

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

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ABSTRACT: This paper develops a two-region (within NUTS III) computable general equilibrium model of the core-periphery type, 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 congestion levels as well as regional differences in housing prices and in the number of varieties of consumption goods. Building on New Economic Geography forces, 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, households do not migrate between the two regions. Then, in the longer run, changed preferences induce urban sprawl and affect settlement structures via a circular linkage of spatial environmental quality and mobility patterns. Thus, differences in both real income and environmental quality constitute the welfare differential for utility maximising households choosing their location of residence. The model is expanded to the empirical domain for the NUTS III region Graz (Austria). Simulation results are to explain the need for a spatial restructuring of urban areas in order to change car-related pollution, predominantly in the centre (PM_{10}). The analysis thus is to investigate the potential of combining spatial planning and transport policy for more sustainable settlement structures, 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

JEL: R13, R14, R23, R41

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1 INTRODUCTION

Mobility activities currently cause detrimental environmental and health effects, predominantly in urban areas. On the one hand, the largest share of of car mileage accrues to central regions. On the other hand, current studies for urban areas identify up to 60% of PM₁₀ concentration levels as triggered by transport (Amt der Steiermärkischen Landesregierung, 2003). As a consequence, the spatial distribution of consumers changes towards dispersed settlement structures, stemming mainly from new environmental preferences within the population. These changing lifestyles imply an increasing demand for housing space, preferably near green belt, whereas cities often lack adequately attractive living space (ÖROK, 2005). While the ultimate objective of mobility is granting access to goods and people, the spatial distribution of economic activities and land use devoted to residence, work, shopping, leisure and production affects the level of fossil fuel emissions. This explains how current mobility patterns such as urban sprawl reinforce the noxious effects of urban transport system characteristics.

We therefore 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. 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. This process in turn is based on the fact that cars increase the possible distance between residences and jobs. In this regard, 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. Subsequently, various policy instruments are analysed with respect to current environmentally unfavorable mobility and spatial trends.

Thus, 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 "sprawl" can take a variety of characteristics (Burchell et al., 1998; Galster et al., 2001), for our purpose, however, urban sprawl is simplified to a process that changes population numbers of a city region and a periurban region towards the latter.

While New Economic Geography has dealt mainly with firms' location of production, the present paper focuses on consumers' housing decisions and the resulting settlement structure. 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. Although traditional urban models and NEG models deal with the same spatial phenomena, they differ in two major respects – the source of dispersion force and the range for political action (Fujita and Mori, 2005):

"On the one hand urban economics models consider land rents for urban housing [...] as a dispersion force. [I]n these models [...] the intra-city and inter-city spaces are not integrated in the same location space. [...] On the other hand, the models in the early stage of the NEG framework [...] considered the immobile resources (such as land) as the source of dispersion force, and by doing so focused on the *spatial distribution of cities*, while abstracting from the intra-city structure [i.e., a city consists of a (spaceless) point in the location space]."

"[U]rban economic models assign big roles to developers and city governments, while the NEG has been concerned with self-organization in space."

Expressed differently, in the present approach, agglomeration and dispersion forces address the economics of residential choice 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. On the contrary, they represent consumer-consumer externalities. 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 equilibrium model, investigating the interlinkage of region specific job and housing structures and mobility-related pollution. The next section is devoted to the numerical implementation of the theoretical approach and to simulation results. First, the model is illustrated by data for one Austrian NUTS III region, comprising a two-region structure of political districts. Second, we shall briefly outline the undertaken CGE approach and discuss the estimation of parameter values. Section 3 then demonstrates how various driving (centripetal and centrifugal) forces trigger interregional migration processes. We shall then go on to suggest a selection of promising policy measures, suitable for directing spatial impacts on urban transport structures, and discuss their integration into the model (section 4). The final section provides conclusions drawn from the theoretical and empirical analysis.

2 MODEL STRUCTURE

We model a single-sector economy consisting of two regions, an urban core and its hinterland. Residents are mobile between regions, thereby determining a specific settlement structure. The focus is on urban sprawl, originating foremost from the circular causality in spatial quality of living and commuting, which reflects the interaction of consumers' location decision of residence and the costs of passenger transport. We assume not only interregional but also intraregional passenger transport costs, following Tabuchi (1998) based on theories by Alonso (1964), Henderson (1974) and Krugman (1991)¹. Moreover, two types of externalities occur: First, agglomeration effects explain why most production is concentrated in core the region. Second, pollution externalities lead to spatial differentiation in environmental quality. Building on New Economic Geography, results are primarily driven by the tension between centripetal (agglomeration) forces centrifugal (dispersion) forces. In the present context, "dispersion" is understood as urban sprawl and "agglomeration" as the development of dense housing structures in the centre.

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*². 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 a single consumption good, i.e. different varieties of that good are imperfect substitutes in consumption.

The representative household's level of utility is a function of a quantity composite of consumption goods X , the housing good H , environmental quality Q and road congestion N , where solely the latter exhibits a negative correlation to utility

$$U = U(X, H, Q, N) \quad (1a)$$

¹ 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.

² The group of consumers who live in region *c* but work in region *h* is assumed to be negligibly small.

Let subscript r refer to the respective region, with $r = c, h$, then the utility levels U_r can be modelled by a nested constant elasticity of substitution (CES) function. The expenditure shares are given by α, β, γ and $(1-\alpha-\beta-\gamma)$; σ^c is the elasticity of substitution in preferences between any pair of goods.

$$U_r = \left(\alpha^{1/\sigma^c} \cdot X_r^{(\sigma^c-1)/\sigma^c} + \beta^{1/\sigma^c} \cdot H_r^{(\sigma^c-1)/\sigma^c} + \gamma^{1/\sigma^c} \cdot Q_r^{(\sigma^c-1)/\sigma^c} + \right. \\ \left. + (1-\alpha^{1/\sigma^c}-\beta^{1/\sigma^c}-\gamma^{1/\sigma^c})^{1/\sigma^c} \cdot N_r^{(\sigma^c-1)/\sigma^c} \right)^{\sigma^c/(\sigma^c-1)} \quad (1b)$$

To model how utility increases via consumers' love 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 $i = 1, \dots, n_r$ is the number of varieties produced in each region. Then the quantity composite X_r is defined by the CES function (2), where $\sigma^x = 1/(1-\rho)$ denotes the elasticity of substitution between any pair of varieties $\{x_i, x_j\}$ with $\rho, 0 < \rho < 1$, representing the intensity of the preference for variety. Thus, doubling industry output means more than doubling (aggregate) utility gained from X .

$$X_r = \left(\sum_i (x_{r,i})^{(\sigma^x-1)/\sigma^x} \right)^{\sigma^x/(\sigma^x-1)} \quad i = 1, \dots, n_r \quad (2)$$

The representative household maximizes equation (1) and equation (2) subject to the budget constraint (3). Let Y represent the exogenous level of income and p be the price of the consumption good; let HC denote housing costs and TC denote transport costs, then we have

$$Y_r = \sum_i p_{r,i} x_{r,i} + HC_r + TC_r \quad i = 1, \dots, n_r \quad (3)$$

Housing costs HC depend on the demand for housing good H and, in this vein, mainly involve real estate prices or rental charges.

Transport costs TC hinge on the number and distances³ of demanded commuting and/or shopping ways as well as on mode choice. Furthermore, transport costs involve congestion costs such as increased gasoline consumption.

On the other hand, environmental quality, supplied as public good – at one level for the centre and one for the hinterland – enters the utility function directly. In this

³ 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.

matter, environmental quality is influenced by regionally differentiated pollution due to commuting, i.e. it is decreasing with the level of local emissions (see section on “pollution”). Thus, only part of the utility is restricted by the budget constraint (3).

This maximisation problem can be solved in two steps: First, the representative household splits income Y_r between goods X_r , H_r and CG_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

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

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. 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 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 m of labour 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 share parameter δ and elasticity of substitution σ^P , involves

$$x_{r,i} = \left(\delta \cdot K^{(\sigma^P-1)/\sigma^P} + (1-\delta) \cdot L^{(\sigma^P-1)/\sigma^P} \right)^{\sigma^P/(1-\sigma^P)} \quad (5)$$

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. 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 .

Hence, 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).

Environmental quality and pollution

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. Importantly, emissions E are raised by particulate matter either emitted or re-circulated by transport. 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 . In this vein, it is equally important to know where pollutants accumulate, not only where emissions are originally caused. To address this issue, we calculate the emissions of different pollutants for both regions separately. We first calculate *emissions per group* of consumers

$$E_1 = E(T_{cc}) \cdot g_1 \quad \text{for group 1} \quad (6a)$$

$$E_2 = E(T_{hc}) \cdot g_2 \quad \text{for group 2 and} \quad (6b)$$

$$E_3 = E(T_{hh}) \cdot g_3 \quad \text{for group 3,} \quad (6c)$$

where emissions from commuting arise in a fixed proportion of units driven. 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 $g_1 + g_2 + g_3 = 1$. The same applies for groups 1 (share g_1) and 3 (share g_3)⁴. Importantly, the specific emissions per average commuting way $E(T_{cc}) < E(T_{hc}) \leq E(T_{hh})$ diverge for the two regions due to the differences in the modal split and the absolute distances in passenger transport. Then, since residents of group 2 contribute to emissions in the core region c , *emissions per region* are

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

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

with $0 \leq \alpha \leq 1$.

It follows that differences in emissions between the two regions cannot be reduced to differences in commuting distances between the two regions. 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 influenced by the availability of public transport alternatives, with a lower car-dependency in the core than in the hinterland.

The present model gives emissions not only as an output but has an impact on utility through the environmental quality variable Q . Assuming that emissions thus cause a disutility, environmental quality is reduced by pollution such that Q 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,

$$Q_c = G_c - \lambda_c \cdot E_c \quad \text{for the core and} \quad (9a)$$

$$Q_h = G_h - \lambda_h \cdot E_h \quad \text{for the hinterland} \quad (9b)$$

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. In the initial equilibrium of settlement distribution, per person utility levels are equalized

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

⁴ 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 .

such that the marginal household in each region is indifferent with respect to resettlement in the other region. I.e., for the 3 consumer groups, the utility maximising bundle of consumption and housing goods, environmental quality and congestion differs with respect to the component-specific contribution to welfare. In particular, 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 regions⁵. 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.

As a second step, an exogenous change in environmental preferences leads to a new equilibrium⁶. To address this issue, we model city residents' raised environmental awareness by a decline in city environmental quality. In thin vein, environmental quality contributes less to group 1 consumers' utility. As a consequence, overall dispersion forces improve and per capita utility levels differ such that

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

leading to interregional migration. In this context, the first important assumption is that households adapt slowly in their housing conditions, such that housing structures in period $t+1$ reflect preferences from quite some time ago (15 years or more). I.e. in the short term (until period t), no change of location takes place, while in the longer term (until period $t+1$) migration is possible. A second important point is to distinguish between (i) migration to the hinterland while remaining within the centre economic sphere and (ii) full migration to the hinterland:

- (i) Due to the increased importance of environmental considerations some type 1 consumers decide to relocate their residence to the hinterland. However, they commute to the centre region to further on benefit from both adequate and attractive urban job opportunities. In this regard, *urban sprawl* arises as changed proportions g of consumers in groups 1 and 2 (compare equations 6a,b,c and the explanations below)

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

⁵ The underlying assumption is that lower real estate prices together with a higher average quantity of space consumed results in equal shares.

⁶ 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.

- (ii) On the other hand, existing incentives for a relocation of both residence and place of work initiate shifts in consumer type towards group 3. With respect to full migration to the peripheral region, *urban sprawl* implies

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

As a consequence, the amount of labour available in region h rises. Since it is the labour force that determines the variety of consumption goods offered to households and the diversity of inputs available to firms, the well being of hinterland residents rises.

Let the share of households living in either region be $g_c = g_1$ and $g_h = g_2 + g_3$. Then, referring to (12) and (13), *urban sprawl* results in a settlement structure characterised by

$$(g_c)_t > (g_c)_{t+1} \quad \text{and} \quad (g_h)_t < (g_h)_{t+1} \quad \text{with} \quad g_c + g_h = 1 \quad (14)$$

for each point in time

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 dispersed housing structures. With slow adaptation in housing conditions, utility levels will have equalised across regions in the long run. I.e. in period $t+1$ marginal revenue equals marginal cost.

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

This new equilibrium does not solely stem from changed preference, but it results from the interaction of centrifugal and centripetal forces inherent in the present 2-region set up. In particular, the resulting dynamics of residential adjustments, predominantly towards the hinterland⁷, leads to an equilibrium (15) with more dispersed settlement structures.

⁷ Despite a deterioration of urban environmental quality, migration from region h to c might occur. In this case, centripetal forces outweigh dispersion forces for some proportion of type 2 or 3 consumer, e.g. the housing or lifestyle effect is weakened due to stronger competition for land and/or due to higher hinterland congestion levels.

3 NUMERICAL IMPLEMENTATION AND SIMULATION INSIGHTS

Using a two-regional split up of economic data of the NUTS III region Graz (Austria), derived by using the provincial input-output structure of Styria, the model at hand can be tested. Firstly, structural trends as identified by empirical data exemplify the adjustment processes inherent in the present model. The empirical model thereby helps us to identify the relevance of centrifugal and centripetal forces. Secondly, the model of section 2 is implemented within GAMS (Brooke et al., 1998) using the modelling framework MPSGE (Rutherford, 1998) and the solver PATH (Dirkse and Ferris, 1995) in its – with Todd Munson – expanded version 5.6.04.

3.1 EMPIRICAL IMPLEMENTATION

The NUTS III region Graz in Austria consists of the two political districts Graz city and Graz hinterland. In fact, past decades have shown a strong movement of its population towards the hinterland, with currently 20% of the labour force working in the city commuting from outside. Table 1 indicates an increasingly dispersed settlement structure with a rise in share of hinterland residents from 28.6% in 1971

	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)

to 36.7% in 2001 of total NUTS III region population. Due to wide-ranging job opportunities and attractive shopping facilities prevailing in the centre region, the change in housing patterns towards dispersed structures (Table 1) implies an increase in the number of commuters from the hinterland to the centre (Table 2).

	commuters from the hinterland to the city	commuters from the city to the hinterland	hinterland residents (workforce)
1971	14.921	1.304	40.238
1981	21.995	1.806	45.485
1991	26.530	4.060	51.717
2001	29.801	6.960	59.053

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

In particular, since 1971 the number of in-commuters from the hinterland has increased considerably and reached 29.801 in 2001. In the context of our model, the share of consumers in group 2 (g_2) has grown due to households switching from

type 1 to type 2 (see equation 12). Besides, Table 2 indicates that currently (2001) some 50% of hinterland workforce residents commute into the centre for work. Municipalities within Graz hinterland with a respective share of 40.1% and more are illustrated in Figure 1.

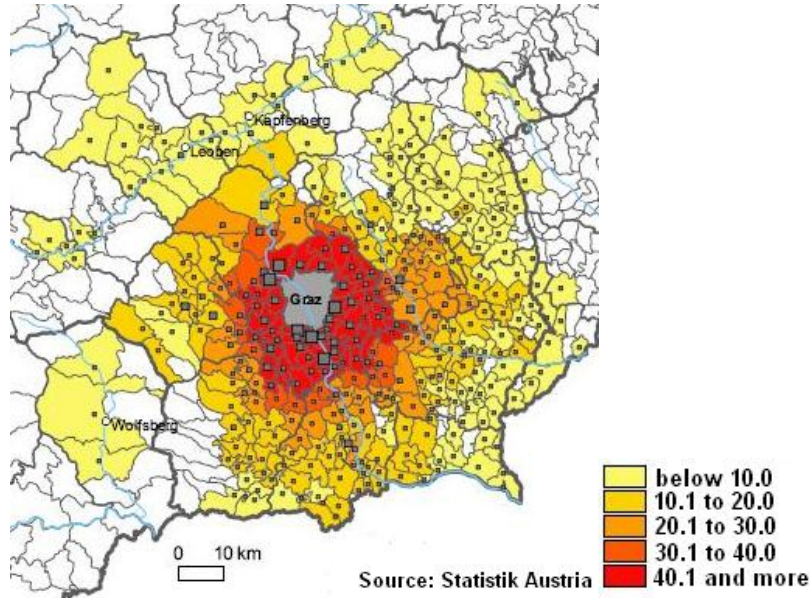


Figure 1: Share of commuters in hinterland workforce population (municipality level)

An important point is, however, to differentiate the growth in Graz city in-commuters and the growth in the number of hinterland workforce population. In past decades, the increase in commuters has been weaker than the rise in the hinterland workforce population (Figure 2). In our model language, the incentives to switch to type 3 consumer instead of getting a type 2 resident are strengthening.

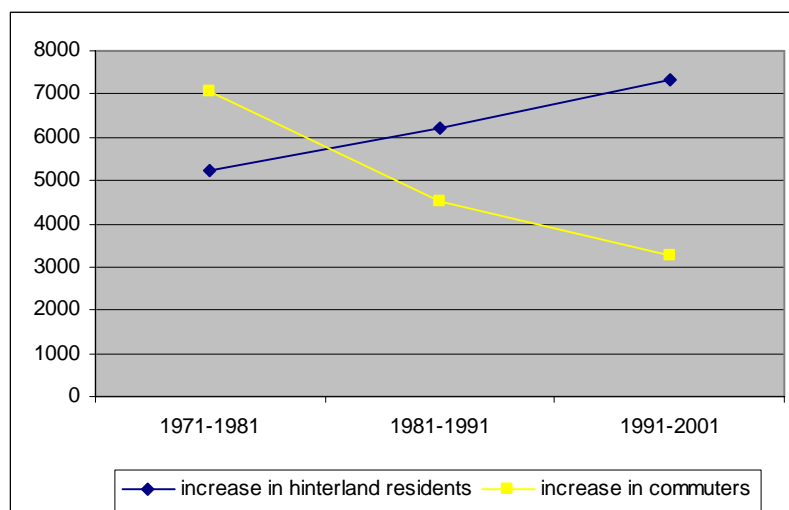


Figure 2: Change in hinterland workforce population vs. change in hinterland to city commuters
Source: Statistik Austria (population census 1971/1981/1991/2001)

This shift in residence location towards the hinterland is due to a variety of factors, including for example shifts in real estate prices and, increasingly, environmental considerations. This arises since 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 particulate matter (PM₁₀) and regular collapses of traffic flows in rush hours. Firstly, concentration levels are high due to large amounts of emissions, and, secondly and more importantly, due to high levels of ground PM₁₀ raising when no reduction processes are at work. The latter is particularly the case in inversion layer weather situations, which some cities – like Graz – are subject to due to their basin-like topography.

It is these environmental considerations that we take as a starting point in our analysis, and look at their interaction with other forces such as housing prices or congestion costs. More specifically, we use an initial share of environmental quality contributing to welfare by 25% with inhabitants of Graz city and by 33% with hinterland inhabitants. We calibrate the model to the 2001 data set, including the 2001 reference split up of residence location in the centre and hinterland region. We then exogenously shock the initial equilibrium by a 10% decline in environmental quality supplied in the centre. City inhabitants thus experience an incentive to resettle to the peripheral region.

In this respect, the empirical implementation estimates parameter values and helps us to gain further insights into interdependencies in the economy. The CGE approach serves as a valuable backing for the analytical general equilibrium model, since the complexity, mainly in terms of endogenous transport-related pollution and Dixit-Stiglitz (1977) variety effects, make the model mathematically intractable. The CGE model is equally useful to estimate the magnitude, not only the sign, of the impact of changes in exogenous conditions on key economic variables. Besides, the model can help to identify general equilibrium effects of exogenous shocks that initially were not obvious.

As for the present model, with respect to the sign and magnitude of interregional migration processes, three fields require a sensitivity analysis. These include (i) the elasticity between hinterland housing prices, real estate prices mainly, and the number of hinterland residents, i.e. the housing congestion impact of migration, (ii) the elasticity between (external) congestion costs and the number of commuters, i.e. the transport congestion impact of commuting, and (iii) the elasticity between the region specific amount of pollutants and the number of commuters, i.e. the environmental impact of commuting. In a first step, the respective parameter values are aligned with empirical data for the two Austrian regions addressed. Secondly, the extent of sensitivity in the above-mentioned three dimensions is determined for the base case scenario.

3.2 INCENTIVES FOR MIGRATION

We introduce a 10% decline in environmental quality in the centre region – an exogenous shock indicating the increased environmental awareness of Graz city residents – to investigate the forces triggered by an environmentally motivated change in awareness: Both centripetal and centrifugal forces are strongly interlinked with the spatial differentiation in environmental quality and, equally important, with transport and housing costs. Moreover, agglomeration forces originate from increasing returns to scale and the implied spatial distribution of jobs with consumers minimising commuting effort. In our analysis the following forces are at work:

Centrifugal forces:

Environmental quality and feedback from commuting (*lifestyle-effect*)

New environmental preferences demand a high quality of living, vast space and a high recreation value, prevailing in peripheral regions.

Real estate prices (*housing effect*)

Residents tend to migrate to the region with less competition for land and housing, i.e. where real estate prices are lower. In the present model, hinterland housing prices depend on the extent of change in urban sprawl and are given by

$$HC_h = p_h \cdot (1 + \alpha \cdot \Delta sprawl) \quad (16)$$

Centripetal forces:

Transport (including congestion) costs (*cost-of-transport effect*)

The costs for passenger transportation due to congestion are lower in less dense areas. In the present model, type 2 consumers pay congestions costs due to their daily commuting activity.

$$p_c^{CONS2} = p_c \cdot (1 + \beta \cdot \Delta sprawl) \quad (17)$$

Product variety and infrastructure (*proximity effect*)

People want access to a variety of differentiated products and to local public goods. Urban agglomerations offer wide-ranging job opportunities as well as attractive shopping facilities.

While the environmental quality is a centrifugal force, driving towards migration to become a type 2 or type 3 consumer equally strong, there are centripetal forces,

driving towards remaining in the centre, yet of different magnitude across consumer types 2 and 3. Thus, city residents are confronted with the choice whether to relocate their residence to the hinterland, and if so, whether also to change their place of work.

We find the following housing congestion impacts (centripetal) on the number of commuters, i.e. the change in urban sprawl, once we reduce the observed environmental quality in the centre by 10% (centrifugal) (Figure 3). We do not account for commuter pollution or transport congestion. With a housing price impact of $\alpha=1$, the new endogenous equilibrium is characterised by an increase in the number of commuters by 14.5%. If we let $\alpha=3$, we find a rise in commuters by 5.6%. This demonstrates the strong centripetal impact of housing price adjustment in the hinterland.

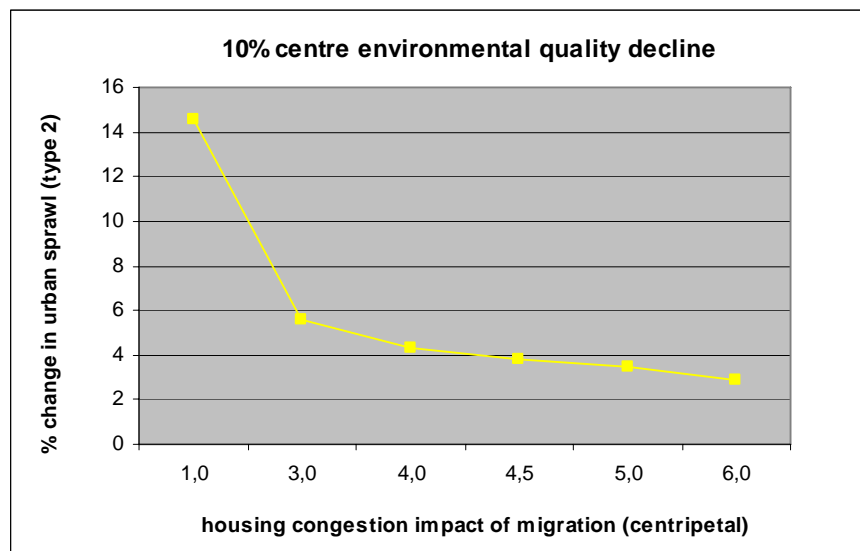


Figure 3: Housing congestion impact of migration (α) on the number of commuters after 10% decline in city environmental quality

Building on empirical data for the period 2001 to 2004, we find that a 1% rise in Graz hinterland population increases real estate prices in hinterland region h by some 9%. The parameter estimation is based on 600 to 800 m² pieces of land for normal-quality sites. Since operating costs are not included, we estimate a medium housing parameter of $\alpha=4.5$. Yet the short period of reference data requires a sensitivity analysis for different values of α .

However, acknowledging the importance of pollution feedback effects from commuting (centrifugal), which are generally more important in the centre, we observe a re-enforcement of urban sprawl. Figure 4 shows the additional increase in type 2 consumers due to the environmental impact of commuting for low ($\alpha=6$), medium ($\alpha=4.5$) and strong ($\alpha=3$) housing effects. Including the pollution feedback impact and solving for the endogenous equilibrium, we find the share of

commuters to rise by another 0.5% points (pollution impact = 1.0) and 1.2% points (pollution impact = 2.0), respectively, for the medium housing case of $\alpha=4.5$.

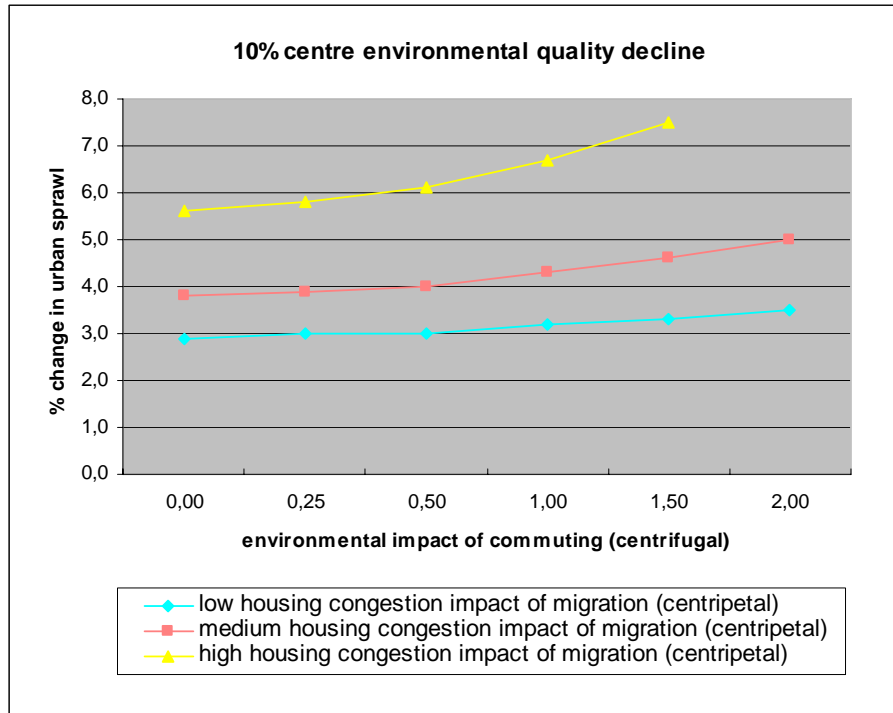


Figure 4: Environmental impact of commuting on the number of commuters after 10% decline in city environmental quality

Additional transportation congestion costs due to commuting are inter alia responsible for the balance between type 2 and type 3 consumers. These costs basically act as centripetal forces, since they increase costs to commute to the centre. In the context of our model, however, they incite type 1 consumer to fully migrate to the hinterland. Table 3 depicts transportation congestion impacts on the number of commuters for different housing congestion levels. The strength of this force in terms of reducing commuting activities turns out to be clearly weaker than the housing price adjustment. This is due to its type 2 consumer specific character (see equation 17).

β	α				
	1	3	4	4.5	5
0,000	14.6	5.6	4.3	3.8	3.5
0.007	14.4	5.5	4.2	3.7	3.4

Table 3: Transport congestion impact (β) for different housing congestion impact levels (α) on the number of commuters (in %) after 10% decline in city environmental quality

4 POLICY ISSUES

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 (OECD, 2005). 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). Thus, choices in transport and long-term choices in land use and settlement structure 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. It comprises both long-term instruments and instruments available for short-term effects. 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.

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 environmental quality 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 (with respect to quantity of transport demanded and modal split) for the overall region, i.e. for the centre and the hinterland. This changed demand can be modelled through a shorter average commuting way T_{rr} (in units driven), thereby indicating lower levels of emissions per group and region (see equation 6).

5 CONCLUSIONS

This paper formulates a two-region general equilibrium model, in which residents are mobile between an urban core and its hinterland. Using a spatial CGE analysis we supply an empirical implementation in the new economic geographic sphere. Starting from spatially differentiated pollution levels, caused by commuting patterns, we look at their interactions with other forces involved such as shifts in congestion levels and housing prices. Differences in both real income and environmental quality constitute the welfare differential for households choosing their region of residence. A higher esteem of environmental quality drives settlement to the hinterland, until the marginal benefit is counterbalanced by increased transport or housing costs.

The resulting increase in commuting activities triggers a pollution feedback-effect, starting a vicious circle. The long term equilibrium, equating per capita utility in the two regions, implies both too high hinterland population and too high commuting levels. Thereby, the cumulative result of individual utility maximising actions leads to a socially suboptimal outcome. It follows that, with an expected exceedingly high level of resource wastage, there is obviously room for policy intervention, both for spatial planning and transport policy, in order to foster more sustainable settlement structures.

Housing price adjustment in the hinterland was found as having the strongest centripetal impact. The empirical analysis therefore suggests redirecting provincial funding schemes for housing construction and development from new construction to the remodelling of old houses and dense housing, thereby steering long-term transport demand. What follows is that 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.

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