industrial facilities and associated jobs follow the people into the surroundings and complete this new spatial arrangement within urban fringes (Hellberg 1975; Glaeser and Kahn 2004). As a consequence, these centrifugal movements have dissolved the dichotomy between urban and rural areas (Boustedt 1975). At this development stage urban fringes are primarily functionally dependent on their core cities, which are still the dominant part in the urban landscape.

Suburban processes have been studied quite extensively by different interdisciplinary fields, including geography, economics, urban and transport planning. Numerous disquisitions cover theoretical discussions (Mieszkowski and Mills 1993; Brake et al. 2001; Johnson 2001; Carruthers and Ulfarsson 2003; Glaeser and Kahn 2004), methodical approaches (Loibl and Toetzer 2003; Herold et al. 2005; Torrens 2006, 2008) and case studies (Ning and Yan 1995; Wang and Zhou 1999; Feng and Zhou 2005; Burchfield et al. 2006; Voss and Chi 2006; Lee 2007).

Currently there is an on-going debate in urban geography about a postmodern change in or a reorientation of the spatial structure towards something “new”, something that is different from Suburbia (Fishman 1987; Garreau 1992; Kling et al. 1995a, b; Sieverts 1998; Soja 2000; Borsdorf 2004; Brake 2005). However, until today there has been no common agreement in the literature on how to label this new spatial structure. The literature refers to this new structure in numerous different terms. All existing terms describe (nearly) the same spatial phenomena, but they focus on different characteristics. The most often mentioned terms are “Edge City” (Garreau 1992), “Postsuburbia” (Kling et al. 1995a, b), “in-between-city“ (Sieverts 1998) or “Exopolis” (Soja 2000). All labels have two things in common: They refer to a postmodern society and urban development (Dear and Flusty 2002), which highlight a certain “maturity process” of the suburban structure. This includes a functional enrichment and a spatial reorganization qualitatively benefitting the suburban landscape in various facets, including, for instance, the social structure of the inhabitants. In former times only the rich and the well-educated upper class families lived in their detached houses in well accessible and scenic attractive parts of the urban fringes. Nowadays, this has changed, because the demographic and socio-economic composition of the inhabitants has become much more diverse. For instance, single parents, marginal groups, etc. live in such areas, as well (Hall 1998; Soja 2000, 2001; Borsdorf 2004; Brake 2005). As the above example shows, this discourse goes beyond the ongoing debate in urban economics (Anas et al. 1998) about new polycentric urban forms, because it also includes socio-economic, demographic, and architectural considerations (Sieverts et al. 2005). In order to avoid terminological uncertainties, the process to create this new spatial structure will be called postsuburbanization process in the remainder of this paper. The new spatial structure itself will be denoted as Postsuburbia (Kling et al. 1995a, b). The reasons for selecting this terminology are that Postsuburbia integrates various development tendencies such as agglomeration of offices and retail spaces in urban fringes and the diversity of the population. Also this term comprises a spatiotemporal component (the Latin word "post" refers to both "behind" and "after").

Primary characteristics of such postsuburban landscapes is the fragmentation of the metropolitan area into independent settlement areas, economies, societies and cultures (Wood 2003). Therefore, the classical monocentric urban models (e.g. Alonso's (1964) land rent model) do not correspond to this current reality any more and have lost their explanatory power (Anas et al. 1998; Hall 1998; Clark 2002). These models are replaced, for example, by polynucleated, fractal and chaotic patterns (Borsdorf 2003). Thus, postsuburban landscapes are based on polynucleated urban structures, which are, because of a functional enrichment, mostly independent of their core cities (Fishman 1987; Brake 2005). This means that inhabitants living in these new polynucleated urban structures can demand and consume higher-order and, for suburban areas, atypical goods or services (e.g. lifestyle services) without ever visiting the core city. This is in contrast to the central place hierarchy (Christaller 1933), because such higher-order goods and services should only be available in appropriate central places and not decentralized in the fringes. Due to the increased importance of agglomeration economies, services form functional spatial clusters (Soja 2001). This has extensive spatial impacts, as well. One such consequence is that original suburban interaction patterns (e.g. commuter patterns), which primarily ran radial from the periphery to the core city have become obsolete. These interaction patterns are replaced by diffuse and multidirectional ones (Hesse 2001) and the daily travel behaviors are now more tangential to the core city (Schwanen et al. 2001). Additionally, the former dormitory settlements – these are settlements wherefrom the economic active population has commuted to the nearby core city – are now transformed to places of residence and work. Besides these structural and functional changes, there have also been changes in the social composition. The prior homogeneous suburban neighborhoods have become demographically and socio-economically more heterogeneous (Brake 2005).

While spatial changes from Sub- to Postsuburbia are theoretically and conceptually well known at present, an empirical proof of such spatial changes is lacking so far. The purpose of this research is to provide an empirical assessment of these theories and concepts using the metropolitan area of Vienna as a case study. Because of the diversity of this urban development (e.g. economic, social, and demographic), this research primarily focuses on the urban-to-rural migration and their driving forces. Friedrichs and Rohr (1975) see therein the major spatial effects concerning the urbanization of the fringes.

The following specific research questions will be addressed in this paper: What forces determine the urban-to-rural migration process to the urban fringes? Can this migration be explained with (prototypically) well-known suburban factors or play new postsuburban factors already an important role? What are the most important determinants responsible for these spatial changes?

The structure of this paper is as follows: The next section provides some background literature of this research field and presents some findings, which are important for the context of this study. In the third section, the Vienna metropolitan area and the data are introduced. The fourth section consists of two parts. In the first part some sub- and postsuburban factors, which use a fuzzy set approach, are defined. In the second part, the main spatial analysis methodology is presented. The fifth section presents the empirical results and relates them to the sub- and postsuburban theory. The paper concludes with a brief summary and some future research questions.

Literature Review

Because of the interdisciplinary nature of this research field (e.g. geography, economics, and sociology), a vast amount of literature exists on the topic of urban spatial structures today. This literature still focuses on classical suburbanization processes and Suburbia.[1] Therefore, it is necessary to extend this literature review to studies, which implicitly analyze Postsuburbia and postsuburbanization processes, including the spatial evolution of polycentric urban landscapes, fractal urban structures, etc. The first part of this literature review discusses suburbanization processes. The second part discusses some Postsuburbia research, in which the main focus is on the German speaking part of Europe.

Burchfield et al. (2006) analyzed the evolution of land use in the United States from 1976 until 1992 using remote sensing data. Surprisingly, the extent of urban sprawl, which can be seen as a result of the suburbanization processes, was nearly unchanged during this time period, even though the extend varied across metropolitan areas. On this large scale the driving forces to increase sprawl were population growth, early public transport infrastructure and decentralized employment. These results were also confirmed by Baum-Snow (2007) and Voss and Chi (2006), who estimated the effects of highways on population growth. For example, Baum-Snow (2007) showed that an additional highway crossing an US city results in a population decline in the core city and doubles the number of people relocating from the core of the city to the suburbs. Similarly, using spatial regression models Voss and Chi (2006) found a modest relationship between highway expansion and population growth within 10 to 20 miles of highways in Wisconsin. Hence, infrastructure developments, such as highways, have strong and diverse economic, social and environmental impacts and enforce suburbanization processes.

A different approach was taken by Johnson (2001). The focus was on development strategies and environmental aspects of urban sprawl. Furthermore, he defined a future research agenda, and emphasized the immanent significance of this research field for future sustainable developments, spatial structures and societies. Johnson's (2001) ideas were followed up by Carruthers and Ulfarsson (2003), who analyzed monetary costs of suburbanization processes for some US counties. They concluded that suburbanization increases the costs for public services and for that reason compact

[1] A Google Scholar search conforms this: 21,900 entries for the term "suburbanization" and only 14 entries for the terms "postsuburbanization" or "post-suburbanization" (last accessed Jan 8 2009).

cities are preferable. Additional (negative) economic aspects of suburbanization are discussed for instance by Voith (1998) and Madden (2003).

Suburbanization is not only a phenomenon in advanced economies of European or US cities. It also exists in classically capitalistic-market-oriented societies like China. For example, two different case studies for Beijing (Wang and Zhou 1999) and Shanghai (Ning and Yan 1995) showed that both cities are affected by suburbanization processes. The differences to European or US cities lie in the impetus of these suburbanization processes and include for example, reform of land use or the expansion of the suburban infrastructure.

In addition to these statistical approaches presented above, now available micro-data linked with current geographic information technologies like automata models (either cellular automata or multi-agent systems; Clarke and Gaydos 1998; Batty et al. 1999; Loibl and Toetzer 2003; Torrens 2006) permit to model future (suburban) land use patterns. Of special interest is the spatial agent model from Loibl and Toetzer (2003). It simulates regional in-migration for the year 2011, within the Vienna Region. As driving forces they determined the factors accessibility, land price, landscape attractiveness, social and commercial services supply. The model results show that the center of suburbanization had moved over time (1968–1999) and continues to depend on the transportation system. A current study by Fassmann et al. (forthcoming) confirms this shift, which seems to be still ongoing. Nowadays more distant areas and municipalities especially in the north of Vienna show high growth rates of population. Very similar driving forces, as discussed by Loibl and Toetzer (2003), resulted from a qualitative survey of 250 suburban Viennese households conducted in 2004 (ÖIEB 2004). These findings can be used in the following spatial analysis as a basis for defining ideal type suburban proxy variables.

The urban spatial structure will now be discussed under a postmodern perspective. As already mentioned a fractal pattern put forward by Batty and Longley (1994) is an important characteristic of postsuburban landscapes (Borsdorf 2003). Fractal geometry was applied to explain the morphology and spatial organization of city growth. In the meantime some European metropolises like Brussels (Belgium), Dresden (Germany) and London (United Kingdom) have already been analyzed with this approach (Keersmaecker et al. 2003; Thinh 2003; Frankhauser 2004). For example, the results for the city of Dresden show an urban structure that approaches this fractal structure and increases in complexity over time (Thinh 2003).

Other scholars, including Batty (2001) have studied the transformation of metropolitan areas from monocentric to polycentric structures. Currently, this kind of research is an en vogue research topic. Such studies analyzed both employment/firm subcenters (Gordon et al. 1986; McMillen and McDonald 1998; Kloosterman and Lambregts 2001) and population subcenters (Gordon et al. 1986; Getis 1983) of different cities or metropolitan areas like Randstad (Netherlands), Chicago (USA) and Los Angeles (USA), which is considered to be the prototype of a postsuburban landscape (Soja 1996, 2000). All of these studies were able to provide evidence for polycentric urban landscapes using different methodical approaches including different kinds of density functions (McMillen and McDonald 1998) or point pattern analysis (Getis 1983).

One possible occurrence of polycentric postsuburban landscapes are Edge Cities (Garreau 1992), which are multifunctional concentrations of offices, retail, leisure and housing areas at a considerable distance of the core city. In this context Bontje and Burdack (2005) analyzed whether such patterns represent a typical North-American phenomenon or can emerge in European metropolitan areas, as well. In their study, Bontje and Burdack (2005) use the Paris metropolitan area and the Dutch Randstad as study sites. They concluded that Edge Cities are not a typical European development. The reason is that Garreau's (1992) criteria[2] to be an Edge City were not found in the two European cities investigated. Because of their smaller size, both European cities were thus named "city-edges". Nevertheless, city-edges have some similarity to North American Edge Cities in the range of specialization (e.g. finance and insurance), but are not spatially independent of the traditional core city. Consequently, city-edges cause no economic decline of their core cities. For instance, Rohr-Zänker (1996) and Anas et al. (1998) came to similar conclusions when comparing German with US-American cities. Contrary to these explanations, Batty (2001) argued that the explanations of polynucleation such the rise of Edge Cities are largely false. He showed with spatially disaggregated models of urban development that such multicentered urban landscapes are the result of a temporal evolution from initial, random distributions of urban activities.

As a result of such polycentric structured metropolitan areas, the commuter patterns have theoretically changed from radial to diffuse patterns. As Schwanen et al. (2001) state, the literature concerning how the metropolitan structure affects the travel behavior is, at present, still polarized. There is empirical evidence which suggests that a deconcentrated structure tends to reduce commuting distance and time (Gordon and Richardson 1997). Others, like Ewing (1997) see in decentralization of firms and households a disaster for travel behavior. Nevertheless, for several metropolitan areas including the Randstad region the increased tangential interaction-patterns to the core city have already been verified (Cortie et al. 1992).

Most of the above cited literature has its origin in the US. However, because of historical and cultural differences, as well as other planning traditions, a non-critical transfer of above technical terms and empirical results into the European context should be avoided or at least should be done with caution (Burdack and Herfert 1998). In the German speaking countries of Europe (Austria, Germany, Switzerland), postsuburban research has at present a high significance (Sieverts 1998; Aring 1999; Brake 2005; Görgl 2005; Helbich under review). One of the main study areas is the Rhein-Main region (Sieverts et al. 2005). In the "Mitten am Rand" research project new qualities of "in-between-cities" (Sieverts 1998) were extracted for instance with interviews of inhabitants concerning the new qualities of life (Hahn and Steinbusch 2006). Another part of this research discussed the driving forces for these spatial structures (Brake 2005). Also for some other German metropolitan areas empirical evidence for postsuburban processes already exists, including the region in the south of Stuttgart. In this region, Eisenreich and Schenk (2002) discovered some autonomous and economically independent developments from the core city (Stuttgart). Similarly, Kagermeier et al. (2001) could provide evidence for a

[2] Garreau (1992) defined Edge Cities as centers with more than 5 million square feet of office space, 603,000 square feet of retail space and 24,000 employees. Further characteristics are that Edge Cities emerged during the last 20 or 30 years, that they are perceived by the population as one place and that they have a commuter surplus due to a high concentration of jobs.

multicentered postsuburban spatial organization in the Munich region, where some firms were organized in functional homogeneous clusters.

Concerning the Viennese metropolitan area, analysis of postsuburban processes is almost lacking and is still entrenched in the traditional thinking of suburbanization processes (Giffinger et al. 2001; Loibl and Toetzer 2003). Two exceptions are Görgl (2005) and Helbich (under review). Görgl (2005) used a hermeneutic approach and interpreted the residential community of Fontana in the south of Vienna as a distinctive postsuburbanization process. Helbich (under review) discovered some new urban spatial structures in the Viennese urban fringes, including some significant hot spots of enterprises, when applying a point process modeling framework.

Overall, the literature review makes the necessity of quantitative research in the field of postsuburban processes obvious, because no empirically secured knowledge yet exists whether the Viennese metropolitan area still persists in a suburban or already in a postsuburban state.

Materials

Study Area

The study area for this research is the city of Vienna, Austria, which according to the 2001 census had a population of 1,550,000. Several concepts to delimit the metropolitan area of Vienna do exist. In this research, a slightly modified version of the Vienna metropolitan area delimited by Fuchs (1997) is used. In this modified version the core city is excluded (Fig. 1) because, as the literature states, the urban structure outside the traditional core city has matured and has broken away from its core. Consequently, the city center has become marginalized, since it is only one of many nuclei of the urban structure (Fishman 1987; Brake 2005). Secondly, the focus in this study is exclusively on the driving forces behind urban-to-rural migration. Altogether, the study area consists of 183 municipalities and has a size of nearly 1,800 square miles.

The first phase of suburbanization of the Viennese metropolitan area can be dated back to the 1960s (Lichtenberger 2000). The Vienna metropolitan area has experienced growth of the residential population since the 1980s, primarily due to in-migration from the city, itself, but also from adjacent districts. Since 1981 (517,000 inhabitants) the residential population of the entire study area has increased continually and reached about 615,000 inhabitants (a 19% increase compared to 1981) in 2001. The Vienna metropolitan area has been chosen for this investigation because a) it marks the greatest urban-to-rural migration flows in Austria within the last two decades (1981–2001) and b) following population forecasts this trend will also hold in the future (Hanika et al. 2004).

Data and Data Preparation

The data for this research were primarily collected from Statistics Austria[3], which is the main official data provider in Austria. Most of the data emanate from the last

[3] Statistics Austria http://www.statistik.at/web_en/ (last accessed Nov 10 2008)

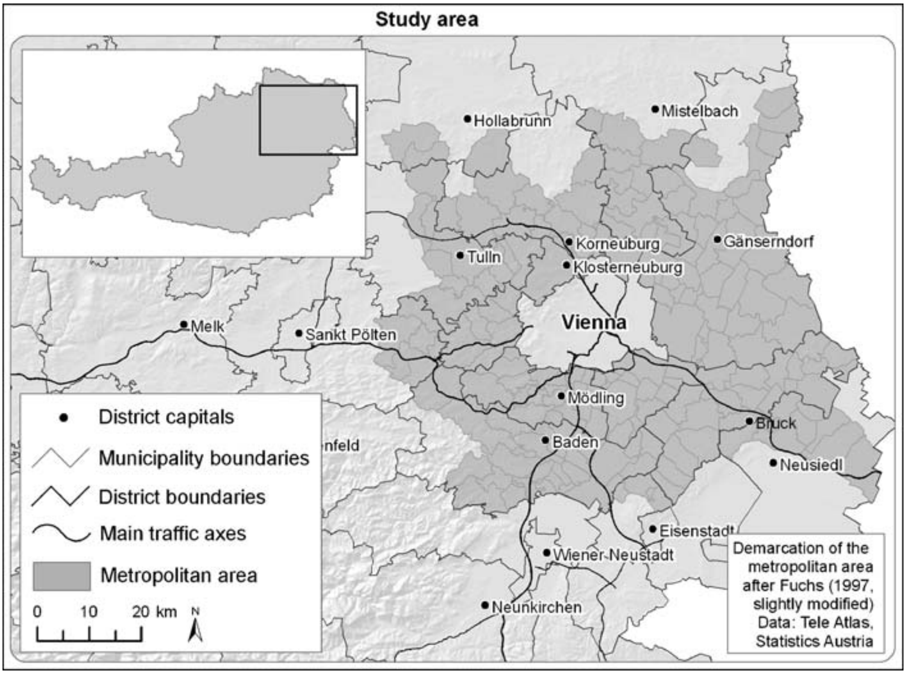

Fig. 1 Metropolitan area of Vienna

census in 2001. Variables which were not available needed to be modeled with a geographical information system. For example, the variable "accessibility to the core city by motorized individual transport" was computed using the hierarchical best route network analysis algorithm. With this algorithm driving times from centroid locations of the largest settlement areas in each municipality to the center of the core city were calculated. A second variable, the "scenic attractiveness index", was modeled using some map algebra functions (Tomlin 1990) and methods from multi-criteria evaluation (Malczewski 1999). In the calculation of the scenic attractiveness, the following gridded variables were used: "weighted cost distances to forests", "weighted cost distances to water bodies", and "relief intensity". These three factors were subsequently weighted using an Analytic Hierarchy Process (Saaty 1990). When using such a weighting scheme based on pairwise comparisons between these three factors, it is possible to objectify a subjective factor like scenic attractiveness. Therefore a small sample of subjects ($n=5$) were interviewed and on the basis of their statements the final weights were calculated. Finally, these three factors were aggregated using weighted linear combination (Voogd 1983) and averaged for each municipality. Details about the calculation of this "scenic attractiveness index" can be found in Helbich (2008). Table 1 shows all data applied to this analysis.

Table 1 Data used in this analysis

Data	Source
Average in-migration rate 2001–2003 (per mill)	Statistics Austria[a]
Land price index 2005/2006 (in euros)	Center of Regional Science[b], Vienna University of Technology, GEWINN[c] 2006
Accessibility to the core city by motorized individual transport 2005 (in minutes)	Tele Atlas provided by WIGeoGis[d]
Scenic attractiveness index	Institute of Photogrammetry and Remote Sensing[e], Vienna University of Technology, National Aeronautics and Space Administration[f], Department of Geography and Regional Research[g], University of Vienna
Per capita purchasing power 2004 (in euros)	Michael Bauer Research GmbH[h]
Percentage of high school diploma and graduates 2001	Statistics Austria
Percentage of female labor force participation rate 2001	Statistics Austria
Percentage of metropolitan area commuters 2001	Statistics Austria
Percentage of labor force commuters to core city 2001	Statistics Austria
Percentage of single- and dual-persons household 2001	Statistics Austria
Average household size 2001	Statistics Austria

[a] Statistics Austria: http://www.statistik.at/web_en/

[b] Center of Regional Science: http://www.srf.tuwien.ac.at/

[c] GEWINN: http://www.gewinn.com/

[d] WIGeoGis: http://www.wigeogis.com/

[e] Institute of Photogrammetry and Remote Sensing: http://www.ipf.tuwien.ac.at/

[f] National Aeronautics and Space Administration: http://www.nasa.gov/

[g] Department of Geography and Regional Research: http://www.univie.ac.at/geographie/

[h] Michael Bauer Research GmbH: http://www.english.mb-research.de/

Methods

Data Processing: Definition of Sub- and Postsuburban Proxies – a Fuzzy Set Approach

At this stage of the research no distinction can be made between suburban and postsuburban processes. Therefore it is necessary to add an intermediate step to this analysis. For this step, a fuzzy set approach to model the qualitative differences between these two processes will be applied.

The physical-material world that we live in is arguably based on some kind of fuzziness. As Leung (1982) noted geographic theories and concepts derived from this world must be necessarily fuzzy, as well. The same can be said about the "suburban and postsuburban theory" because knowledge about the spatial development is still imperfect. As already mentioned above, postsuburbia is the next development stage following suburbia (Brake 2005). Both stages can almost be described with identical variables, but the range of the variables is different. For instance, an ideal suburbian stage is characterized by in-migrations demanding *highly* scenic attractive areas. On the other hand, for a postsuburban stage *moderate* scenic attractiveness is of interest.

More than 30 years ago, Friedrichs and Rohr (1975) already regarded this fuzziness in the "suburban theory" as a methodical problem in the delimitation of suburban regions. In addition, no threshold values can be found in the literature to classify the variables into different classes. Instead, only vague knowledge based on metaphorical descriptions about the driving forces of sub- and postsuburban processes exist. But with the development of the fuzzy set theory (Zadeh 1965) such problems were ready to be solved. With this new approach qualitative differences are expressed as linguistic variables, which are "variable[s] whose values are words or sentences in a natural or synthetic language" (Zadeh 1994, p 50). If X is a set of objects x, than a fuzzy set $\tilde{A}$ can be defined as:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in X\} \tag{1}$$

Where $\mu_{\tilde{A}}(x)$ is the degree of the membership in the range of values between 0 and 1 of x to $\tilde{A}$ (Zimmermann 1987). The membership value expresses the degree to which an event occurs (Openshaw 1997) and can be modeled with a membership function. In this research the following linear $\mu_{\tilde{A}_{lin}}(x)$ and sinusoidal functions $\mu_{\tilde{A}_{sin}}(x)$ are used (Leung 1987; Zimmermann 1987):

$$\mu_{\tilde{A}_{lin}}(x) = \begin{cases} 0 & \text{if } x < a \\ \frac{x-a}{b-a} & \text{if } a \le x \le b \\ 1 & \text{if } b < x < c \\ \frac{d-x}{d-c} & \text{if } c \le x \le d \\ 0 & \text{if } x > d \end{cases} \tag{2}$$

$$\mu_{\tilde{A}_{sin}}(x) = \begin{cases} 0 & \text{if } x < a \\ 0.5\left(1 - \cos\left(\pi \frac{x-a}{b-a}\right)\right) & \text{if } a \le x \le b \\ 1 & \text{if } b < x < c \\ 0.5\left(1 + \cos\left(\pi \frac{x-c}{d-c}\right)\right) & \text{if } c \le x \le d \\ 0 & \text{if } x > d \end{cases} \tag{3}$$

where a, b, c and d are the model parameters. With this methodological enhancement it is now possible to characterize complex and/or imprecise defined phenomena (Openshaw 1997). Table 2 shows the re-expression of original variables from Table 1 as fuzzy sets. The choice of an appropriate membership function and their corresponding parameters are defined according to the literature (Brake et al. 2001; Borsdorf 2004; Brake 2005). For further details concerning this method and its geographical application consult Burrough and Frank (1996), Robinson (2003) and Petry et al. (2005).

Table 2 Re-expression of original variables from Table 1 as fuzzy sets

Suburban fuzzy sets	Postsuburban fuzzy sets
High in-migration rate[a]	High in-migration rate[a]
High scenic attractiveness[a]	Moderate scenic attractiveness[b]
Good accessibility[a]	Moderate accessibility[b]
High land price index[a]	Low land price index[a]
High per capita purchasing power[a]	Moderate per capita purchasing power[b]
Many high school diploma and graduates[a]	Not many high school diploma and graduates[b]
Many labor force commuters to core city[a]	Many metropolitan area commuters[a]
Small average household size 2001[a]	Many single-and double persons household[a]
	High female labor force participation rate[a]

[a] linear membership function, [b] sinusoidal membership function

Exploratory Spatial Data Analysis

With the introduction of geographical information technologies and the improved availability of geographical data, spatial analysis became an essential part of geography (Anselin 2005). Nowadays, a large number of statistics to analyze spatial processes, demask their patterns, explore and model their relationships exist (Fischer 2006). These methods also consider and handle some of the pitfalls of spatial data (O'Sullivan and Unwin 2003), like spatial autocorrelation, nonstationarity, edge effects, scale effects, and the modifiable areal unit problem (MAUP). Because this research uses discrete areal units (census tracts), a well known spatial analytical issue, namely the MAUP, influences the results. This means that a certain modeling outcome can result from the underlying aggregation level and the configuration of zones (Openshaw 1984). Thus, the result is solely one manifestation of a range of possible results. The MAUP affects, for instance, autocorrelation statistics (Jelinski and Wu 1996) and regression analysis (Fotheringham and Wong 1991). Furthermore, it is inadmissible in accordance with the ecological fallacy to make conclusions on an individual level about relations between some determinants based on aggregated area data (Wrigley et al. 1996; Fischer 2006). These issues have to be taken into account during the interpretation of the results.

This research applies the geographically weighted regression (GWR) approach to determine the spatial relationships between in-migration and different sub- and postsuburban data sets (see Table 2). To start off, it is necessary to explore some spatial effects like spatial autocorrelation and nonstationarity in the variables using the global Moran's *I* (Cliff and Ord 1981) and the local Moran's *I* statistic (Anselin 1995). These statistics evaluate the spatial distribution of a pattern, using locational and attribute similarities. Therefore, it is necessary to define the spatial configuration of the spatial entities with a spatial weight matrix (Cliff and Ord 1981).

Formally, the Moran's *I* is based on a covariance structure and has a range of -1 to +1, where values > 0 indicate spatial clustering of high or low values (positive spatial autocorrelation) and values < 0 indicate that neighbors are dissimilar (negative spatial autocorrelation) (Goodchild 1986). Because the global Moran's *I* does not provide insights into each location about presence or absence of significant spatial hot spots, cold spots and spatial outliers, it is necessary to calculate the local counterpart, as well. Details about the local Moran's *I* statistic can be found in Anselin (1995).

Geographically Weighted Regression

Spatial processes are analysed to model the underlying factors and interactions between spatial variables. For this purpose regression analysis is an often used method. Due to the fact that spatial variables have some spatial effects, one can model the spatial relationship between them, allowing variations in the parameter estimations. Such a modelling framework is the GWR (Brunsdon et al. 1996; Fotheringham et al. 1996). Numerous applications show the usefulness of this spatial analysis technique (Brunsdon et al. 2000; Fotheringham et al. 2001; Huang and Leung 2002; Malczewski et al. 2004; Lloyd and Shuttleworth 2005; Yu 2006). The following provides a brief discussion of the GWR framework. An in-depth discussion of this method can be found in Fotheringham et al. (2002).

GWR extends the traditional ordinary least squares (OLS) regression framework by allowing local spatial variations of the parameters, so that spatial nonstationarity can be examined. This means that there are multiple relationships between the response variable and the covariates in different parts of the study area. Therefore, the traditional OLS model must be rewritten to:

$$y_{(u_i,v_i)} = \beta_{0(u_i,v_i)} + \sum_k \beta_{k(u_i,v_i)} x_k + \varepsilon_{(u_i,v_i)} \tag{4}$$

where y is the response variable, x_k the k^{th} predictors, (u_i, v_i) the coordinates of the i's point, $\beta_{k(u_i,v_i)}$ a continuous function $\beta_{k(u,v)}$ on the location i and ε the error term. The estimate of β at the location (u_i, v_i) is being made over a locally weighted OLS approach, which is extended by a $n \times n$ dimensional weighting matrix **W**. The estimator for the $\hat{\beta}$ parameters at location (u_i, v_i) in this model is defined as:

$$\hat{\beta}_{(u_i,v_i)} = \left(\mathbf{X}^T \mathbf{W}_{(u_i,v_i)} \mathbf{X}\right)^{-1} \mathbf{X}^T \mathbf{W}_{(u_i,v_i)} \mathbf{y} \tag{5}$$

The weighting matrix **W** for point i at (u_i, v_i) has as diagonal elements the respective distance-dependent weights w_{in} and 0 as non-diagonal elements. The weights are determined by a kernel function moving from regression point i to regression point j and include n nearest-neighbor points. With a larger distance d_{ij} between point i and j, a continual reduction of the weighting factor w_{ij} occurs. Because the regression points are not distributed uniformly over space, the following adaptive bi-square kernel function was chosen:

$$w_{ij} = \begin{cases} \left[1 - \left({}^{d_{ij}}/_{b}\right)^2\right]^2 & \text{if } d_{ij} < b \\ 0 & \text{if } d_{ij} > b \end{cases} \tag{6}$$

where b is the bandwidth, which is dependent on the spatial distribution of the regression points i. Thus, if the regression points are dispersed distributed over space, than the bandwidth will be increased and vice versa. For that purpose the Akaike Information Criterion (AIC) is minimized.

As a result the method produces localised versions of standard regression diagnostics, which are mapable and provide important knowledge about the analyzed process. Finally, it should be mentioned that the local coefficients are potentially collinear, which can affect the interpretations of the spatial patterns (Wheeler and Tiefelsdorf 2005).

Empirical Data Analysis

Spatial Dimension of In-migration and their Covariates

Generally, in-migration into the urban fringes possesses a high spatial relevance, because it changes the settlement structure and the proportion between supply and demand of the offered goods and services between firms and population. Friedrichs and Rohr (1975) confirmed this and considered in-migration as the primary indicator for the urbanization of the urban fringes. In this research in-migration is defined as the response variable. Its spatial distribution for the Viennese urban fringe is shown in Fig. 2.

In general, there are some regional differences in the in-migration rate and the spatial variation shows increasing rates with closer proximity to the core city and

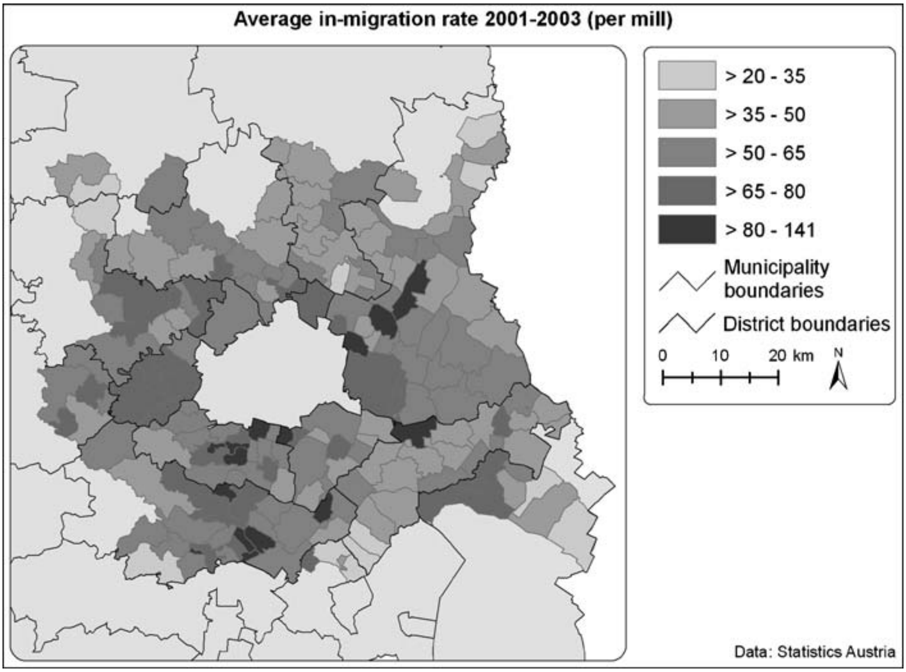

Fig. 2 Spatial distribution of the in-migration

along the main traffic axes. For calculating spatial autocorrelation, the spatial configuration of the municipalities was defined as a row-standardized first order queen contiguity matrix. Table 3 represents the results of the global Moran's *I* statistic for in-migration (response) and all the sub- and postsuburban covariates. All variables show highly significant positive spatial autocorrelation ($p<0.001$). This means that they possess some spatial structure and are not randomly distributed over space.

Using the local Moran's *I* the local spatial pattern of in-migration is examined again and the results are visualized in Fig. 3. One distinct significant hot spot appears, as expected, in the south of Vienna and along the major traffic axes. Within this hot spot municipalities with a high in-migration rate are surrounded by other high in-migration municipalities. In comparison, cold spots are primarily located near the boundary of the metropolitan area, especially in the north and the southeast. To sum up, these results clearly show that all variables used in this study are significantly spatially autocorrelated that is there is strong evidence of spatial nonstationarity within the spatial patterns of all variables. This will be explored in more detail in the following sections.

Estimating the Relationships: Exploring Nonstationarity

This section focuses on the spatial relationship between in-migration and several sub- and postsuburban covariates, with the aim to discover the driving forces of the urban-to-rural migration process. Because a priori the most reasonable variable combination was not known, all possible variable combinations were modeled; a total of 128 models for the suburban fuzzy sets and 256 models for the postsuburban fuzzy sets (see Table 2). The final model that was selected was the model with the lowest AIC-value. This value represents an information criterion, and also includes the model's complexity (Burnham and Anderson 2002).

Table 3 Results of the spatial autocorrelation statistic for the sub- and postsuburban fuzzy sets

Suburban fuzzy sets	Moran's *I*, *p*-val.	Postsuburban fuzzy sets	Moran's *I*, *p*-val.
High in-migration rate	0.336; 0.001	High in-migration rate	0.336; 0.001
High scenic attractiveness	0.712; 0.001	Moderate scenic attractiveness	0.403; 0.001
Good accessibility	0.838; 0.001	Moderate accessibility	0.667; 0.001
High land price index	0.753; 0.001	Low land price index	0.759; 0.001
High per capita purchasing power	0.625; 0.001	Moderate per capita purchasing power	0.347; 0.001
Many high school diploma and graduates	0.603; 0.001	Not many high school diploma and graduates	0.628; 0.001
Many labor force commuters to core city	0.643; 0.001	Many metropolitan area commuters	0.400; 0.001
Small average household size 2001	0.285; 0.001	Many single-and double persons household	0.310; 0.001
		High female labor force participation rate	0.261; 0.001

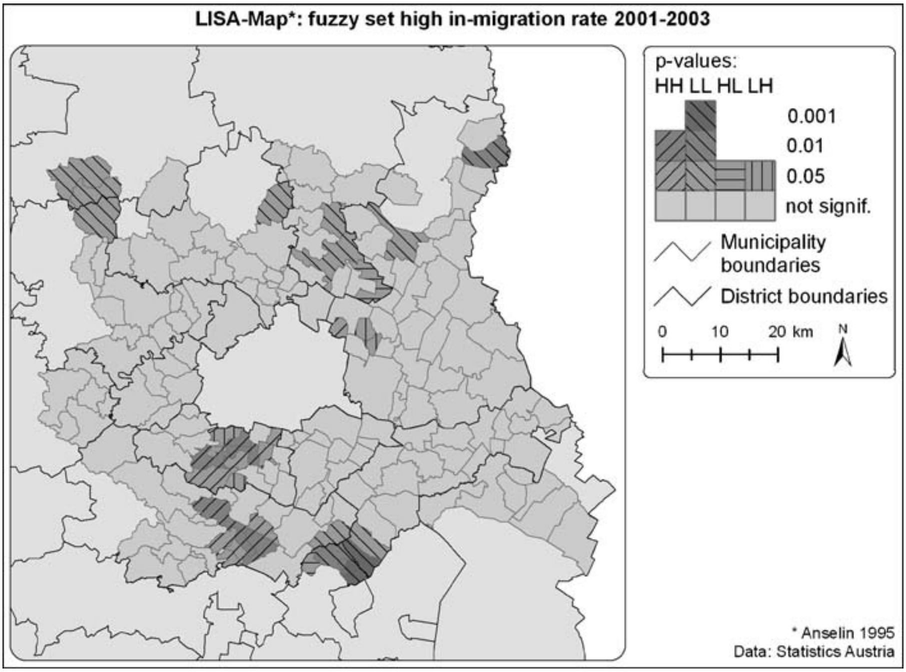

Fig. 3 Hot and cold spots of urban-to-rural migration. HH: hot spots, LL: cold spots, HL and LH: spatial outliers

The results show that the in-migration rate is best modeled through a function of the suburban predictor variables "good accessibility to the core city" and the square root of "high land price index" (Tables 4 and 5).

The *F*-test with a *p*-value < 0.001 indicates that the OLS model is statistically highly significant. Moreover, only around 25% of the variation in the in-migration rate is explained by this model according to the adjusted R^2. This means that 75% of the variance is still unexplained. With respect to the intercept term, the good accessibility and the high land price index are positively associated with the high in-migration rate. The *t*-statistics of the estimated parameters indicate that only the intercept and the good accessibility variable are statistically significant. The land price index is not statistically significant. That the accessibility variable has a significant impact on in-migration supports the hypothesized relationship that in-

Table 4 Results of the global regression

Parameter	Estimates	*t*-Statistic
Intercept	0.265	8.992
Good accessibility	0.251	2.981
High land price index	0.123	1.262

adj. R^2 0.249; AIC -119.001, RSS 5.346, *F*-Test: $p<0.001$, Moran's *I* (err.): 0.166 $p<0.001$

Table 5 Results of the geographically weighted regression

Parameter	Estimates			MC test
	Min.	Med.	Max.	p-value
Intercept	−0.195	0.284	0.709	0.000
Good accessibility	−0.358	0.208	1.360	0.040
High land price index	−0.767	0.100	0.804	0.070

adj. R^2 0.393; AIC -128.027, RSS 3.773, Moran's I (err.): 0.042 p=0.181, NN=45, ANOVA = 2.887

migration prefers areas with good accessibility to the core city, as long as these areas are located close to the city and along the main transportation routes. Such a location ensures a quick connection to the city center. These results are based on the incorrect assumption of uncorrelated model residuals (Moran's I (err.): 0.166; $p<0.001$). On the contrary, GWR explicitly accounts for spatial effects and should provide an improvement over the OLS regression results.

Spatial variations in urban-to-rural migration may exist, because individuals have specific location preferences, which depend on their social, economic and demographic background. For instance, suburbanites prefer areas in the metropolitan area, which are well accessible by car, have certain scenic attractiveness, etc. As already mentioned the GWR method also considers the spatial configuration. In this research the location of the regression points (u_i, v_i) are defined as the centroid locations of the largest settlement areas within each municipality. The same response variable and covariates that were used in the OLS regression above are tested again, but this time the following GWR model is used:

$$Y_{(u_i,v_i)} = \beta_{0(u_i,v_i)} + \beta_{1(u_i,v_i)} X_{1(u_i,v_i)} + \beta_{2(u_i,v_i)} \sqrt{X_{2(u_i,v_i)}} + \varepsilon_{(u_i,v_i)} \tag{7}$$

where Y is the "in-migration rate", X_1 is the predictor "good accessibility to the core city" and X_2 is the square root of the predictor "high land price index". This transformation resulted in a more Gaussian like distribution for the "high land price index" variable. The iterative minimization of the AIC score showed that 45 neighboring municipalities are included in each local model. In general, a reduction of the included neighbors offers detailed insights in the existing relations and an increase in the variance. The model diagnostics in Table 5 show that compared to the global OLS model, the GWR model has clearly better results. Especially the AIC score is noticeable reduced from -119 to -128 and the adjusted R^2 has increased to an average of nearly 0.4, with a minimum of 0.06 and a maximum of 0.63 (Fig. 4a). This indicates a much better goodness-of-fit than the OLS model. Nevertheless, there is still a high unexplained variation, which must be addressed in future studies. The improved GWR results are also statistically tested with an ANOVA test (Brunsdon et al. 1999). This test rejects the null hypothesis that the GWR model does not cause any significant improvement, at p=0.05. With the exception of one municipality, the standardised residuals (Fig. 4b) show no outliers and are no longer spatially

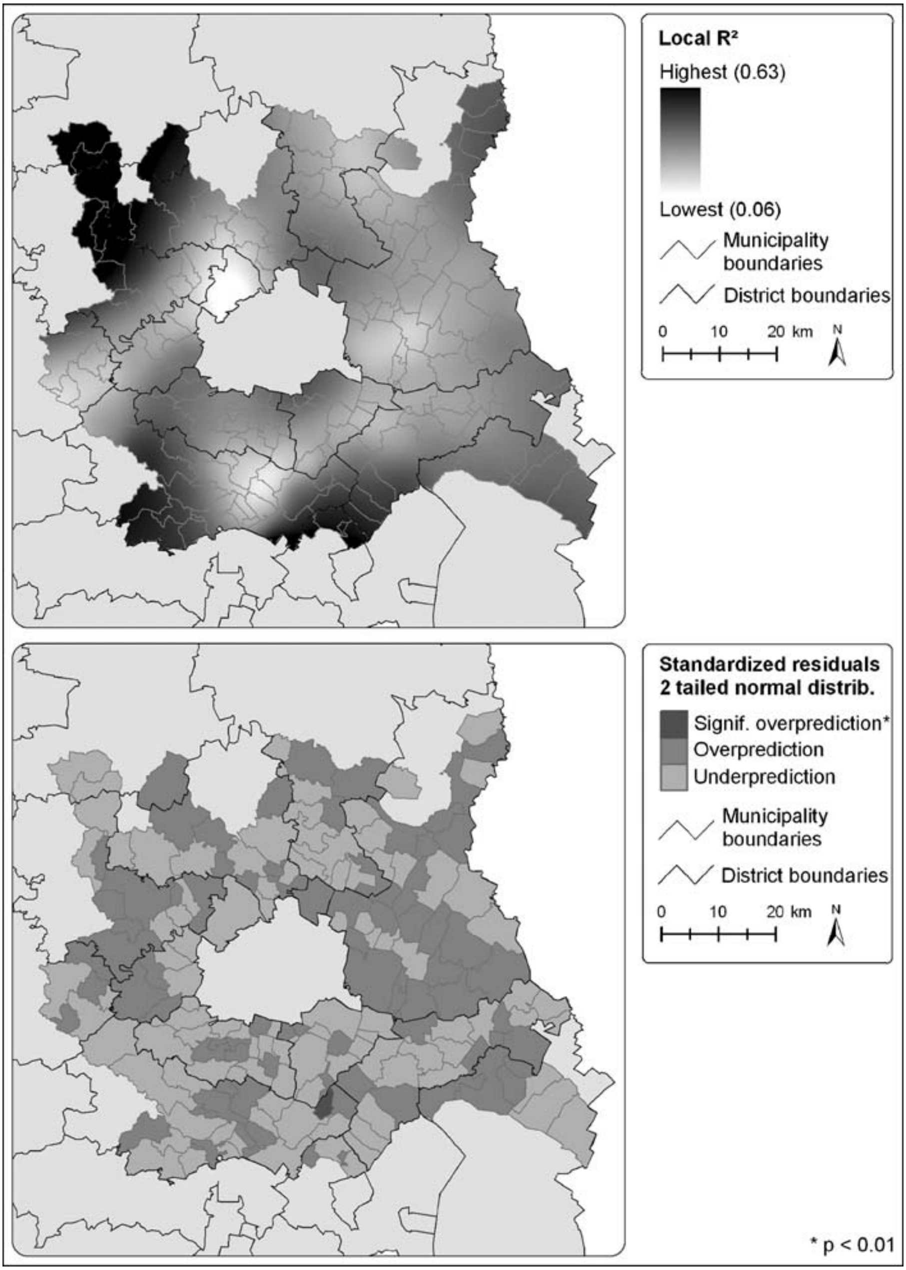

Fig. 4 Spatial distributions of the GWR parameters (part 1): local R^2 and standardized residuals

autocorrelated (Moran's I (err.): 0.042; p=0.181). Also the Cook's distance D does not show any anomalies. Finally, the spatial variability of the parameters was tested using a Monte - Carlo simulation (MC), which resulted in the following p-values: p=0.00 for the intercept, p=0.04 for the good accessibility, and p=0.07 for the high land price index. These results verify nonstationarity in the relationships. The spatial distributions of the specific parameter estimates are discussed now and presented in Figs. 5 and 6a.

In most parts of the study area the intercept parameters are significantly and positively related to the response variable and measure the degree of in-migration excluding all other effects of the covariates. Almost 2/3 of the GWR intercept values exceed the single intercept value from the OLS model. Highest in-migration rates can be found in southern municipalities, starting from around 6 miles from the city boundary to about 12 miles along the highway A2. A similar pattern can be observed in the west of the study area along the highway A1 and in the east of Vienna. A negative but insignificant in-migration rate was found in the south of Vienna. With the exception of the northwest and the northeast of the study area, the determinant good accessibility contributes positively to the high in-migration rate. However, the local pseudo *t*-values only show significant areas in the north of Vienna and at the southern border of the metropolitan area. The spatial distribution of the high land price variable shows a different trend as compared to the intercept and the good accessibility variable. A high land price reduces the in-migration rate in the northeastern part and in the remote southern parts of the study area. Similar to good accessibility, the high land price variable exhibits both positive and negative effects on the in-migration rate. This predictor variable has a positive effect on in-migration in the south however their pseudo *t*-values are not significant. Significant relationships are apparent in the northwest and in some southern municipalities. This confirms the hypothesis that these areas are preferred settlement areas of socially higher classes, who accept paying a higher land price to live next to like-minded people and for whom high land price values are definitely not a hindrance to move into such areas.

Summary and Conclusion

The spatial structures of urban fringes have recently changed with respect to the diversity of their inhabitants, their morphology and their relationship to the core city. This paper examined one of these changes, namely the urban-to-rural migration and its driving forces. This was tested using the Viennese metropolitan area as the study area and the GWR as the main method of investigation.

The results from this analysis showed that suburban determinants, including hard location factors, such as good accessibility and high land prices, played an important role. In addition, the relationship between the response variable “high in-migration rate” and the two predictors “good accessibility” and “high land prices” showed a considerable high spatial variability. It was possible to identify suburban areas in the southern part of the study region, where the connection with the core city is considered to be still important. This is in agreement with Clark (2002), who also highlights the importance of the location factor “accessibility”. A further conclusion was that in these areas a high land price augments the in-migration rate.

Summarizing, this study did not find evidence that the Viennese metropolitan area has already made a transition from Sub- to Postsuburbia by analyzing urban-to-rural

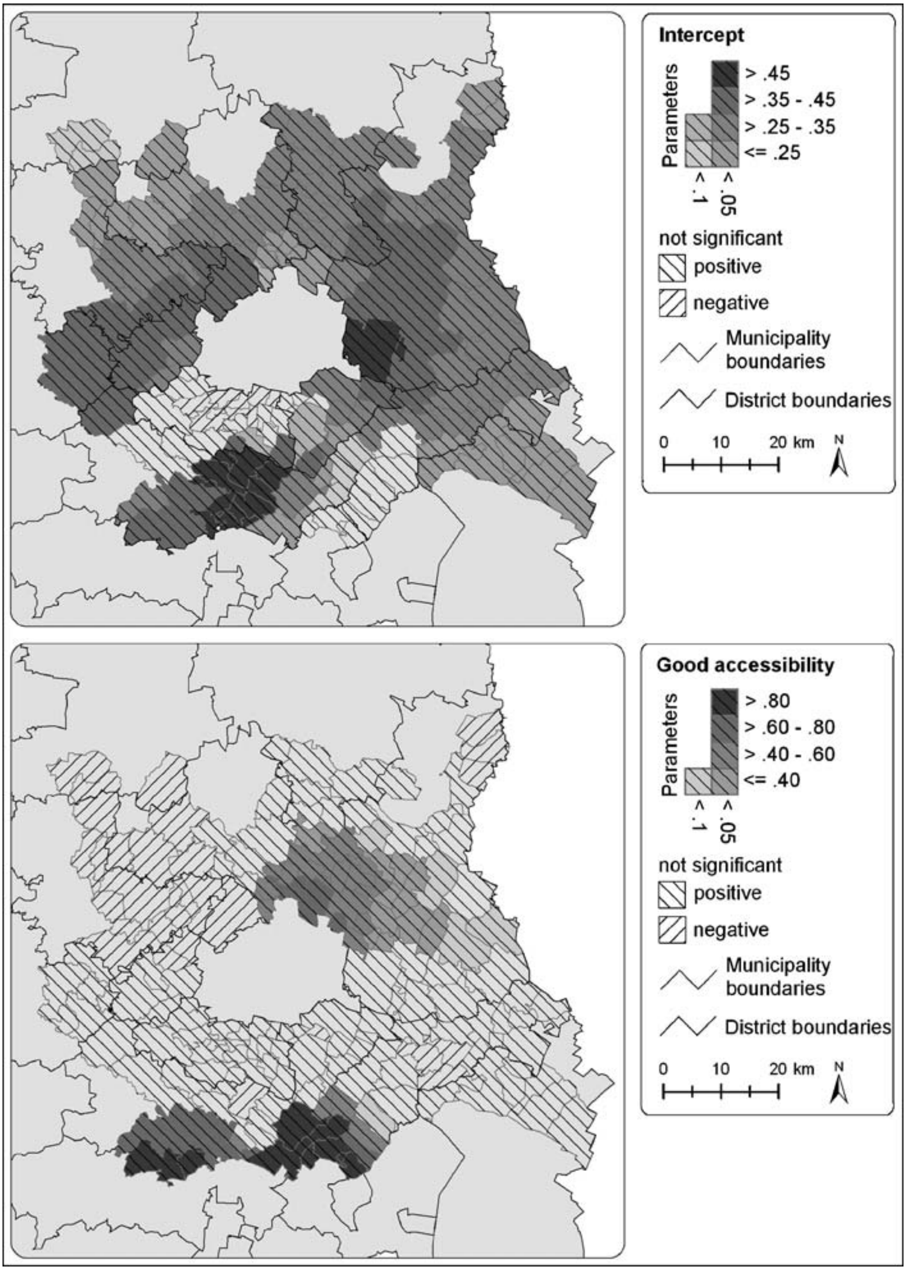

Fig. 5 Spatial distributions of the GWR parameters (part 2): coefficient estimates for the intercept and for good accessibility

migration. In general, a typical postmodern city, as described in the Introduction, does not yet exist in Europe. However, recent research already shows some evidence of partial transformations to a European postmodern city. Such examples include functional firm clustering in Vienna (Helbich under review) and Munich, Germany

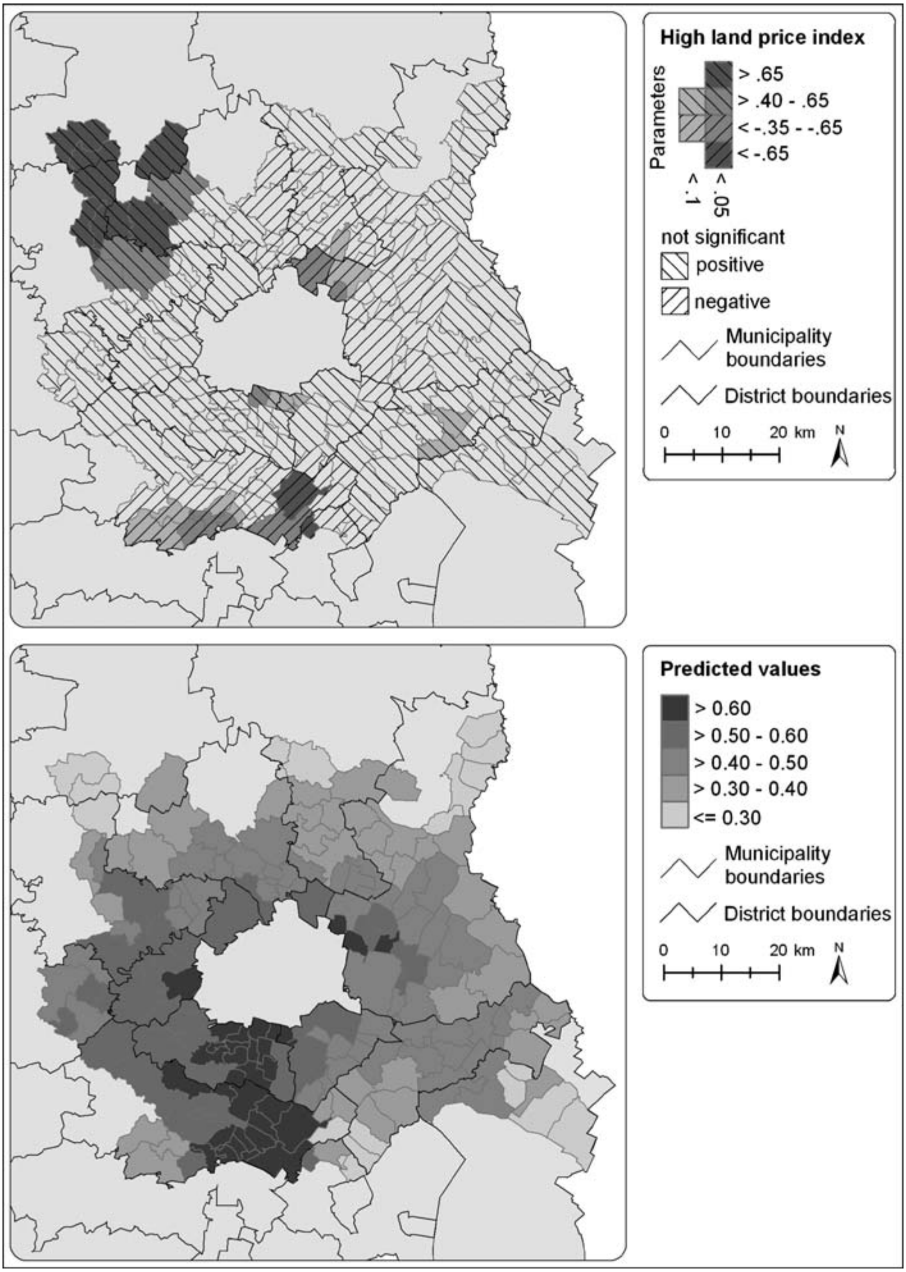

Fig. 6 Spatial distributions of the GWR parameters (part 3): coefficient estimates for high land price index and predicted in-migration rates

(Kagermeier et al. 2001), economic disengagement of urban fringes of Stuttgart, Germany (Eisenreich and Schenk 2002), and a polycentric urban landscape in the Dutch Randstad (Kloosterman and Lambregts 2001). These examples agree with Soja's (2001) statement that there will always be an influence of both processes and that there will never exist an exhaustive reorganized and restructured postmodern urban landscape.

Nevertheless, the Viennese urban fringe will undergo a huge spatial restructuring process in the next two decades. According to population forecasts (Hanika et al. 2004) Vienna will increase by 200,000 inhabitants until 2030. This would have major effects on the city, one of which might be a transition to a postsuburban landscape. For this reason, further investigations of the urban structure and of the urban morphology will be necessary.

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