Urban sprawl, car-related pollution and settlement structure: Insights from a two-region general equilibrium model

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ABSTRACT: This paper investigates the potential of combining spatial planning and transport policy for more sustainable settlement structures, i.e. to counteract pollution due to urban sprawl and commuting. To this end, we develop a two-region general equilibrium model to study the interactions between agglomeration externalities and passenger transport-related pollution for an urban core and its hinterland. Building on elements of New Economic Geography, the settlement structure of commuting consumers is determined by the trade-off between the housing quality and transportation costs. The initial equilibrium of utility equality across consumers settling in the two regions, and working in either of the two, is shocked by an exogenous change in environmental preferences. As a first step, we do not allow for migration of households between the two regions. Then, in the longer run, changed preferences induce urban sprawl and affect housing structures via a circular linkage of spatial environmental quality and mobility patterns. The theoretical approach is illustrated by spatially disaggregated data for the NUTS III region Graz (Austria) and explains the need for a fundamental spatial restructuring of urban areas in order to change car-related pollution. The analysis indicates policy options suitable to overcome current trends, with instruments including the restructuring of home construction subsidies, cordon pricing, strict parking management or the improvement of public transport and cycling infrastructure.

KEYWORDS: urban sprawl, pollution, quality of life, settlement structure, geographical economics, spatial planning, transport policy

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1 INTRODUCTION

We start from the assumption that urban sprawl is driven by a declining quality of life in cities which is reinforced by the rising awareness of health impacts. We could think of city inhabitants increasingly becoming aware of local pollutants – an empirically relevant development currently observable. A high degree of motorisation and accessibility by road in the hinterland (e.g. Glaeser and Kahn, 2003) as well as a rising per capita income (OECD, 2005) add to this trend. Starting from spatially differentiated pollution levels, caused by residents' mobility patterns, we look at their interactions with other forces involved such as shifts in congestion levels and housing prices. Thus, differences in both real income and environmental quality constitute the welfare differential for households choosing their location of residence. Obviously, there is a link between settlement structure and automobile use, stemming from a circular causality in spatial environmental quality and commuting. We investigate how environmental and health effects in urban areas caused by transportation may be re-enforced by dispersed settlement structures due to urban sprawl.

Broadly speaking, sprawl is associated with any expansion of the developed land of an urban area. Burchell et al. (1998) suggest that sprawl can take several characteristics including low density, leapfrog development, and widespread commercial strip development. Galster et al. (2001) propose that sprawl can be defined as a pattern of land use that exhibits some combination of dimensions including low density, discontinuity of development, and little open space within the urban area. For our purpose, urban sprawl is simplified to a process that changes population numbers of a city region and a periurban region towards the latter.

The explanatory focus of this paper is dynamic spatial land use development, arising from the interaction of consumption and production activities at various locations with the respective transport system characteristics. The mutual interlinkage of transport and economic activity is a conclusion from the New Economic Geography literature (e.g. Fujita et al., 1999). Importantly, space matters not only by inducing transport costs but also by reducing pollution via spatial planning. To address that issue, in a two-region general equilibrium model of a city centre and its hinterland, we show how the interactions between agglomeration economies and passenger transport-related pollution affect the urban settlement structure. Sprawl is a regional-level phenomenon driven by individual choices over location and land use which are influenced by population numbers, access to infrastructure and real estate prices. In this approach, we investigate how consumers' utility maximising residential decisions "aggregate up" over time and space and thereby steer the spatial extension of the city region.

While New Economic Geography has dealt mainly with firms' location of production, the present paper focuses on consumers' housing decisions. In this vein, the present model unifies elements of urban economics and New Economic Geography to study both the development of cities, having spatial extent, and agglomeration in the same space. Expressed differently, the economics of residential choice is addressed by agglomeration and dispersion forces at two levels. First, at the interregional level, households face a trade-off between transport costs for space and amenity (see Fujita, 1989; Anas et al., 1998), based on the monocentric residential model (Alonso, 1964). Second, at the intraregional level, households search for amenities that are provided by the neighbourhood of a given location. These include the openness of the landscape and environmental quality as well as the proximity to infrastructure and shops.

Existing spatial models of pollution often presume a predetermined separation between polluters and pollutees, usually into a Central Business District and a residential ring (e.g. Verhoef, 2002), taking the pattern of land use between housing and industry as fixed (e.g. Tietenberg, 1974; Henderson, 1977, 1996; Hochman and Ofek, 1979). The present model, first of all, integrates space due to the inherent circular causality in environmental quality and mobility patterns, treating the pattern of land use as endogenous. A second important point is that pollution is caused by commuting residents only. I.e. the occurring externalities are not of the producer-producer type (e.g. Yoshino, 2004) or producer-consumer type (e.g. Verhoef, 2002; Arnott et al., 2004; Marrewijk, 2005) typically found in environmentally oriented models. An urban general equilibrium model with pollution from commuting was developed by Verhoef and Nijkamp (2003), but, unlike the present approach, in a monocentric city setup with all production located in a spaceless Central Business District and in the absence of New Economic Geography forces. Thirdly, contrary to traditional urban models which assume agglomeration benefits as purely external to firms, we assume that externalities emerge due to market interactions involving internal economies of scale at firm level. This results in a monopolistically competitive market structure (Dixit and Stiglitz, 1977). Thus, we investigate how pollution interacts with the other forces which have been identified in the literature as affecting the pattern of land use such as returns to scale in production and products variety as well as traffic congestion. This, together with the circular linkage of car-related pollution and housing structures, is therefore the innovative aspect of the present paper. The literature on spatial (economic) aspects of environmental quality is growing (Nijkamp, 1999), yet, interactions between externalities in an urban context have only been investigated since recently (e.g. Verhoef et al., 1997). However, the present approach explores such interactions as well as interactions between externalities and urban form.

The paper is organised as follows: Section 2 presents a two-region general equilibrium model, investigating the interlinkage of the spatial structure of job location and housing and mobility-related pollution. Section 3 then demonstrates how the tension between centrifugal and centripetal forces create incentives for migration and lead to adjustment processes towards a new equilibrium. In section 4, the theoretical approach is illustrated by spatially disaggregated data for one Austrian NUTS III region, comprising a two-region structure of political districts (city of Graz, Graz hinterland), followed by a selection of promising policy measures, suitable for directing spatial impacts on urban transport structures, and their integration into the model. The final section provides conclusions drawn from the theoretical and empirical analysis.

2 THE THEORETICAL MODEL

Structure

We model a single-sector economy consisting of two regions, an urban core and its hinterland. In particular, we address the political districts of Graz (core) and Graz-Umgebung (hinterland). The focus is on urban sprawl, originating foremost from the circular causality in spatial quality of housing and commuting, which reflects the interaction of consumers' decision of location of residence and the costs of passenger transport. The regions are closed in the sense that we have a constant population. There is no interregional trade in the first and simplest version of the model. Moreover, we assume not only interregional but also (positive) intraregional passenger transport costs, following Tabuchi (1998) based on theories by Alonso (1964), Henderson (1974) and Krugman (1991).[3]

Two types of externalities occur. On the one hand, agglomeration effects explain why most production is concentrated in core the region. On the other, pollution externalities lead to spatial differentiation in environmental quality. Emissions are solely caused by passenger transport, and differences between the two regions in terms of pollution are mainly driven by commuting to work. *Commuting* also includes intraregional ways to work, not only interregional. Another important point is that we model two labour markets, two housing markets, two markets for consumption goods and one capital market with capital flowing freely across regions.

[3] In a "Synthesis of Alonso and Krugman", Tabuchi (1998) presents a two-city system framework with two regions, each containing a central business district. He concludes that while Alonso and Henderson assume zero *interregional* (interurban) transportation costs and positive *intraurban* commuting costs, Krugman assumes positive *interregional* transportation costs and ignores *intraurban* commuting costs.

Consumption

We assume three groups of consumers each living in one of two regions. The representative consumer of *group 1* both lives and works in region *c*, the consumer of *group 2* lives in region *c* (core) and works in region *h* (hinterland), and the consumer of *group 3* both lives and works in region *h*.[4] Moreover, we assume that only consumers of group 2 can choose to shop in either of the regions whereas groups 1 and 3 shop in the region they live and work in.

Consumers across all groups are identical. They have a preference for variety of the single consumption good, i.e. utility levels depend inter alia on the availability of different varieties which better fit their preferences. Assuming utility maximising behaviour, consumers' location decision (whether to stay or move to the other region) is based on the level of utility gained for the region they live in, i.e. region *c* for group 1 and region *h* for groups 2 and 3.

The representative household's level of utility is a function of a quantity composite of (non-transport) consumption goods *X*, the quality of housing *H* and transport *T*. Let subscript *r* refer to the respective region, with $r = c, h$, then we have

$$U_r = U\left(X_r, H_r, T_r\right) \tag{1a}$$

More specifically, the utility levels for each region U_r can be modelled by a nested constant elasticity of substitution (CES) function. The expenditure shares are given by α, β and ($1\text{-}\alpha\text{-}\beta$); σ^c is the elasticity of substitution in preferences between any pair of goods.

$$U_r = \left(\alpha^{1/\sigma^c} X_r^{(\sigma^c-1)/\sigma^c} + \beta^{1/\sigma^c} H_r^{(\sigma^c-1)/\sigma^c} + \left(1-\alpha^{1/\sigma^c}-\beta^{1/\sigma^c}\right)^{1/\sigma^c} T_r^{(\sigma^c-1)/\sigma^c} \right)^{\sigma^c/(\sigma^c-1)} \tag{1b}$$

The representative consumer's preferences are characterised by love for variety, i.e. different varieties of goods are imperfect substitutes in consumption. To model how utility increases via this preference for variety, following Dixit and Stiglitz (1977), let X_r be a subutility function defined over a range of varieties of consumption goods, where $x_{r,i}$ denotes the consumption of each variety, and $i = 1,..., n_r$ is the number of varieties produced in each region. Then the quantity composite X_r is defined by the CES function

$$X_r = \left(\sum_i \left(x_{r,i}\right)^{(\sigma^X-1)/\sigma^X} \right)^{\sigma^X/(\sigma^X-1)} \qquad i = 1,..., n_r \tag{2}$$

[4] Since the group of consumers who live in region *c* but work in region *h* is assumed to be negligibly small, we abstract from including this group in our analysis.

where σ^x denotes the elasticity of substitution between any pair of varieties $\{x_i, x_j\}$. If we set $\sigma^x = 1/(1-\rho)$ with $0 < \rho < 1$, then ρ represents the intensity of the preference for variety in consumption goods. When ρ is close to 1 (i.e. σ^x is very high and increases towards infinity), differentiated goods are nearly perfect substitutes. Reversely, when ρ is close to 0 (i.e. σ^x is close to 1), consumers prefer to consume a greater variety of consumption goods. Since utility is greater if consumers have access to a larger number of varieties, equation (2) is suitable to model the advantage of proximity, prevailing in the city centre.

The representative household maximizes equation (1) and equation (2) subject to the budget constraint

$$Y_r = \sum_i p_{r,i} x_{r,i} + HC_r + TC_r \qquad i = 1,\ldots,n_r \tag{3}$$

where Y is the exogenous level of income and p is the price of the consumption good; HC denote housing costs and TC denote transport costs.

This maximisation problem can be solved in two steps: First, the representative household splits income Y_r between goods X_r, H_r and T_r. Second, each $x_{r,i}$ is chosen such that costs of attaining the level of X_r^*, as determined in the first step, are minimized. The maximisation problem's lower-level step is therefore an expenditure minimization problem:

$$\begin{aligned} &\min \ \sum_i p_{r,i} x_{r,i} \\ &\text{s.t.} \quad X_r^* = \left(\sum_i \left(x_{r,i} \right)^{(\sigma^X - 1)/\sigma^X} \right)^{\sigma^X/(\sigma^X - 1)} \end{aligned} \tag{4}$$

Housing costs HC depend on the quality of housing H. Importantly, housing quality also includes environmental quality, which is a public good yet determined by the level of pollution caused by commuting. Thereby, the housing quality is decreasing with the level of local emissions (see section on "pollution"). Then, housing costs represent the fraction of housing quality that has to be paid for in monetary terms. They mainly involve real estate prices or rental charges.

Transport costs TC depend on the demand for transport required for commuting to work, for the main part, or for shopping. They hinge on the number and distances[5] of demanded transport ways and on mode choice. Moreover, transport costs involve congestion costs such as increased gasoline consumption. Thus, a lower car dependency due to better public transport infrastructure, smaller distances and less congestions imply lower TC.

[5] Distances determine the type of way, i.e. if it is interregional or intraregional, which, in turn, depend on the consumer group (1, 2 or 3) the respective household belongs to.

Production

We assume a single sector producing a heterogeneous consumption good. Agglomeration externalities emerge from the interaction of economies of scale at the level of the individual firm, transportation costs (for goods) and factor mobility. With internal economies we need to model an imperfectly competitive market structure. We do so by following the Dixit-Stiglitz (1977) model of monopolistic competition. In this vein, production exhibits economies of scale at the level of the variety yet no economies of scope across varieties, which results in each firm supplying exactly one variety. However, free entry and exit results in zero profits.
More specifically, in the Dixit-Stiglitz setting, agglomeration effects arise through consumers' preferences for heterogeneity (love for variety) and firms' requirements for limited productive resources. As for consumers, the level of utility increases not only with the aggregate quantity of varieties consumed but also with the number of varieties, which are available. The same applies to producers, since the importance of variety of intermediate inputs operates in a parallel fashion. In this vein, final production increases by virtue of sharing a wider variety of intermediate suppliers, with primary factors increasing less than proportionally.[6] Central to the analysis of differentiated products is that variety in consumer goods or producer inputs yield external scale economies, although firms earn normal profits.

Agglomeration externalities are modelled in a reduced form, i.e. no micro-foundation is spelled out explicitly. Every firm has fixed costs in production and a decreasing average cost curve. Based on empirical data for the city of Graz and Graz hinterland, production in either region involves different marginal input requirements of labour (*m*) and capital and different fixed factor requirements (*F*), independently of the quantity manufactured and assumed to comprise labour only: $l = F + m \cdot x$, where *l* is the labour required to produce any output *x*. Then, the production of a quantity *x* of any variety *i* in region *r*, with production coefficients γ and δ, involves

$$x_{r,i} = l^{\gamma_r} \cdot k^{\delta_r} \qquad \text{with } \gamma_r + \delta_r > 1 \qquad (5)$$

Thus, there are increasing returns in the production of each variety. This and the fact that there is an unlimited number of varieties that could be produced, together with consumers' love for variety, imply that each firm produces just one variety and no variety is produced by more than one firm. Central to the Dixit-Stiglitz approach is that the number of varieties *n* produced in either region *r* becomes an endogenous variable.

[6] Duranton and Puga (2004) identify *sharing, matching* and *learning* as the three types of theoretical mircro-foundations of urban agglomeration economies. Thereby, for example *sharing* the gains from a wider variety of differentiated intermediate inputs produced by monopolistically competitive industry acts as a production-side version of the Dixit-Stiglitz setting.

The profit-maximising price for each variety in either region is a fixed markup on marginal cost. The markup is determined by the price elasticity of demand, which is constant and equal to $\sigma^x = \varepsilon = 1/(1-\rho)$. Since the number of varieties produced, in the base year, is higher in the centre, i.e. $n_c \geq n_h$, we assume a higher markup and a lower elasticity of substitution, respectively, for region *c*.

Internal scale economies and agglomeration externalities, accordingly, explain why most production is located in the centre region *c*. This in turn implies a corresponding distribution of jobs, since forward and backward linkages create an incentive for workers to be close to the production of consumer goods. It follows that the size of a market (or a region) and its labour force L_r determine the variety of consumption goods offered to households and the diversity of inputs available to firms. Thus, for the equilibrium number of firms, which equals the number of varieties produced, we have $\partial n_r / \partial L_r > 0$. The aggregate positive relation between labour supply and productivity is consistent with most structural models of agglomeration benefits (Duranton and Puga, 2004).

Pollution and quality of housing

We assume that emissions are solely caused by passenger transport and that differences between the two regions in terms of causing pollution are mainly driven by commuting to work. We further assume that the daily commuting distance is higher for the hinterland *h* than for the core *c* and that the residents of region *h*, more specifically group 2 consumers, contribute considerably to emissions in region *c*. To address this issue, we calculate the emissions of different pollutants for both regions separately. To that end, we first calculate *emissions per group* of consumers

$$E_1 = E\left(T_c\right)\cdot g_1 = E\left(T_{cc}\right)\cdot g_1 = E\left(T_1\right) \qquad \text{for group 1} \qquad (6a)$$

$$E_2 = E\left(T_h\right)\cdot g_2 = E\left(T_{hc}\right)\cdot g_2 = E\left(T_2\right) \qquad \text{for group 2 and} \qquad (6b)$$

$$E_3 = E\left(T_h\right)\cdot g_3 = E\left(T_{hh}\right)\cdot g_3 = E\left(T_3\right) \qquad \text{for group 3,} \qquad (6c)$$

where emissions from commuting arise in a fixed proportion of units driven. Then, for example, pollution caused by group 2 (E_2) is the product of emissions per average commuting way from region *h* to region *c*, T_{hc} (in units driven), and the share of consumers in group 2 (g_2), with $g_1 + g_2 + g_3 = 1$. Alternatively stated, it is a function of total transport demand of group 2, T_2 (in units driven). The same applies for groups 1 (share g_1) and 3 (share g_3). The underlying assumption for (6) is only one average commuting way per consumer and day, which comprises the daily way to work and the proportionate way for shopping per day. However, this

simplifying assumption for (6b) does not hold if some group 2 consumers shop in region *c* and some in *h*.
Then, since residents of group 2 contribute to emissions in the core region *c*, *emissions per region* are

$$E_c = E_1 + \alpha \cdot E_2 \qquad \text{for the core and} \qquad (7)$$

$$E_h = E_3 + (1-\alpha) \cdot E_2 \qquad \text{for the hinterland,} \qquad (8)$$

with $0 \le \alpha \le 1$.

Differences in emissions between the two regions cannot be reduced to differences in commuting distances between the two regions, however. An important point is that people mainly commute into the core region for work not the other way round. Moreover, the modal split of commuting is also influenced by the availability of public transport alternatives, with a lower car-dependency in the core than in the hinterland. Accordingly, the specific emissions per average commuting way $E(T_{cc}) < E(T_{hc}) \le E(T_{hh})$ diverge for the two regions due to the differences in the modal split and the absolute distances in passenger transport.

The present model gives emissions not only as an output but has an impact on utility through the quality of housing variable, caused e.g. by particulate matter emitted or re-circulated by transport. Assuming that emissions thus cause a disutility, the quality of housing is reduced by pollution such that the quality of housing is defined as the level of green environment and the amount of space offered, expressed by *G*, and is decreasing with the level of local emissions,

$$H_c = G_c - \lambda \cdot E_c \qquad \text{for the core and} \qquad (9a)$$

$$H_h = G_h - \lambda \cdot E_h \qquad \text{for the hinterland} \qquad (9b)$$

For the base year, the hinterland is assumed to offer a better environmental quality and more space compared to the hinterland, i.e. $G_c \le G_h$.

3 THE INCENTIVES FOR MIGRATION

Dispersion and agglomeration forces [7]

In the present context, “dispersion“ is understood as urban sprawl and “agglomeration” as the development of dense housing structures in the centre. Accordingly, agglomeration and dispersion forces shape the spatial distribution of *consumers*, not firms. Dispersion and agglomeration processes are strongly interlinked with the spatial differentiation in environmental quality and, equally important, with transport possibilities and costs. Moreover, consumers in the centre have access to a larger range of varieties than in the hinterland. Thus, agglomeration forces originate from increasing returns to scale and the implied spatial distribution of jobs with consumers minimising commuting effort. One usually distinguishes two opposite forces, the first leading to urban sprawl (centrifugal) and the second causing dense housing (centripetal):

centrifugal forces:

> *lifestyle effect*: people want to enjoy much living space and high recreation due to an increasing per capita income, a high degree of motorisation and high accessibility by road.
>
> *housing effect*: consumers tend to migrate to the region with less competition for land and housing, i.e. where real estate prices are lower
>
> *congestion effect*: the costs for passenger transportation due to congestion and the level of pollution are lower in the hinterland.

centripetal forces:

> *cost-of-transport effect*: people tent to migrate to the region where distances are shorter and the possibility for modal choice is higher, i.e. provision of public transport is better.
>
> *proximity effect*: people want to enjoy spatial proximity (thereby saving transport time and costs) and access to a variety of differentiated products as well as to local public goods

To sum up, centrifugal forces imply more settlement in the hinterland *h* associated with a higher demand for passenger transport and a higher car dependency in the overall region. Centripetal forces, on the contrary, favour urban agglomeration,

[7] Agglomeration and dispersion forces refer to the spatial distribution of *consumers*, not firms. Of course, firms may follow consumers or vice versa.

such as core region *c*, and can lead to a reduction in the demand for passenger transport and a higher share of public transport. Both forces will be addressed by policy measures in order to reduce transport demand.

Adjustment processes and model solution

The economy is analysed for three points in time: period *t-1*, the base year, period *t* thereafter and period *t+1*, which follows period *t* with a lag of some 15 years or more. For the base year, we assume, first of all, equal utility levels in regions *c* and *h*, that is

$$(U_c)_{t-1} = (U_h)_{t-1} \qquad \text{for period } t\text{-}1 \qquad (10)$$

This implies that for the three consumer groups the utility maximising bundle of consumption goods *X*, housing quality *H* and transport good *T* differs with respect to the component-specific contribution to welfare. In the initial state, we assume that environmental quality contributes more to welfare in region *h* than in *c*. However, the expenditure share for housing is assumed to be equal for both regions.[8] Moreover, group 2 workers make up only for a small share of the centre labour force, and wage per capita is assumed to be the same for both regions in the base equilibrium.
Then, this equilibrium implies, for group 1 consumers, that the advantages of proximity and variety compensate the lower quality of housing, including the quality of environment, in the centre. Accordingly, the overall housing quality's contribution to welfare is low compared to residents of the hinterland. Then, for group 2 consumers the housing advantages in the hinterland compensate higher transport costs, and for group 3 consumers the advantages of housing compensate the loss in welfare due to a smaller number of varieties available. This base-case equilibrium is stable in the sense that the migration of one single household from region *c* to region *h* causes another household from the hinterland to move to the centre in turn (and vice versa). This is because one additional resident in the hinterland raises congestion costs and/or housing costs, which changes the location decision for another resident, accordingly.

As a second step, we use an exogenous change in environmental awareness which leads to a new equilibrium.[9] To address this issue, we integrate the *lifestyle effect* to model consumers' changed environmental preferences. For example, the city residents raise their environmental awareness. Thereby, the housing quality, or more specifically the environmental quality, is modelled such that it contributes

[8] The underlying assumption is that lower real estate prices together with a higher average quantity of space consumed results in equal shares.
[9] Although in reality preferences may change continuously, thereby always seeking for a new equilibrium, we model a discrete change of preferences to explicitly show the effects of such a change.

less to group 1 consumers' utility. The integration of the *lifestyle effect* therefore implies that the overall dispersion forces are strengthened. Importantly, the centrifugal forces are modelled by having different assumptions in the short and long term. In the short term (until period *t*), no change of location can take place, while in the longer term (until period *t+1*) we allow migration. This assumption is based on the fact that households adapt slowly in their housing conditions, such that housing structures in period *t+1* reflect preferences from quite some time ago, let's say 15 years or more. Consequently, after the change in preferences utility levels differ for the two regions due to stronger centrifugal forces:

$$(U_c)_t < (U_h)_t \qquad \text{for period } t \tag{11}$$

As a consequence of (11), migration can result until period *t+1*. In particular, some group 1 consumers may change their place of residence yet not the location of work. Migration therefore initially arises as changed proportions *g* of consumers in groups 1 and 2 (compare (6a)-(6c) and the explanations below). Then, *urban sprawl* arises as

$$(g_1)_t > (g_1)_{t+1} \text{ and } (g_2)_t < (g_2)_{t+1} \tag{12}$$

Thus, the share of consumers in group 1, who live and work in region *c*, decreases while the share of consumer in group 2, who live in region *h* and work in region *c*, increases.

Adjustment also occurs between groups 1 and 3. In this context, *urban sprawl* arises as

$$(g_1)_t > (g_1)_{t+1} \text{ and } (g_3)_t < (g_3)_{t+1} \tag{13}$$

As a consequence, the amount of labour available in region *h* rises (and declines in *c*). Based on the approach of Dixit and Stiglitz, the size of the labour force L_r determines the variety of consumption goods offered to households and the diversity of inputs available to firms. The larger variety of consumption goods available in the hinterland therefore increases the well being of households living in the respective region (*love of variety*).

In order to determine the settlement structure, let the share of households living in either region be $g_c = g_1$ and $g_h = g_2 + g_3$. Then, taking into account the adjustment processes presented above, *urban sprawl* implies

$$(g_c)_t > (g_c)_{t+1} \text{ and } (g_h)_t < (g_h)_{t+1} \qquad \text{with } g_c + g_h = 1 \text{ for each point in time} \tag{14}$$

A decrease in the share of households living in the centre and, accordingly, an increase in the share of households living in the hinterland imply new housing structures. Finally, with slow adaptation in housing conditions, we assume that in the long term utility levels from housing and transport costs will equalise across the two regions, i.e. marginal revenue equals marginal cost. Then we have

$$(U_c)_{t+1} = (U_h)_{t+1} \qquad \text{for period } t+1 \tag{15}$$

This new equilibrium does not solely stem from changed preferences but also, and most importantly, from the circular causality in spatial environmental quality and migration. I.e. new environmental preferences induce urban sprawl (12) which is reinforced by resulting commuting levels and mode choice. Thus, from equations (7) and (8) and equation (12) we find that urban sprawl, in the sense of residents solely changing their place of residence, increases emissions in the overall region

$$(E_c + E_h)_t < (E_c + E_h)_{t+1} \tag{16}$$

$$\text{with } (E_c)_t < (E_c)_{t+1} \text{ and } (E_h)_t < (E_h)_{t+1}$$

due to an increased transport demand and a modal shift towards a higher car dependency. Since $E_c \geq E_h$ for the base period and assuming that migration flows towards region *h* (12), increases emissions predominantly in the centre such that

$$\left(\frac{E_c}{E_h}\right)_t < \left(\frac{E_c}{E_h}\right)_{t+1}, \tag{17}$$

the resulting levels of the quality of housing in equation (9) imply, other things equal, a re-enforcement of urban sprawl.

Adjustment processes also take place in the opposite direction, thereby leading to migration from region *h* to region *c*. This can happen, despite an increase in environmental preferences of group 1, when the centripetal forces outweigh the centrifugal ones for some proportion of consumers of group 2 or 3. They may decide to live in the centre, because the *housing effect* is weakened due to stronger competition for land and/or due to higher congestion costs in the hinterland. Another reason is the deterioration in environmental quality in the periphery. In this vein, the *cost-of-transport effect* and the *proximity effect* dominate the households' residential decision. In particular, the fact that consumers in group 2 can shop in either region creates an incentive for them to live in the centre. This arises since the core region offers a larger range of varieties.

The resulting dynamics of residential adjustments, predominantly towards the hinterland, leads to an equilibrium with more dispersed settlement structures (15).

We are particularly interested in this new equilibrium and its housing structures, accordingly, since it presumably won't give a socially optimal solution. With an expected exceedingly high level of resource wastage there is obviously room for policy intervention to overcome structures resulting from individual optimisation under suboptimal framework conditions.

4 EMPIRICAL ANALYSIS AND POLICY ISSUES

The theoretical analysis is illustrated by spatially disaggregated data for the NUTS III region Graz (Austria), comprising a two-region structure of political districts. Structural trends as identified by empirical data exemplify the adjustment processes inherent in the present model.

Empirical data

In Austria, the spatial distribution of consumers changes towards dispersed settlement structures – a process characterised by urban sprawl, stemming mainly from new preferences within the population. These changing lifestyles imply an increasing demand for housing space, preferably near green belts with a high recreation value. In fact, cities often lack adequate living space and possibilities for individuality. In addition, suburbanisation is driven by a high degree of motorisation and a high accessibility by road in areas surrounding the city centre (ÖROK, 2005, 4, 97).

The model of section 2 and, accordingly, the adjustment processes of section 3 are motivated by empirical data for the NUTS III region Graz inclosing the political districts "Graz" (city of Graz) and "Graz-Umgebung" (Graz hinterland). In fact, past decades have shown a strong movement of its population towards Graz hinterland (see Table 1), with currently 20% of the labour force working in the city commuting from outside. In addition, the region is characterised by a very dynamic development with substantial detrimental effects in the transport sector. These include high amounts of local pollutants like fine dust (particulate matter), regular collapses of traffic flows in rush hours and noise effects. Moreover, due to the Graz basin and inversion layers in winter, the accumulation of pollutants in the core

	city of Graz	share [%]	**Graz hinterland**	share [%]
1971	249.089	71,4	99.806	28,6
1981	243.166	69,6	106.343	30,4
1991	237.810	66,8	118.048	33,2
2001	226.244	63,3	131.304	36,7

Table 1: Development of population split up in NUTS III region Graz
Source: Statistik Austria (population census 1971/1981/1991/2001)

region is strong. Table 1 indicates an increasingly dispersed settlement structure with a rise in share of hinterland residents from 28.6% in 1971 to 36.7% in 2001 of total NUTS III region population. Reversely, the number of city inhabitants falls accordingly. This change in the housing structure reflects a considerable increase in the number of commuters from Graz hinterland to the city centre (see Table 2). In particular, since 1971 the number of ingoing commuters from the hinterland has more than doubled and reached 29.801 in 2001. In the context of our model, the share of consumers in group 2 (g_2) rises mainly due to households switching from type 1 to type 2 (see equation (12)). At the same time, we observe an increase in

	commuters from the hinterland to the city	commuters from the city to the hinterland
1971	14.921	1.304
1981	21.995	1.806
1991	26.530	4.060
2001	29.801	6.960

Table 2: Commuters within NUTS III region Graz
Source: Statistik Austria (population census 1971/1981/1991/2001)

the number of city residents commuting to Graz hinterland albeit not by comparable numbers. However, the development presented in Table 2 reflects current urban mobility patterns that are inter alia driven by changed lifestyles and characterised by an increasing degree of motorisation. Mobility patterns are equally demonstrated in Table 3 by rising numbers of both ingoing and outgoing commuters in both political districts. "Balance", for Graz city, then denotes the difference between ingoing commuters (living in Graz hinterland or any other outer part of Austria and commuting into Graz city for work) and outgoing commuters

		residents	workers	ingoing commuters	outgoing commuters	balance
city of Graz	1981	105.981	151.449	53.169	7.701	45.468
	1991	102.196	156.475	65.858	11.579	54.279
	2001	103.860	157.005	70.257	17.112	53.145
Graz hinterland	1981	46.359	27.065	11.251	30.545	-19.294
	1991	53.054	33.079	18.469	38.444	-19.975
	2001	63.956	43.309	28.697	48.344	-19.647

Table 3: Development of commuters into and out of NUTS III region Graz within Austria
Source: Statistik Austria (population census 1981/1991/2001)

(living in Graz city and commuting to Graz hinterland or any other outer Austrian region for work). From Table 2 and Table 3 we find that more than 40% of Graz city ingoing commuters within Austria live in the political district of Graz hinterland, alternating between 40.3% in 1991 and 42.4% in 2001. This is essential for interpreting numbers in Table 3 in terms of the two-region structure of the NUTS III area Graz. Most interesting among these, city residents (103.860 for 2001), living in Graz city and also working there or at any other location in Austria, make up for two thirds of city workers (157.005 for 2001), working in Graz city and also living there or at any other location in Austria. This is because the difference between residents and workers equals the difference between ingoing and outgoing commuters ("balance"). Since ingoing and outgoing city commuters are linked to Table 2, the decline in city residents, together with the rise in city workers and the fact that hinterland residents and workers both increase in numbers (Table 3), demonstrate the impact of urban sprawl on housing and working structures.

A selection of policy measures suggested by the present analysis is given in the next section. It comprises both long-term instruments and instruments available for short-term effects in directing impacts on urban housing and transport structures.

A selection of policies

Central to the idea of policy selection is the spatial restructuring of urban areas in order to change car-dependent mobility patterns. As the design of urban cores is a major reason for urban sprawl, a support of dense living with high living quality would counteract this process. Thus, the aim is to make the urban centre more attractive and, equally important, to regulate land use in order to create mixed-used areas with high density and polycentrism (OECD, 2005, 110). This supports public transport infrastructure and results in a lower car dependency in the overall region.

Clearly, current health and noise impacts call for a transport reorganisation in order to achieve mobility and access options that do not involve substantial environmental effects. However, though the spatial structure of an economy depends on transport organisation, spatial planning policy is more effective in steering (long-term) mobility patterns than transport policy (OECD, 2005, 110). Thus, choices in transport and long-term choices in land use and the settlement structure, accordingly, are mutually dependent. The following list comprises a selection of policy measures we consider suitable for directing spatial impacts on urban transport structures to address car-related pollution. For each instrument, the integration into the model of section 2 is discussed briefly.

Restructuring of home construction subsidies

Subsidies for new constructed homes are redirected to the remodelling of old houses. This promotes dense living in two different aspects: One the one hand, it reduces urban sprawl and fosters dense living in the centre. While, on the other, it promotes dense living in the periphery and therefore supports public transport. An additional effect is the reduction of overall (private) energy consumption since new houses are generally better isolated due to stronger legal requirements. Importantly, the restructuring of subsidies steers long-term transport demand via its influence on the settlement structure. It can be integrated into the model via higher housing costs HC_h in the hinterland and a lower quality of housing H_h accordingly.

Cordon pricing

The mechanism of cordon pricing charges cars that enter a high-activity area. Thus, region *c* is encircled with a cordon such that fees are collected from people driving into the encircled region via toll booths or parking permits. Moreover, prices may vary by time of day in order to address peak congestion periods. Cordon pricing aims at consumers covering infrastructure maintenance costs or internalising environmental and health costs of passenger transport. It enters the model as a lump sum tax on transport costs per commuting way (constant fee per entry in the central region) for group 2 consumers.

Improvement of infrastructure for pedestrians and cycling (centre)
or *establishment of parks and recreation areas* (centre)

Cycle tracks are improved in terms of safety and extended to build up a larger network for bikers. New recreation areas such as small parks and other car-free zones are established in the core region and existing ones are maintained accurately. This results in a reduction in car use and, accordingly, in a reduction of space requirements for transport infrastructure and parking in the centre. Consequently, reduced levels of pollution and congestion and more space to live out individuality make the core region more attractive. This policy measure is implemented as an increased quality of housing in region *c*.

Strict parking restrictions and provision of park&ride facilities
or *improvement of public transport infrastructure and service* (overall region)

In the centre, the number of parking lots is reduced and/or parking fees are increased considerably. On the outskirts, park&ride facilities, offering connections at frequent intervals, are provided at moderate prices. The measure enters the model via changed transport demand for the overall region, i.e. for the centre and the hinterland. This changed demand can either be modelled through a shorter average commuting way T_{rr} (in units driven) or equally through a reduced transport demand per group of consumers or per region.

4 CONCLUSIONS

This paper formulates a two-region general equilibrium model including New Economic Geography forces, in which residents are mobile between an urban core and its hinterland. Migration is linked to shifts in pollution levels, caused by residents' mobility patterns, and shifts in congestions levels as well as regional differences in the number of varieties of consumption goods. Consumers choose to reside in the region that gives a higher level of utility. Differences in both real income and environmental quality constitute the welfare differential for households choosing their location of residence. Thus, we show how preference for variety on the demand side and increasing returns on the supply side interact with urban externalities.

A higher esteem of environmental quality drives settlement to the hinterland, until the marginal benefit is counterbalanced by increased transport costs due to a rise in absolute levels of commuting costs and/or due to higher congestion levels and by increased housing costs. The long term equilibrium, equating per capita utility in the two regions, implies more people settling in the hinterland and thus an increasing number of commuters. The cumulative result of individual utility maximising actions leads to a socially suboptimal outcome. The analysis is therefore suited to an exploration of residential preferences in order to avoid wastage of resources and a non-parsimonious use of land.

In fact, over the past decades, urban growth has taken the form of sprawl. The theoretical analysis shows, illustrated by spatially disaggregated data for the NUTS III region Graz, how the spatial structure of job location and housing is linked to mobility-related pollution, and, reversely, how a reorganisation of the transport system via changes in the spatial structure can reduce emissions. The resulting environmental quality decline both in the centre and the hinterland as well as the rise in congestion for commuters can be mitigated by spatial planning instruments. Space thus matters not only because of the transportation costs it imposes on the economy, but also because spatial planning can serve as an effective instrument to counteract current mobility patterns and thereby control pollution damages.

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