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Sprawl or No Sprawl?
A Quantitative Analysis for the City of Vienna

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A Quantitative Analysis for the City of Vienna[1]

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Urban sprawl has been a hotly debated issue in urban development policy in recent decades. The discussion originated in the U.S.A. and has been transferred to Europe in recent years. In this paper we use existing quantitative measures that have been applied to other cities as well to generate indicators for whether or not urban sprawl is an important problem for the city of Vienna. The analysis clearly shows that the city has become less densely populated in the last 30 years. However, when comparing our results with those of other cities we see that Vienna scores quite favorably on practically all sprawl indicators.

1. INTRODUCTION

There are many ideas of urban sprawl. Originally the term was introduced by the urban planning field in the late 1930s and referred to an unaesthetic and uneconomic form of settlement (Wassmer, 2002). Today urban sprawl is used in a more diverse and as such broader sense. In fact, it is sometimes even perceived as too broad a concept: "the term urban sprawl has been so abused that it lacks precise meaning, and defining sprawl has become a methodological quagmire" (Audirac, Shermyen, & Smith, 1990). Partly, this lack of a precise definition stems from the fact that the phenomenon has received growing attention from various scientific disciplines, each of which have their own subject-specific approach in dealing with the issue. What is troublesome, however, is that causes, characteristics and consequences of sprawl are seemingly arbitrarily mingled together resulting in a pot-pourri of definitions addressing conceptually different things (Galster et al., 2001).

In recent years sustainable development policies have become more and more important. This has drawn widespread public attention towards the issue of sprawl and placed the phenomenon on the political agenda. Urban sprawl is now often associated with an undesirable spatial urban expansion; positive insights as to the nature of sprawl and its mechanism remain modest. On closer scrutiny we find not only a conceptual haziness with regard to what urban sprawl actually is but also a remarkable lack of understanding

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concerning the forces underlying the urban development process. Obviously, this fosters confusion rather than comprehension, effectively misleading the discourse and thus limiting society's possibilities to deal with urban issues successfully.

In this paper we examine whether or not urban sprawl is an important problem for the city of Vienna. Considering the numerous and multi-faceted definitions of sprawl, the equally large number of methods proposed to measure the phenomenon comes to no surprise. A broad distinction can be made between methods using a single indicator and methods using several indicators, the latter often being referred to as sprawl indices. Our survey of the literature yielded two quantitative measures suitable for the purpose of our study (Franz, Maier, & Schröck, 2006): We employ (population) density gradients since they allow statements concerning urban compactness, a lack of which is often associated with sprawl. More specifically, density gradients describe variations in density across space. They are a widely used measure in urban economics and particularly useful when studying urban structure over time and across cities. However, relying on a significant yet single indicator, namely density, to account for sprawl seems a critical issue, especially when bearing the complex nature of the phenomenon in mind. We therefore additionally draw on a multi-dimensional approach, in particular the sprawl index by Galster et al. (2001).

As mentioned above, sprawl indices consist of several indicators. The sprawl index applied here is one of the most sophisticated concepts, employing eight dimensions of land use that if present at low values and in some combination, characterize sprawl. Thus, different types of sprawl as well as changes in patterns of land use over time can be captured, the latter being especially useful when sprawl is conceived a process rather than a condition. The concept is based on grid tables containing block-level geography and block-level housing unit data, indicating fairly high data requirements. In general, the availability of such data is one of the most severe drawbacks of multi-dimensional approaches and perhaps a reason why sprawl indices are rarely applied to a large number of urban areas. This shortcoming in combination with a lack of agreement on which sprawl index is best suited, suggests a very careful approach when drawing conclusions regarding the occurrence of sprawl.

From the above it should be clear that we base our study on a relative notion of sprawl. More precisely, urban sprawl is considered to occur in the Viennese setting if [1] the density gradient flattens over time, [2] the density gradient is less steep than the density gradients of other, comparable cities and [3] the land use pattern exhibits low values along the dimensions specified by the sprawl index applied. In the absence of generally accepted benchmarks that are a prerequisite for a distinct classification, our notion of the adjective “low” is also a relative one, implying that we are comparing our results to the results of the study carried out by Galster et al. (2001).

The paper proceeds as follows: In the next section we explore the relationship between urban sprawl and urban development in the context of urban economic theory. Section 3 gives a brief outline of the urban history of Vienna. In section 4 we take a closer look at the applied quantitative measures and present our results. In the last section conclusions are drawn addressing the question whether or not sprawl is an important problem for the city of Vienna.

2. SPRAWL AND URBAN ECONOMICS

According to urban economic theory a city’s spatial size is determined by competition among urban and agricultural land users. This insight rests on the mechanism of the monocentric city model first introduced by Alonso (1964) and later extended by the works of Mills (1967), (1972) and Muth (1969).[4] The model assumes homogenous space and a central business district (CBD) into which citizens commute for work. Transportation and commuting costs are perceived as decisive locational factors, generating a spatial variation in the price of land/housing depending upon distance to the CBD. As a result a distinctive urban structure emerges. More specifically, the model predicts a circular urban form composed of concentric rings of urban land use similar to those of the Von Thünen (1826) rings of agricultural land use, implying that over distance the price of land/housing falls. The spatial implications of this price decline are twofold: [1] households and businesses located further away from the CBD consume more housing space than those residing in central locations and [2] real estate developers construct taller buildings near the CBD and shorter ones in the suburbs. It follows that density declines with increasing distance to the city centre dropping to zero where urban land use is less valuable than its agricultural counterpart. This reveals a direct link between price and density gradients: while the former expresses the rate at which land/housing prices change with distance to the CBD the latter describes the corresponding spatial variation in (population) density. From the foregoing we may conclude that the density gradient is essentially a result of the underlying price gradient.

From an urban economist’s point of view spatial urban growth is not per se an undesirable development. Rather, it is an efficient adjustment to a change in conditions. It is

[4] For a synthesis see (Fujita, 1989).

comprehensible that a city must grow spatially if it is to accommodate a larger population. Similarly, rising incomes cause cities to expand since a richer population demands larger housing space. The fact that dwellings become cheaper the further one moves outward from the CBD reinforces this effect somewhat naturally. The same line of thought can be applied with respect to a reduction in transportation and commuting costs (Mieszkowski & Mills, 1993). Since all these conditions increase the demand for urban land, competition at the urban fringe naturally becomes more intense. As a consequence, some agricultural land is bid away from agricultural land users and converted to urban use. The economic implication of this conversion, however, is not a loss of valuable farmland but an efficient shift towards a land use that society values more, namely urban use. Such a shift is accompanied by a flatter price gradient and thus entails a flatter density gradient. The extent to which agricultural land is converted to urban use depends on the value of agricultural land. If agricultural land is productive its value will be high and it will thus be more difficult for developers to outbid agricultural land users. On the other hand, if agricultural land is less productive its value will be lower. This will make agricultural land more vulnerable to competitive bids from developers and increase its chances of being converted to urban use (Brueckner, 2000b).

The success of the traditional monocentric model stems from its ability to explain the general features of existing cities. However, predictions of urban morphology on a more detailed level, in particular those concerning the pattern of land-use intensity and sequencing of land development, are often not consistent with findings in real-world cities. This shortcoming is primarily ascribed to the static nature of the model, referring to the fact that malleable rather than durable housing capital is assumed. In order to solve this problem a lot of research effort has been undertaken to enlarge the model in terms of dynamic aspects. Broadly speaking, two types of so-called durable-housing models have been developed (Brueckner, 2000a): [1] models with irreversible housing development and [2] models where redevelopment may occur. Contrary to the traditional model these models can generate upward-sloping and discontinuous building height contours, phenomena that can frequently be observed in real cities. Furthermore, leapfrog development which is often associated with sprawl and characterized by a patchwork of developed and undeveloped tracts within city boundaries (Altshuler & Gomez-Ibanez, 1993), is shown to be a natural outcome when development is irreversible.

Recalling that some spatial urban growth and shift in density is a natural by-product of economic growth, urban economists usually define urban sprawl as excessive spatial growth of cities (Brueckner, 2000b). What is considered crucial in this definition of urban sprawl is the adjective “excessive”, implying that land conversion is happening too fast. Unfortunately this definition is missing a benchmark pinpointing where the “natural” ends and the “excessive” begins. This limits its usefulness for empirical research on the occurrence of the phenomenon. However, the notion of speed/time has raised the question of market failure and in so doing has shed light on potential causes of and possible solutions to urban sprawl.

In general, market failure describes a situation in which the forces underlying the market mechanism are distorted resulting in an economic outcome that is perceived undesirable from societies’ point of view. The literature has identified several market failures as potential sources for excessive spatial growth of cities (Brueckner, 2000b): The first market failure identified is ascribed to the neglect of a positive externality, namely the social value of open space. Because social benefits of open space do not have a price, their loss, inevitably brought about when agricultural land is converted into urban land, is not reflected in land use decisions. As a result, land conversion may be spurred on purely economic grounds, leading to excessive spatial urban expansion. A proposed solution to the problem is a development tax charged for each acre of land converted from agricultural to urban use. As the tax increases the cost of conversion it slows down the rate at which conversion takes place and therefore works in opposition to the illustrated growth process. Assigning a monetary value to open space benefits however is not an easy task and maneuvers policy makers in the uncomfortable position of having to more or less guess the magnitude of the tax.

The second market failure identified is rooted in the neglect of a negative externality, precisely the social costs of road congestion. Because individual commuters bear only the private costs of commuting while the social costs of congestion created by their presence on the road are borne by all commuters, commuting on congested roads looks artificially cheap to the individual commuter. This constitutes a market failure. Since road congestion is essentially a result of commuting distances that are too long, the latter indicating excessive urban space, urban sprawl is explained via road congestion-related market failure. To call the individual commuter’s attention to the “true” costs of commuting a congestion toll could be introduced charging each commuter for the congestion damage imposed on others. This would effectively raise commuting cost, promote shorter commuting distances and thus shrink spatial city size. The implementation of congestion tolls is considered relatively easy, since the magnitude of such tolls can be computed reliably on the basis of well known commuting behavior. However, congestion tolls are politically difficult to enforce. Perhaps this explains why in reality congestion tolls are largely an exception. In fact, the exact opposite is sometimes implemented: commuter tax allowances. For the reasons outlined above, this is obviously a counterproductive measure, if urban spatial growth is to be slowed down.

Another potential source for excessive spatial urban expansion results from the failure to account for the infrastructure costs of new development. Infrastructure such as roads and sewers are a prerequisite for new homes and offices. Because these infrastructure costs are usually financed by the public through the property tax system, they do not show up in the calculations of housing developers. Thus, households and businesses that choose suburban locations do not fully pay the costs they induce. The property tax being based on the now artificially cheap development costs effectively lowers the tax burden of the new homeowners. This causes a market failure because due to the tax benefit these homeowners are able to pay higher purchasing prices for their houses than if they were fully charged with the infrastructure costs they create. Because developers can place higher bids on land if their houses are selling for more, the spatial implication of this fiscal distortion is a more rapid conversion of land and thus excessive spatial urban growth. It has been suggested to correct this problem with a system of impact fees. Impact fees reflect the infrastructure costs of new development, provided they are computed correctly. Since they are paid in lump sum fashion by housing developers, they reduce the amount that can be offered for land and therefore slow down the urban expansion process.

A paper by Brueckner & Kim (2003) addresses the question whether the property tax itself belongs on the list of causal factors of urban sprawl. To see the connection between urban sprawl and the property tax it is essential to perceive the latter as a tax levied at equal rates on both the land and the capital tied up in structures. Recalling the classical insight that a pure land tax has no effect on resource allocation in a static setting, it follows that the land proportion of the property tax leaves resource allocation unaffected. The capital proportion of the property tax however, is not neutral since it places a levy on structures and in so doing lowers the equilibrium level of improvements to the land. The spatial implication of this distortion is less intensive land use, implying shorter buildings, less housing floor space, lower population density per acre of land and thus greater spatial urban expansion, provided of course, population size is fixed. As the tax induced depression of land-use intensity may however be offset by an effect running in opposite direction, namely the tax’s impact on dwelling size, the net effect of the property tax on the spatial size of cities remains ambiguous.

3. BRIEF URBAN HISTORY OF VIENNA[5]

Vienna was first mentioned by name in 881. It was not until the 12th century however, that Vienna changed from a mostly rural into a predominantly urban area. Cornerstones of this development were the construction of St. Stephens' cathedral (1137 - 1147), the decision of the Austrian margraves to locate in Vienna (1150) and the construction of a circular city wall that placed the cathedral at the city centre (1200).

Similar to many other Central European cities Vienna's economic and cultural ascent is closely linked to the advent of industrialization. From the mid 19th century onwards Vienna experienced a remarkable growth spurt. A particularly favorable condition for this development was "Gründerzeit", an economic upswing that gave way to several large infrastructure projects. Among those projects were the construction of a railroad connection between Vienna and Triest (1857) and the regulation of the river Danube (1870 - 1875), the former effectively directing urban growth towards the south, the latter facilitating urban expansion towards the east. As a consequence, population size increased from 175.400 in 1754 to 900.998 in 1869 reaching 1.430.213 in 1890 and 2.083.630 in 1910 (Statistics Austria, 2007). World War I set an abrupt halt to the growth process and eventually ended the 640-years-old Habsburg regency. On November 12th 1918 a substantially smaller Austria with a considerably oversized Vienna as its capital was declared a Republic.

The situation after World War I was severe. The widespread lack of food and shelter lead to illegal land seizure mostly aimed at self-supply. Due to high inflation and rent control – an emergency measure that had been introduced during the war – there was almost no private construction taking place at all. In order to solve the housing misery the government promoted dense multi-storey housing. The program was quite successful but brought to an end after the social democratic party was banned in 1934. After the "Anschluß" to Hitler-Germany in 1938 Vienna was supposed to be rebuilt completely. What NS-housing policy came down to was "aryanization" of roughly 70.000 dwellings. The occupants – mostly Jewish tenants – were dislodged or killed. By 1939 the population had dropped to 1.770.938 (Statistics Austria, 2007).

At the end of World War II Vienna was badly damaged. The unfortunate situation was used for extensive reconstruction which accelerated in the 1960s when the economy had stabilized. The general ideas were to separate land uses and redesign the city for the automobile. In the

[5] For this section we drew heavily on (Eigner & Schneider, 2005)

1970s it became apparent that heavy traffic in combination with a lack of green space and a housing stock no longer up to standard caused households and businesses to relocate increasingly to the cheaper, more favorable hinterland. Population size declined from 1.619.885 in 1971 to 1.531.346 in 1981 (Statistics Austria, 2007). Since the end of the 20th century a number of measures have been taken to reverse this process. Highways bypassing the city were built in order to sooth the continuous congestion on inner-city roads. The city has transferred public facilities to the suburbs and extended public transport – in particular the metro system – accordingly to promote polycentric structures rather than focus solely on the old center. Within the dense urban core dwellings and their surroundings were and still are being upgraded. In recent years the population has again increased albeit only slightly, reaching 1.550.123 in 2001 (Statistics Austria, 2007). With a total land area of 414,65 km^2 this results in a population density of 3.738 inhabitants per km^2. Vienna's average population density is thus significantly higher than the national average of 96 inhabitants per km^2 (Statistics Austria, 2009).[6]

4. MEASUREMENTS

Density Gradient

Urban economists use density gradients as a measure of urban compactness. Since a lack of urban compactness is often associated with sprawl, density gradients represent a useful measure for the purpose of our study. Following Clark (Clark, 1951) we assume urban population densities to be well described by the exponential function:

$$\widehat{D}_i = D_0 e^{\beta d_i}$$

were $\widehat{D}_i$ is the theoretical population density at a location i, D_0 is the density at the centre, e is the base of natural logarithms, β is the density gradient, i.e. the rate at which densities fall from the centre and d_i is the distance between a location i and the centre. The actual population density at a location i, D_i, is composed of the theoretical population density at a location $i, \widehat{D}_i$, and an error term ε_i. Taking logs yields a linear function:

$$ln(D_i) = ln(\mathrm{D}_0) + \beta(d_i) + \varepsilon_i$$

[6] 80% of Vienna's total land area, i.e. 333,52 km^2 and 39% of Austria's total land area, i.e. 32.439,52 km^2 are suitable for settlement purposes. Average population density on the basis of this so-called "permanent settlement area" is 4.648 inhabitants per km^2 for Vienna and 248 inhabitants per km^2 for Austria (Statistics Austria, 2009).

With information on densities at different distances from the centre we can estimate $ln(\mathrm{D}_0)$ and β with standard econometric methods. Since it is an estimated parameter and for simplicity of notation, we use α to represent $ln(\mathrm{D}_0)$ below. To estimate α and β we used data from the Population Census 1971, 1981, 1991 and 2001 respectively. The data used was based on registration districts and provided by Statistics Austria. The densities of the registration districts were expressed as the ratio of the resident population to the land area (in hectares [ha]). The registration district "Altstadt-Mitte" (zbz-id 9010107) was chosen as the city center. The criteria for this choice were "highest employment density" and "central location" following Alonso's (Alonso, 1964) notion of a CBD. In order to compute the distances between the registration districts and the city center we defined population-related focal points and used their coordinates to compute the required distances (in kilometers [km]).

Table 1 reports the results of the regression analysis.

Table 1: Results of Linear Regression

	1971	1981	1991	2001
α	6,016	5,772	5,628	5,526
β	-0,383	-0,344	-0,332	-0,299

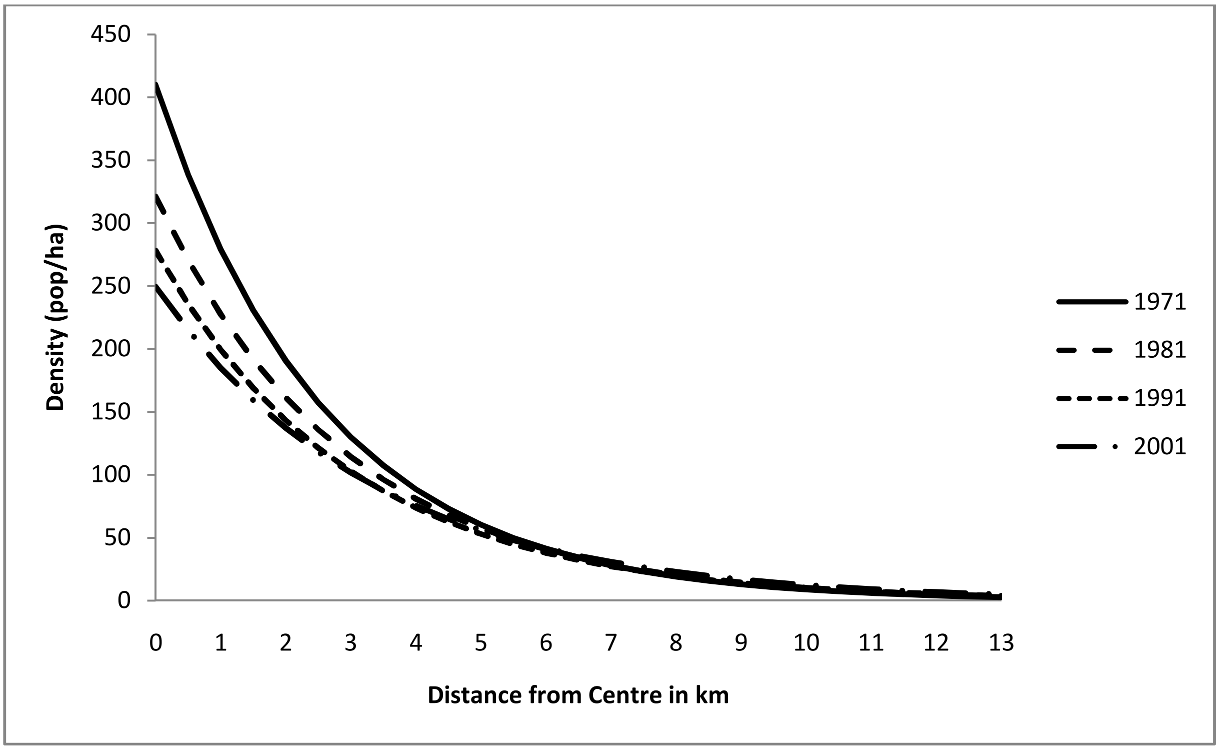
Inserting the estimated parameters α and β in the inverse function, written

$$\widehat{D}i = e^{\alpha+\beta d_i}$$

yielded density values which were plotted against distance from the city center. The resulting curves are illustrated in Figure 1. Due to the negative β-values their slopes are negative indicating that densities are falling with distance to the city center. This result is consistent with the predictions of the traditional monocentric city model.

While the parameter α determines the y-axis intercept and can be interpreted as the tolerated degree of overcrowding in the center, the density gradient β can be regarded as an expression relating transportation costs and average citizen income (Clark, 1951). A high absolute β-value indicates a sharp drop in densities, whereas a low absolute β-value indicates that densities fall only slightly as one moves outward from the city center. Thus, while the former suggests a more compact, the latter implies a less compact urban form. From Figure 1 we can see that Vienna's density gradient – as predicted by urban economics – has flattened over time. The city has therefore become less compact in the last 30 years. This may indicate sprawl.

Figure 1: Density Gradient of Vienna 1971 - 2001

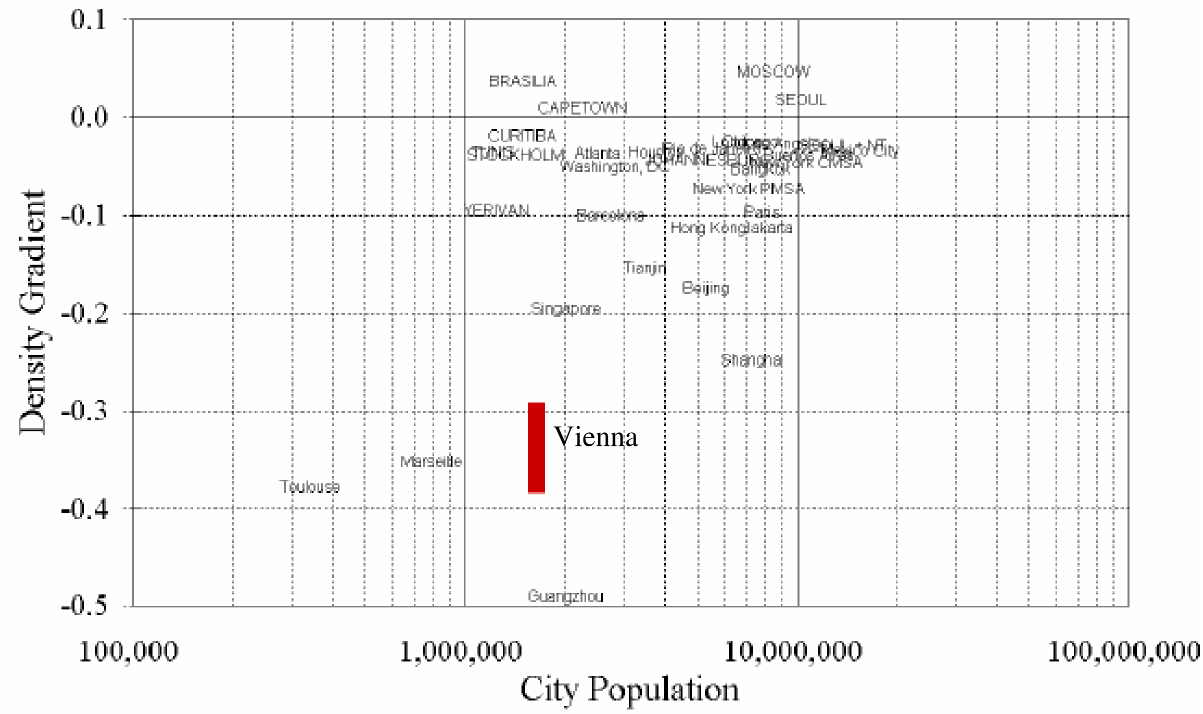


Our linear regression analysis poses a problem which originates from the fact that the error term ε was added to the linearized function. As a result, a central assumption of linear regression, homoscedasticity, i.e. constant variance of the error term across the sample, was applied to the transformed function. For this reason we ran a non-linear regression as well. The results resembled those of the linear regression.

Comparing our results with the results of a study by Bertaud & Malpezzi (2003) yielded a number of interesting findings. Figure 2 displays the density gradients of the 48 cities examined by Bertaud & Malpezzi (2003). Since Vienna was not among the cities examined, we added our results – represented by the vertical bar covering the range of estimates we found in our analysis – ex post.

From Figure 2 we can see that in Europe small cities tend to be more compact than large cities. This follows from the observation that the density gradient becomes less steep as we move from Toulouse to Marseille, from Marseille to Vienna and finally from Vienna to Barcelona. Stockholm with a similar population size to Vienna has a relatively flat density gradient. Perhaps Stockholm's natural environment is a reason for this result. A single city, namely Guangzhou, has a larger population size but a steeper density gradient than Vienna. This result is not surprising bearing in mind that due to lower levels of personal income Asian cities are usually more dense than European cities.

Figure 2. Density Gradient and City Population



Source: (Bertaud & Malpezzi, 2003)

From the above we may conclude that Vienna is a relatively compact city. This suggests that a natural rather than an excessive form of spatial growth has taken place in Vienna. However, we have mentioned that drawing conclusions based on a single indicator is a critical issue when studying a phenomenon as complex as sprawl. In order to examine how Vienna scores on indicators other than density, we additionally employed the sprawl index by Galster et al. (2001).

Galster et al.'s (2001) Sprawl Index

Galster et al. (2001) define sprawl as „a pattern of land use that exhibits low levels of some combination of eight distinct dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity." The dimensions are defined as follows:

- Density is the average number of residential units per square mile of developable land in a UA[7].
- Continuity is the degree to which developable land has been built upon at urban densities in an unbroken fashion.

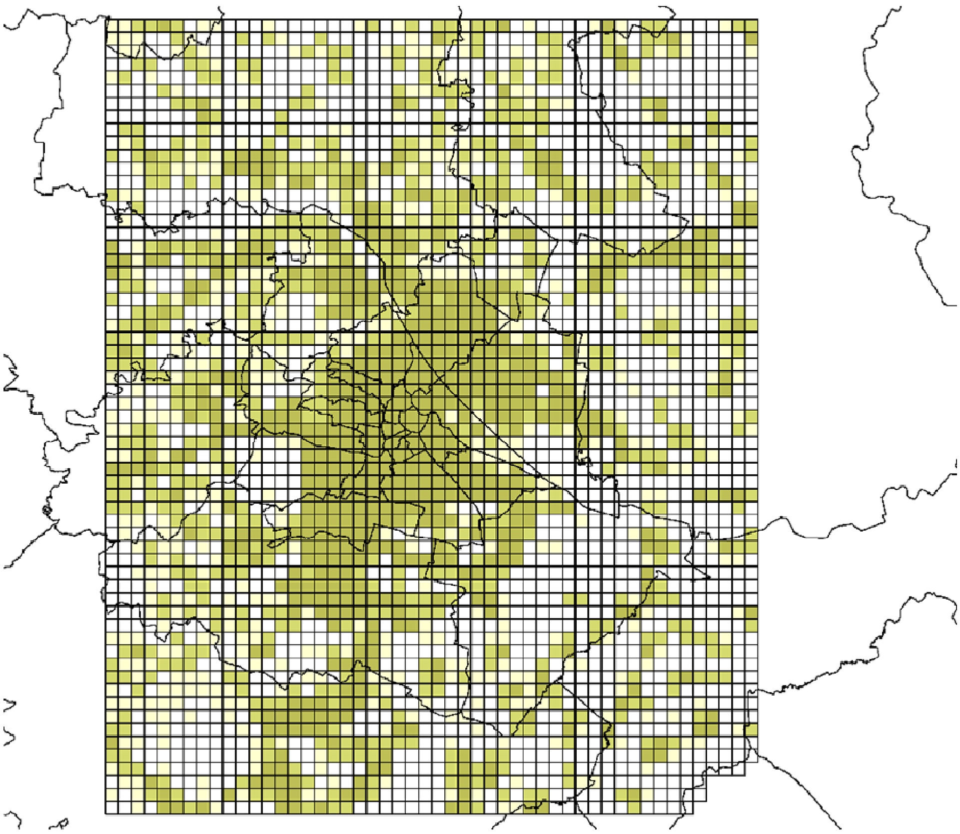
[7] U.S. Census-defined urban area

- Concentration is the degree to which development is located disproportionately in relatively few square miles of the total UA rather than spread throughout.
- Clustering is the degree to which development has been tightly bunched to minimize the amount of land in each square mile of developable land occupied by residential or non-residential uses.
- Centrality is the degree to which residential or nonresidential development (or both) is located close to the central business district (CBD) of an urban area.
- Nuclearity is the extent to which an urban area is characterized by a mononuclear (as opposed to a polynuclear) pattern of development.
- Mixed uses means the degree to which two different land uses commonly exist within the same small area, and this is common across the UA.
- Proximity is the degree to which different land uses are close to each other across a UA.

For their study Galster et al. (2001) chose 13 U.S. Census-defined urban areas (UA) and constructed grid tables composed of one-mile-square grids for each UA with the one-mile-square grids divided further into four one-half-mile-square grids. They then inserted block-level geography and block-level housing unit data into this grid system and operationalized the indicators outlined above mathematically. Ideally, land is divided into 3 types: residential land, non-residential land and non-developable land (because of natural features, public use, regulatory barriers etc…). However, due to resource and time constraints Galster et al. (2001) were not able to separate developable and non-developable land. Instead, they assumed all land to be developable. For the same reason they solely considered residential uses (on the basis of housing units); non-residential uses were not examined. Thus, of the eight indicators mentioned, only six, namely density, concentration, clustering, centrality, nuclearity, and proximity were actually tested. The 13 UAs under study were then ranked according to their scores on each of the six indicators.

Because Statistics Austria has placed a square grid network over the entire territory of Austria providing grid samples containing Census data, we did not face Galster et al.'s (2001) constraints. We obtained a sample of 1000 meter (m) and 500m statistical grid units containing data from the Population Census 2001 (for a diagrammatic example see Figure 3). The data received was based on developable land with principal residences as spatially based observation for residential land use and employees as spatially based observation for non-residential land use.

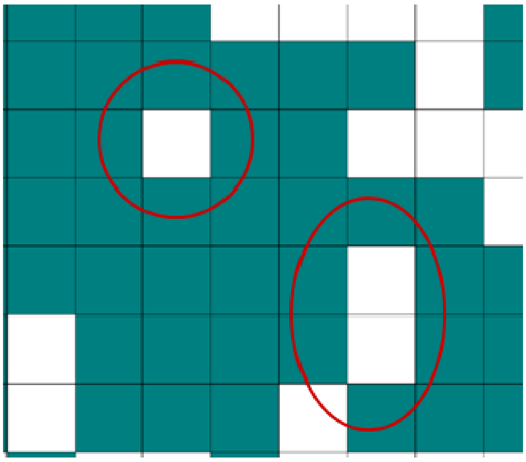
Figure 3. Grid sample for Vienna containing data from the Population Census 2001



As Figure 3 suggests, the grid samples are independent of administrative boundaries, allowing – in general – a more objective delineation of urban areas. For reasons of comparability we applied Census criteria, i.e. density and contiguity requirements, when delineating the area under study (U.S. Bureau of the Census, 2001). Of course the density requirement, originally based on miles, had to be adjusted to meters for the purpose of our study. We proceeded by selecting those grid cells that met the specified density requirement. One problem that arose was the issue of urban "holes". Urban holes are areas/grid cells which themselves do not fulfill the density requirement but are surrounded – either entirely or in part – by areas/grid cells that do. Figure 4 illustrates this point in the context of grid cells.

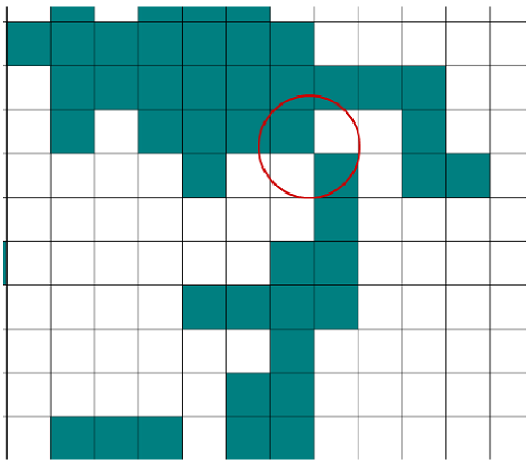
The contiguity requirement demands that census blocks fulfilling the density requirement are only to be considered part of an urban area, if they share a common borderline with an unbroken line of just as densely or even more densely populated census blocks starting from the center of the city. This so-called "rook contiguity" requirement can shrink the area under study considerably when delineating on the basis of grid cells because sometimes large densely populated areas are not connected by common borderlines but by common vertices ("queen contiguity"). Figure 5 illustrates this point diagrammatically.

Figure 4. Urban Holes



Naturally, the values of the indicators mentioned are bound to vary depending on the extent to which urban holes, common borderlines and/or common vertices are considered. To avoid misleading results we used four different urban bases (UB). In the first – and most restrictive – case we considered only those grid cells that met both the density and the rook contiguity requirement. This urban base was called UB 1. In the second case we enlarged UB 1 by considering urban holes. This urban base was called UB 2. In the third case we enlarged UB 1 by considering common vertices. This urban base was called UB 3. Finally, we enlarged UB 1 by considering both urban holes and common vertices. This urban base was called UB 4. It follows that UB 1 represents the smallest and UB 4 the largest geographic scale.

Figure 5. Queen Contiguity



We then computed the values for the indicators according to the computation formulas provided by Galster et al (2001). Again, scale adjustments had to be made since some of the formulas (density, continuity and proximity) involved benchmarks on the basis of miles. The original computation formulas and the adjustments made are summarized in the appendix. For reasons of comparability we followed Galster et al. (2001) in employing the delta index for concentration, in computing the average distance of a land use for centrality, in applying their proposed second-best operationalization for residential mononuclearity and in using the intrause measure for proximity.

Table 2 reports the values of the indicators according to the various bases applied. The first column displays the results of an average U.S. urban area submitted by Galster et al (2001). The second column lists the standard deviation which Galster et al. (2001) used for weighing each of the dimensions equally when calculating their index. As mentioned above only density, concentration, clustering, nuclearity and proximity were tested; continuity and diversity (mixed uses) therefore show no value.

Table 2. Indicators of Urban Sprawl

Dimensions	U.S. UA (μ)	U.S. UA (σ)	Vienna (UB 1)	Vienna (UB 2)	Vienna (UB 3)	Vienna (UB 4)
Density	1.407,42	389,56	4.878,18	4.850,08	4.526,08	4.157,64
Continuity	-	-	1,01	0,98	0,98	0,97
Concentration	0,39	0,06	0,42	0,42	0,43	0,45
Clustering	0,44	0,06	0,51	0,51	0,51	0,51
Centrality	167,46	25,36	3,38	5,45	5,24	5,46
Nuclearity	0,63	25,71	0,33	0,33	0,36	0,36
Mixed Uses	-	-	2,14	2,15	2,26	2,42
Proximity	0,28	0,07	0,47	0,47	0,51	0,49

From Table 2 we can see that Vienna scores quite well on the indicators examined. Most of the values are in the middle or upper range and fairly robust in terms of base variation. In addition, the majority of the values exceed those of an average U.S. urban area: residential density is 3 (UB 4) to 3,5 (UB 1) times higher exhibiting greater concentration (42% - 45% compared to 39%), greater clustering (51% compared to 44%) and greater proximity (47% - 49% compared to 28%). Galster et al.'s (2001) value for residential centrality is inexplicably high. We suspect that it is reported as a percentage value in which case it's index value would be 1,67. This would mean that the average U.S. citizen's commuting distance is 3,26 (UB 2) times larger than the commuting distance of the average Viennese, indicating that Vienna is a relative compact city and confirming the results obtained earlier using density gradients. Due to the relatively low degree of residential mononuclearity (33% - 36% compared to 63%) we believe Vienna to be characterized by a polynuclear development pattern. Unfortunately there are no comparative values for continuity and diversity. However, a continuity degree of 97% (UB 4) - 100% (UB 1) seems very high, implying that leapfrogging is more or less not existent in the Viennese setting. Since the values for diversity reveal a residential-to-non-residential land use ratio of 1:2, spatial segregation of different types of land use can also largely be ruled out. Taken together, these results suggest that the Viennese land use pattern does not resemble a land use pattern associated with sprawl.

A number of points, however, need mentioning. One issue concerns the geographic scale. For reasons of comparability we applied Census criteria when delineating the area under study. Nevertheless, with Galster et al. delineating on the basis of block-level data and this study delineating on the basis of grid cells two differently defined areas were compared. Another issue concerns the notion of developable land. Galster et al. (2001) define developable land as "land that has no natural features, public uses, or regulatory barriers to its development at urban densities". Here, developable land equals permanent settlement area which includes building land, agricultural land, gardens, vineyards, roads, railway tracks, excavation areas and other not further differentiated uses of land. As a consequence, the numerator is per definitionem related to a larger denominator essentially underrating density. Since Galster et al. (2001) consider all land developable this underestimation of density is, however, overcompensated. Thus, in this particular comparison Galster et al.'s (2001) density value is underrated whereas ours is overrated. A third issue concerns the ambiguity of the adjective "low". Bearing in mind that U.S. American cities are usually less dense than European cities it comes to no surprise that Vienna exhibits a relatively high density value. Were Vienna compared to another European city this might not be the case. The same line of thought can be applied to the other indicators as well.

5. SUMMARY

The growing importance of sustainable development policies has heightened the issue of urban sprawl, spawning widespread public attention and directing academic interest towards a more comprehensive understanding of the underlying causes, the characteristics and possible consequences of a highly complex phenomenon. In this paper we explored urban sprawl in the context of urban economic theory, briefly outlined the urban history of Vienna and used existing quantitative measures to analyze whether or not urban sprawl is an important problem for the city of Vienna. Our survey of the literature yielded two concepts suitable for the purpose of our study. Both measures enable comparisons over time and across different urban areas indicating that our study was based on a relative notion of sprawl. This approach seemed appropriate bearing not only the conceptual inconsistency with the term "sprawl" but also the general lack of understanding concerning the forces underlying the urban development process in mind.

We employed density gradients since density gradients allow statements concerning urban compactness, a lack of which is often associated with sprawl. In addition, we drew on Galster et al.'s (2001) sprawl index which – unlike density gradients – employs several indicators and thus represents a more differentiated quantitative measure. We hypothesized urban sprawl to occur in the Viennese setting if: [1] the density gradient flattens over time, [2] the density gradient is less steep than the density gradients of other, comparable cities and [3] the land use pattern exhibits low values along the eight indicators specified by Galster et al. (2001). Due to the absence of generally accepted benchmarks according to which the computed values of the various indicators could have been classified explicitly as "low", we compared our results to Galster et al.'s (2001) results and drew conclusions on the basis of this comparison.

The analysis showed that Vienna's density gradient has become less steep in the last 30 years. Vienna has therefore experienced a loss of urban compactness over time. This could indicate sprawl. Concurrently urban economics literature suggests that some urban expansion is a "natural" by-product of urban development. When we compared Vienna's density gradient to the density gradients of other cities, we found Vienna's density gradient to be relatively steep. Vienna can thus be characterized as a relatively compact city. The application of Galster et al.'s (2001) sprawl index yielded values in the middle to upper range. Comparing our results with the results from Galster et al. (2001), we found that most of the values exceeded those of an average U.S. urban area. The Viennese land use pattern therefore does not resemble a land use pattern associated with sprawl. Since the results from the measures applied support each other, we conclude that a natural rather than an excessive form of suburbanization is taking place in the Viennese setting implying that urban sprawl is not an important problem for the city of Vienna.

Urban sprawl remains a challenging phenomenon. Our analysis revealed a number of aspects that need careful attention when measuring sprawl and drawing conclusion regarding its occurrence. These aspects include the geographical scale applied as well as the land area drawn upon. Extending our study to a large number of preferably European cities appears a promising field for future research on this topic and could aid the development of generally accepted benchmarks according to which non-sprawl urban areas can explicitly be distinguished from sprawling urban areas. If sprawl is considered a process rather than a condition time series can not only provide further insights but support policy makers in dealing with urban issues successfully.

Appendix

Nomenclature

$i =$	a particular type of land use or spatially based observation, in our case, either residential use (for which we use housing units [principal residences]) or non-residential use (for which we use employees).
$j =$	a different type of land use from i.
$u =$	the largest spatial scale used in the analysis; the entire UA.
$m =$	the medium spatial scale used in the analysis: one square kilometer; 1,2, …, m, …, M such medium-sized squares comprise the UA u.
$s =$	the smallest spatial scale used in the analysis: one quarter of a square kilometer (a square with 500m per side); 1, 2, …, s, …, S such small-sized squares comprise the UA u.
$T(i)u =$	the total number of observations (population [principal residences]) of land use i in UA u.
$T(i)m =$	the total number of observations (population [principal residences]) of land use i in land area m (that is also within u).
$T(i)s =$	the total number of observations (population [principal residences]) of land use i in land area s (that is also within u).
$Pm =$	proportion of land area of spatial scale m within u.
$Ps =$	proportion of land area of spatial scale s within u.
$Au =$	The total developable land area within UA u;

$$= \sum_{m=1}^{M} Pm(Am).$$

$Am =$	the total developable land area within a grid of spatial scale $m = Pm$.
$As =$	the total developable land area within a grid of spatial scale $s = 0{,}25 \times Ps$.
$D(i)u =$	the density of land use i over the developable UA $= T(i)u \div Au$.
$D(i)m =$	the density of land use i over the developable area in $m = T(i)m \div Am$.
$D(i)s =$	the density of land use i over the developable area in $s = T(i)s \div As$.
$F[k, m] =$	the distance between the centroids of grid k and grid m.

Computation Formulas

Density

$$DENS(i)u = D(i)u = T(i)u \div Au = \sum_{m=1}^{M} [T(i)m] \div Au$$

$[min = 1.000\ per\ square\ mile\ (U.S.Bureau\ of\ the\ Census\ standard\ for\ a\ \ UA\ ); max = unlimited]$

Adjustment

$$DENS(i)u = D(i)u = T(i)u \div Au = \sum_{m=1}^{M} [T(i)m] \div Au$$

$[min = 386\ per\ square\ kilometer; max = unlimited]$

Continuity

$$CONT(i)u = \sum_{s=1}^{S} [D(i)s > 9\ Residences\ and\ 49\ Employees = 1; 0\ otherwise] \div S$$

$[min = 0; max = 1]$

Adjustment

$$CONT(i)u \sum_{s=1}^{S} [D(i)s > 3\ Residences\ and\ 18\ Employees = 1; 0\ otherwise] \div S$$

$[min = 0; max = 1]$

Concentration (three alternatives)

1. Very high density grids (with respect to housing units (principal residences) or employees) as a percentage of all grids with developable land within the UA. Very high density grids are grids that are two standard deviations or more above the mean of the density of all grids in the 100 largest UAs (or in a sample of the 100 largest UAs.

2. Coefficient of variation

$$COV(i)u = \left(\sum_{m=1}^{M} [D(i)m - D(i)u]^2 \div M \right)^{0,5} \div \left[\sum_{m=1}^{M} D\ (i)m \div M \right]$$

3. Delta index

$$DELTA(i)u = (0{,}5)\sum_{m=1}^{M} |[T(i)m \div T(i)u] - [Am \div Au]|$$

Clustering

$$CLUS(i)u = \left[\sum_{m=1}^{M}\left(\sum_{s=1}^{4}[D(i)s - D(i)m]^2 \div 4\right)^{0{,}5} \div M\right] \div \left[\sum_{m=1}^{M} D(i)m \div M\right]$$

Centrality (two alternatives)

1. The average distance of a land use (e.g., housing units [principal residences]) from the CBD

$$CBDDIST = T(i)u(A^{0{,}5}) \div \sum_{m=1}^{M} F(k,m)\,T(i)m$$

2. Centralization index

$$CEN(j)u = \sum_{h=1}^{H}[T(j)h - 1]\,[Ah] - \sum_{h=1}^{H}[T(j)h]\,[Ah - 1]$$

Nuclearity

Nuclearity involves the identification of nodes or nuclei. The identification proceeds in the following steps:

1. Identify the highest density (in terms of both housing units [principal residences] and, separately, employees) per one-mile-square (one-square kilometer) grid in the UA.
2. Add all adjacent grids within one standard deviation of the density of this highest-density grid to the node, as well as nodes adjacent to the added nodes, provided they are within one standard deviation of the highest-density grid. The result is the central node, c.
3. Recalculate the density of the newly combined highest-density nucleus c (per #2)
4. Consider all other one-mile-square grids in the UA that are within one standard deviation of the recalculated density (per #3) as separate nuclei, n, provided that they are not immediately adjacent to an existing nucleus.

5. Add any grids adjacent to any nucleus identified in #4 that are within one standard deviation of the recalculated highest-density nucleus c (per #3) to the nucleus.

Two alternative measures can be defined now:

$$NODES = c + \sum n = c + N$$

$$MONONUCLEAR = T(i)c \div \left[T(i)c + \sum_{n=1}^{N} T(i)n \right]$$

Second-best operationalization of residential mononuclearity: the percentage of all housing units (prinicipal residences) in the 2 percent of the densest grids in the UA that are located in the central node, with the central node consisting of all grids in the densest 2 percent of the grids that are contiguous and nearest city hall (St. Stephans cathedral).

Mixed uses

$$MXU(j\ to\ i) = \sum_{m=1}^{M} (D(i)m \times [D(j)m \div T(j)u]) \div D(i)u$$

$[min = 0; max = max\ D(i)m\ observed\ in\ any\ area\ occupied\ by\ j]$

Proximity

The average distance between any two randomly choseb observations of different land uses i and j can be expressed as

$$DIST(i,j)u = \sum_{m=1}^{M} \sum_{k=1}^{M} F(i,j)\, mk[T(j)k \div T(j)u](T(i)m \div T(i)u)$$

$[\boldsymbol{min = 1\ mile}; \boldsymbol{max = unlimited}]$

Adjustment

$$DIST(i,j)u = \sum_{m=1}^{M} \sum_{k=1}^{M} F(i,j)\, mk[T(j)k \div T(j)u](T(i)m \div T(i)u)$$

$[\boldsymbol{min = 1.000\ meters};\ \boldsymbol{max = unlimited}]$

Analogously, the average distance between any two randomly chosen observations of the same land use j in the UA can be expressed as

$$DIST(j,j)u = \sum_{m=1}^{M}\sum_{k=1}^{M} F(j,j)\, mk[T(j)k \times T(j)m] \div (T(j)u)^2$$

It makes sense to standardize these distance measures, inasmuch as bigger UAs will tautologically have greater average distances between any pair of land uses. For this standardization, we compute the average distance between centroids of the M medium-scale grid areas:

$$DISTu = \sum_{m=1}^{M}\sum_{k=1}^{M} F[m,k] \div M$$

$[\boldsymbol{min = 1\ mile; max = unlimited}]$

Adjustment

$$DISTu = \sum_{m=1}^{M}\sum_{k=1}^{M} F[m,k] \div M$$

$[\boldsymbol{min = 1.000\ meters; max = unlimited}]$

From the above terms, we can express three alternative measures of proximity: intrause, interuse, and (weighted) average across uses:

$$PROX(j) = [DISTu \div DIST(j,j)] - 1$$

$$PROX(i,j) = [DISTu \div DIST(i,j)] - 1$$

$$PROX(u) = (DISTu[T(i)u + T(j)u]) \div (T(i)u[DIST(i,i)] + T(j)u[DIST(j,j)]) - 1$$

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