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Commuting, externalities, and the geographical sizes of metropolitan areas

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**Commuting, Externalities,
and the Geographical Sizes of Metropolitan Areas**

by

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Commuting, Externalities, and the Geographical Sizes of Metropolitan Areas

Eckhardt Bode*

Abstract:

The paper proposes an econometric approach for quantifying jointly the geographical scope of commuting as well as the various forms of agglomeration economies originating from metropolitan centers. Adopting an urban economics perspective, and using land prices to measure their aggregate effects, the approach estimates the geographical reach of commuting and urban externalities from a hierarchical system of gradient functions. The results for West German NUTS3 regions indicate that metropolitan areas may be larger than suggested by MSA classifications based on commuting only. Metropolitan subcenters are found to enlarge metropolitan areas significantly.

Keywords: urban economics, commuting, agglomeration economies, land price gradient, urban fringe, Germany

JEL classification: C21, C52, R14

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I. Introduction

The functional division of labor within and between companies that has been contributing so much to productivity growth and wealth in market economies is increasingly mapping into a geographical division of labor (Bade et al. 2004; Duranton and Puga 2005). Modern information, communication and organization technologies today allow companies to geographically disintegrate functions that had been tied together by high communication and monitoring costs in the past (Davis and Henderson 2004; Henderson and Ono 2005). At the level of metropolitan areas, firms at the centers have been relocating or outsourcing those activities to suburbs or edge cities that benefit comparatively strongly from lower land prices and wages. And firms at the metropolitan fringes have been relocating or outsourcing headquarter or R&D activities to the centers that benefit comparatively strongly from interactions with other agents at the centers (Henderson and Ono 2005; Rossi-Hansberg et al. 2006). This increasing ‘spatio-functional’ division of labor does, on the one hand, create additional productivity gains from exploiting comparative advantages. On the other hand, it creates additional, extensive spatial interactions and interdependencies between the centers and the fringes. The firm interactions and interdependencies constitute another channel for transmitting the benefits from externalities generated at the centers to the fringes. This channel adds to, and partially substitutes for more traditional transmission channels, including commuting. Workers do not necessarily need to commute to the metropolitan center to benefit from the externalities generated there. Theoretical models that analyze the location decisions of households and workers in cities simultaneously in the presence of multiple transmission channels suggest that the shape of a city may change significantly in response to a changing relative importance (costs) of commuting and inter-firm externalities (e.g., Lucas and Rossi-Hansberg 2002; Anas and Xiong 2005).

Yet, most definitions of statistical aggregates of metropolitan areas¹ still neglect the growing importance of interactions and interdependencies between firms. Using the intensity of commuting to an urban center as the only (or dominant) form of spatial interactions, they are essentially referring to the traditional Alonso-Mills-Muth model of a monocentric city (Fujita 1989; Mills and Hamilton 1989): All jobs are assumed to be located in a central business dis-

¹ Examples are metropolitan statistical areas (MSAs) in the U.S. (OMB 2000), functional urban regions (FUR; Cheshire and Hay 1989) in western Europe, and labor-market regions (Eckey et al. 2006) or planning regions (*Raumordnungsregionen*; BfLR 1996) in Germany. In contrast to MSAs and FURs, the German labor-market and planning regions cover both urban and non-urban locations, and are not designed solely for the purpose of defining metropolitan areas. They can be, and are frequently, divided into metropolitan and predominantly rural regions, depending on the characteristics of the core city, however. The various aggregates will subsequently be referred to as “MSA-type aggregates” or just “MSAs”.

trict (CBD), and all workers have to commute from their residences in the suburbs to the CBD in order to access the jobs. To the extent that firms, workers and landowners in the suburbs do, in fact, benefit from inter-firm externalities, and the spatial patterns of the inter-firm externalities do not accidentally match those of commuting, the MSA-type aggregates will not reflect the sizes of metropolitan areas appropriately. One reason for the statistical aggregates to still focus on commuting is that data on commuting flows are readily available while interactions within and between firms are difficult to measure (e.g., Duranton and Charlot 2006).

The economics discipline may help improve the definitions of MSA-type aggregates by devising methods for defining them on a more comprehensive basis. Still, the discipline has, as yet, shown very little interest in conceptual issues of defining MSAs. The lack of interest is all the more surprising as economists use the MSA-type aggregates extensively in their empirical analysis, and are well aware of the fact that their empirical results will be statistically inefficient and possibly biased, if their observational units are misspecified.

This paper proposes an econometric approach for determining the geographical sizes of metropolitan areas from the geographical reaches of *all* relevant forms of spatial interactions and interdependencies, including commuting and inter-firm externalities. The key assumption that allows to abstract from the individual forms of spatial interactions and interdependencies is that all relevant forms ultimately monetize in land rents and prices.² The approach is based on an urban economics framework that advocates a hierarchy of urban locations: A metropolitan center (or subcenter) generates economic benefits, parts of which diffuse to adjacent locations and ultimately monetize in land prices there.³ Being subject to some form of distance decay,⁴ the benefits will tend to decrease with increasing distance from the centers, and so will land prices. The diffusion patterns are captured by a system of “global” land price gradient functions around metropolitan centers, and “local” land price gradient functions around subcenters. Subcenters are defined as locations that, on the one hand, benefit significantly from nearby metropolitan centers, and on the other hand generate additional benefits on their own

² Abdel-Rahman and Anas (2004) shows that various forms of externalities may generate the same outcome in terms of the internal structure of a city as commuting does in the Alonso-Mills-Muth model. The equivalence of different forms of externalities has also been shown to hold for other classes of models, including the new economic geography (Duranton and Puga 2004).

³ On the one hand, the assumption of an intra-metropolitan hierarchy of locations simplifies matter greatly because it allows to use metropolitan centers as some sort of “fix points” in the empirical analysis. On the other hand, it limits the opportunities for capturing the *interdependencies* between the centers and their hinterlands. The hierarchical approach will match the European situation, where the larger cities still play a dominant role within metropolitan areas, better than that in the U.S., where various city centers have evidently lost their formerly dominant positions (Glaeser and Kahn 2004; Glaeser and Kohlhase 2004).

⁴ The decay may be due to distance-related commuting, transport, or communication costs, or to distance losses similar to iceberg transport costs.

(e.g., jobs, externalities). The fringes of metropolitan areas are the sets of locations where the benefits spilling over from the centers cease to raise land prices significantly above the land prices arising from non-urban land uses. To determine the metropolitan fringes endogenously, the approach explains land prices at urban and non-urban locations simultaneously.

The empirical study is done for West Germany.⁵ Germany is a particularly interesting example because the geographical sizes of metropolitan areas are not too obvious from a glance at the map. The whole country is populated fairly densely, and larger cities are scattered all over the country – with a good chance of overlaps of metropolitan areas. The results for West German NUTS3 regions (*Landkreise, kreisfreie Städte*) indicate that metropolitan areas may, in fact, be significantly larger than suggested by the MSA-type aggregates based on commuting intensities. One reason is found to be metropolitan subcenters that shift the metropolitan fringes beyond the geographical reach of the spillovers from the main metropolitan centers.

Section II reviews the theoretical and Section III the empirical literature. Section IV describes the set up of the empirical model, the estimation strategy, and the data. Section V presents the regression results, and Section VI illustrates their implications by means of simulations. Section VII, finally, summarizes the results and discusses refinements and extensions of the approach left for future research.

II. Theoretical background

This section discusses and interprets two recent contributions to the economic theory of cities, Lucas and Rossi-Hansberg (2002) and Anas and Xiong (2005), to motivate the empirical analysis. Both models analyze the location decisions of households and firms simultaneously in the presence of commuting costs and distance-sensitive inter-firm externalities. Both models can explain the decentralization of firms into urban subcenters or edge cities. And in both models, the distance-sensitive linkages between firms in the center and the suburbs or edge cities substitute for commuting. Even though they are not situated at the center, the decentralized firms benefit from their proximity to the center which raises their productivity, *ceteris paribus*. The benefits are redistributed to their workers via higher equilibrium wages, and ultimately to the landowners via higher equilibrium land rents. Consequently, even though not a single worker residing close to a subcenter is actually commuting to the downtown center in the models, all workers benefit indirectly from the downtown center. The two models differ in the type of city they analyze, and the form of the inter-firm externality.

⁵ East Germany is excluded because land markets there are still far from their equilibrium, as evidenced by a huge excess supply of housing (Dohse et al. 2002).

Lucas and Rossi-Hansberg (2002) analyze the location decisions of firms and workers in a single, circularly symmetric city. In addition to the commuting costs incurred by workers, there is a distance-sensitive Marshallian externality between firms which raises their total factor productivity: A firm's total factor productivity is the higher, the more other firms are in the city, and the closer they are located to the firm. The externality establishes a penalty for firm dispersion.⁶ The firms face a trade-off between being located closer to other firms which raises their productivity, and being located closer to their workers' residences which reduces their factor costs (wages, land rents).

The equilibrium spatial distribution of firms and households depends crucially on the relative magnitudes of the distance decay of the production externality, and the commuting costs. If the rate of decay of the production externality is sufficiently high relative to the unit-distance commuting costs, the model reproduces the result of the traditional Alonso-Mills-Muth model: All firms cluster in a central business district (CBD) because the costs of moving to the suburbs in terms of productivity losses are higher than the respective gains in terms of lower factor costs. And all households reside in a single residential ring spanning from the center to the urban fringe because their costs of moving to the center (higher land prices) are higher than the respective gains in (lower commuting costs).

If the rate of decay of the production externality is sufficiently low relative to the unit-distance commuting costs, a bi- or polycentric city is the equilibrium outcome. Firms find it more profitable to trade off parts of the gains from the externality in the center against lower factor costs in the suburbs. And workers employed by firms in the city center outbid firms on the land market at the city center. Lucas and Rossi-Hansberg show that each worker commutes to his respective closest business district. This implies that there is a watershed in the residential ring between business districts that divide the directions of commuting. An MSA classification based solely on commuting patterns will suggest the watershed to be the metropolitan fringe. It will tend to understate the true size of the metropolitan area. To capture the true size of the MSA, the classification needs to take into account both the commuting patterns and the inter-firm externalities simultaneously.

Anas and Xiong (2005) analyze a system of monocentric cities with pre-determined centers.⁷ The incentives of firms to cluster together in cities result from increasing returns at the firm level. Together with positive transport costs for commodity trade between cities the increas-

⁶ Urban models of this type go back to Ogawa and Fujita (1980), and Fujita and Ogawa (1982). Related models are Berliant et al. (2002), and Wheaton (2004).

⁷ Urban models of this type go back to Henderson (1974). See Abdel-Rahman and Anas (2004) for a review of the systems of cities literature. A related model is Rice and Venables (2004).

ing returns give rise to the home-market and price-index effects known from NEG models (Fujita et al. 1999). Anas and Xiong analyze the formation of new cities in a framework with two traded goods produced in CBDs: A homogeneous manufacturing good, produced under constant returns to scale and sold competitively at the world market under the conditions of a small open economy, and heterogeneous producer services, produced under increasing returns and traded between cities at iceberg transport costs. As an existing (parent) city grows beyond its optimum size due to exogenous population growth, some firms and their workers eventually set up a new city outside the parent city. Provided the transport costs for the producer services are not too high, and the new city is not set up by an urban developer, the daughter city is smaller than the parent city. Depending on the elasticity of substitution between service varieties, and the share of services in manufacturing expenditures, the new city specializes in one industry, manufacturing or services, and trades with the parent city.

Anas and Xiong assume the daughter cities to emerge at some pre-determined places. It may be speculated that the daughter cities will emerge at places close to the parent city's fringe, if the transport costs for producer services are not too low.⁸ Existing villages or small towns in the neighborhood of larger cities have been the natural nodes for the emerging daughter cities. Again, the parent and daughter cities are closely interlinked by home-market and price-index effects, although not a single worker is commuting across the cities' boundaries. An MSA classification based solely on commuting patterns will understate the true size of the system of interrelated neighboring cities. It will suggest the boundary of the parent city to be the metropolitan fringe.

III. Empirical literature

To the best of my knowledge, no attempt has, as yet, been made to determine the geographical sizes of metropolitan areas from the effects of aggregate agglomeration economies on land prices or rents. There are, however, two groups of empirical studies that investigate the distance costs associated with, or the geographical reaches of individual forms of spatial interactions and interdependencies.⁹ One group estimates urban rent or density gradient functions to assess the effects of commuting costs on land rents, population densities or employment densities within a single metropolitan area (see Mills and Tan 1980; Anas et al. 1998). The other

⁸ Analyzing an urban developer's decision problems for the location and size of an edge-city, Henderson and Mitra (1996) show, however, that this is not necessarily true. They find a rather complex relationship between the economic power of the parent city and the location of the edge city. Although firms in the edge city may benefit from distance-sensitive agglomeration economies originating from the parent city, the developer may, under specific conditions, locate the edge city at a place out of reach of the parent city.

⁹ The following review focuses on regression-based approaches. A related literature seeks to identify agglomerations using probabilistic approaches: see Mori et al. (2005), and Mori and Smith (2006).

group focuses on the attenuation of individual forms of urban externalities.¹⁰ These studies will be discussed with a view to the role of geographical distances in the spatial diffusion, and the accessibility concepts employed.

As to the role of geographical distances, the two literatures agree in that the intensities of both commuting and the diffusion of various forms of urban externalities decrease systematically with increasing distance.¹¹ The attenuation speeds may differ, however.

Virtually all studies estimating urban rent or density gradient functions find land prices, or rents, population densities and employment densities decrease systematically with increasing distance from the urban center or a subcenter (Mills and Tan 1980; Anas et al. 1998). Moreover, in line with the underlying urban theory which suggests the gradients to depend on commuting costs and the wage rate paid at the center, they find the gradients to decrease systematically with increasing size of the center.

The results available so far from the empirical literature investigating the spatial attenuation of individual forms of urban externalities can be sketched as follows:¹² (i) Industry-specific localization and urbanization economies attenuate systematically and very rapidly with increasing distance. Rosenthal and Strange (2003) estimate their effects on the birth rates of firms in the U.S. to die out after 5 or at most 10 miles. (ii) Human-capital externalities also attenuate systematically and very rapidly with increasing distance in U.S. metropolitan areas. Rosenthal and Strange (2005) find their wage effects to become irrelevant at distances of about 25 miles. (iii) Localized “knowledge spillovers” from private and university R&D extend beyond the boundaries of MSA-type regional aggregates (Anselin et al. 1997; Bode 2004). The results for Germany in Bode (2004) indicate, however, that the interregional knowledge spillovers are rather small in terms of their effects on R&D productivities, and mostly uni-directional, going from the R&D centers to their less R&D intensive neighbors in the first line. (iv) Market potential effects decrease systematically with increasing distance but extend significantly beyond the boundaries of MSA-type regional aggregates (Combes and Overman 2004). The results in Hanson (2005: Table 4c) indicate, e.g., that the half-life

¹⁰ See Rosenthal and Strange (2004), Moretti (2004), Audretsch and Feldman (2004), and Combes and Overman (2004) for reviews.

¹¹ To be precise, all studies *assume* commuting intensities and the geographical spillovers of externalities to depend on geographical distances. While this assumption is not rejected by the estimation results, the commuting decisions of workers are apparently affected by a variety of factors other than commuting costs as well (Giuliano and Small 1993; Anas et al. 1998).

¹² The literature is still in its infancy. The parameter estimates seem to be rather sensitive to the details of the models specifications and estimation methods in several studies.

distance of a demand shock of a given magnitude is about 60km. It is virtually irrelevant at distances beyond 200km.

In summary, these results suggest that geographical distances may, indeed, be a suitable indicator of the intensities of aggregate urban interactions and interdependencies, commuting as well as the various activities that generate externalities. Non-linearities need to be accounted for, however, because the individual forms of spatial interactions and interdependencies appear to decay at different rates.

The accessibility concepts used in the two literatures differ in one important aspect: The estimations of gradient functions in the first literature adopt the hierarchical, uni-directional concept emphasized by most theoretical models of cities. They assume that there is a limited number of (employment) centers in a metropolitan area that attract all commuting flows, resp. generate all benefits available in the city. From the centers, they may diffuse to any destination that is close enough in geographical terms. Using an urban land price gradient function with inverse exponential distance weights as an example, a typical model estimated in this literature reads (Anas et al. 1998)

$$P_n = \sum_{c=1}^C P_c e^{-\delta_c D_{cn}} + u_n . \quad (1)$$

The land price at a metropolitan location n (e.g., a census tract), P_n , is explained by the sum of the geographically discounted land prices at all centers and subcenters, P_c , and an idiosyncratic error term, u_n . The P_c are (sub)center-specific dummy variables identifying the predetermined C centers and subcenters. The discounting factor, $e^{-\delta_c D_{cn}}$, is a function of the distance between location n and the c^{th} (sub)center, D_{cn} , and a (sub)center-specific urban price gradient, δ_c ($\delta_c > 0$), which, according to the theory, depends positively on commuting costs and negatively on the wage rate paid at the c^{th} (sub)center.¹³ One crucial aspect which will be discussed below in more detail is that the centers and subcenters have to be determined outside the empirical model (1).

The estimations of attenuation speeds in the second literature adopt the completely non-hierarchical concept of mutual accessibility advocated, among others, by the new economic geography. Each location may affect each other location. Using a market potential approach with

¹³ The model (1) includes as a special case for $C=1$ models of monocentric cities. See Mills and Tan (1980) or Anas et al. (1998) for more details. McDonald and Prather (1994) discuss and test of alternative functional forms of the gradient functions.

inverse exponential distance weights as an example,¹⁴ a typical model estimated in this literature reads (Combes and Overman 2004)

$$\ln w_n = \alpha_0 + \alpha_1 \ln \left(\sum_{s=1}^N Y_s^D e^{-\delta D_{sn}} \right) + X_n \beta + u_n. \quad (2)$$

The (logged) nominal wage in region n , w_n , is explained by the region's real market potential which is the sum of geographically discounted real demand (Y^D) from all N regions in the sample. D_{sn} denotes the geographical distance between any two regions s and n ; δ the distance decay parameter which, according to the underlying Helpman-Hanson model (Helpman 1998; Hanson 2005), reflects transport costs and the substitution elasticity between product varieties. The parameter α_1 is the real-demand elasticity of wages. X_n denotes a set of control variables. While there is no need for determining centers and subcenters *ex ante*, the non-hierarchical models introduce other problems, including an inherent endogeneity of the potential variable.¹⁵

Which of the two approaches is preferred for assessing the geographical reach of aggregate agglomeration economies, resp. the sizes of metropolitan areas is largely an issue of the theoretical perspective, the relative economic importance of the centers and hinterlands, and the quality of the information about the locations of centers and subcenters, resp. the quality of the available instruments. Brakman et al. (2004) use a (nominal) market potential approach (Harris 1954) similar to (2) for assessing the effects of the market potential on land prices in Germany. Abstracting from endogeneity issues, their estimates indicate that the effects are highly localized. A simulated demand shock that raises a region's market potential by 10% and that, if arriving at the region itself, raises its land price by almost 4%, has virtually no effect (+0.1%) if arriving at a distance of 60km. The half-life distance (+1.94%) is about 12km. The present study uses instead an extended gradient approach based on (1) for assessing the geographical reach of agglomeration economies in (West-) Germany. One reason is that the larger cities appear to still play an important role as the main economic centers of their surrounding hinterlands, unlike various U.S. cities that apparently have been losing their formerly dominant positions within metropolitan areas (Glaeser and Kahn 2004; Glaeser and Kohlhase 2004). Another reason is that the potential centers of metropolitan areas can be identified from the available data at the county (NUTS3) level: Virtually all larger cities are city-counties.

¹⁴ Most studies of localization economies, human-capital externalities, or knowledge spillovers use an accessibility concept very similar to that in (2). The potential-generating variable (Y in 2) differs, however, depending on the form of the externality investigated.

¹⁵ See Combes and Overman (2004) for a detailed discussion of estimation issues.

IV. Empirical model, estimation strategy, and data

1. Setup of the empirical model

The empirical model uses land prices as the response variable to account for the effects of different forms of spatial interactions and interdependencies. Land prices are assumed to monetize all relevant forms of externalities arising from economic activities in cities in a consistent way. In contrast to land rents which are not available, land prices also monetize expected future gains resulting, among others, from expected future in-migration or economic growth. The expectations need to be controlled for in order to not over-estimate the effects of current agglomeration economies on land prices.¹⁶

Following the density-gradient literature, a limited, pre-determined set of larger cities is assumed to be the prime sources of all forms of agglomeration economies.¹⁷ They will be labeled “*potential* metropolitan centers” henceforth. Formally, let n ($n \in \mathbf{N}=\{1, \dots, N\}$) index the set of regions in the sample, and j ($j \in \mathbf{J}=\{1, \dots, J\}$; $\mathbf{J} \subseteq \mathbf{N}$) potential metropolitan centers. Then, a dummy variable C_{jn} is defined which is 1 for $n = j$ and 0 else. The parameter of C_{jn} , β_j , reflects the effects all forms of agglomeration economies generated at the metropolitan center on its own land price. Potential metropolitan centers where commuting or externalities turn out to not raise land price significantly are excluded from the regression model, using an a selection procedure that will be described below in detail. The selection procedure identifies subset of \mathbf{J}^* “*actual* metropolitan centers”; $\mathbf{J}^* \subseteq \mathbf{J}$; $\mathbf{J}^* = \{1, \dots, J^*\}$.

Each actual metropolitan center is the center of a system of concentric, consecutive and non-overlapping rings, labeled a “*global* land price gradient function”, where “*global*” actually means metropolitan area-wide. Unlike monotonously decreasing distance decay functions, a system of rings can capture discontinuities and local peaks in the metropolitan land price gradient function. To make sure that metropolitan areas around the centers are not fragmented, the selection procedure mentioned above is also used to determine the optimal spatial lag lengths of the global land price gradient functions, i.e., the optimal number of rings. Formally, I define, for each metropolitan center j , a sequence of consecutive, non-overlapping rings, $\tau = 1, 2, \dots$, such that the first, innermost ring ($\tau = 1$) spans 20km from the geographical mid-

¹⁶ Another indicator would be wages. Wages are, however, somewhat ambiguous in the presence of significant urban consumption amenities. Urban consumption amenities tend to raise land prices and rents but reduce wages.

¹⁷ Endogenizing the locations and sizes of metropolitan centers by, e.g., using structural indicators of all locations’ potentials of generating agglomeration economies from first- and second-nature geography is left to future research.

point of metropolitan center j ,¹⁸ and each higher-order ring ($\tau = 2, 3, \dots$) the subsequent 10km, respectively. Moreover, I define, for each ring around each metropolitan center, a variable A_{jm} which is the share of the total area of region n covered by the τ^{th} ring around metropolitan center j . The associated parameter $\gamma_{j\tau}$ reflects the effects of commuting and all forms of agglomeration economies originating from metropolitan center j on the land prices at any location at a distance from the center covered by the τ^{th} ring.¹⁹ The selection procedure mentioned above is also used to determine, for each global land price gradient function, the optimal sequence $\tau = 1, \dots, T_j^*$ of rings that actually reflect a significant influence of the center on land prices in its neighborhood. T_j^* is denoted the “optimal spatial lag length” for the j^{th} global land price gradient function.

Taken together, the metropolitan centers and the global land price gradient functions explain circularly symmetric metropolitan area-wide elevations in the two-dimensional land price surface in West Germany. They do not explain local peaks in the metropolitan area-wide land price surface, typically created by subcenters. Subcenters are, in the interpretation of the present paper, locations that, on the one hand, are affected significantly by a nearby metropolitan center, i.e., are situated in one of the T_j^* ($j \in \mathbf{J}^*$) rings around a metropolitan center, and on the other hand generate agglomeration economies on their own which raise land prices at the subcenter itself as well as at its neighboring locations above the level explained by the global land price gradient function.²⁰ This approach utilizes the selection procedure mentioned above to identify subcenters simultaneously with metropolitan centers and the optimal lag length of the global land price gradient functions. More specifically, a second set of land price gradient functions, labeled “*local* land price gradient functions”, is defined that captures the

¹⁸ To obtain a system of circular rings, the geographical midpoint of the metropolitan center is preferred as the reference over the actual boundary of the metropolitan center. The center itself, which is represented by a dummy variable in the regression model, is excluded from the innermost ring.

¹⁹ Each square kilometer at a given distance from the center is assumed to be affected to the same extent. If a region is covered by several consecutive rings, the total effect of the center on the region’s land price is the weighted average of the ring-specific effects, with the weights being just the shares in the region’s total area covered by the respective rings, i.e., $\sum_{\tau=1}^{T_j} \gamma_{j\tau} A_{jm}$. If region n is covered entirely by the global land price gradient function of metropolitan center j , $\sum_{\tau=1}^{T_j} A_{jm} = 1$. The sum over all ring variables for all centers, $\sum_{j \in \mathbf{J}^*} \sum_{\tau=1}^{T_j} A_{jm}$, may, however, exceed one, if region n is covered by the global gradient functions of several metropolitan centers.

²⁰ In the literature on urban density gradients, a two-step procedure has usually been employed to identify subcenters within metropolitan areas: In a first step, *potential* subcenters are identified from the sample of all intra-metropolitan locations, usually by analyzing the residuals generated by a monocentric model. In a second step, the *actual* subcenters are identified from the set of potential subcenters, using a semi- or non-parametric approach. See Craig and Ng (2001), McMillen (2001; 2003; 2004), and McMillen and Smith (2004) for a detailed discussion. Semi- or nonparametric methods require a rather fine grid of locational observations which is not available here.

effects of commuting attracted, or agglomeration economies generated by subcenters on the land prices at the subcenter itself and its neighboring locations. A local land price gradient function is represented by a circularly symmetric, inverse exponential distance decay function which includes the subcenter. Formally, I define a set of *potential* subcenters, $\mathbf{S} = \{1, \dots, S\}$, indexed by s , which comprises all regions covered by at least one global land price gradient function.²¹ And I define, for each potential subcenter, a variable

$$B_{sn} = (\sum_{j \in \mathbf{J}^*} \sum_{\tau=1}^{T_j^*} A_{j\tau}) e^{-\delta D_{ns}} \quad (3)$$

which reflects the local land price gradient function. The term in parentheses in (3) is the sum of the shares in the subcenter's area covered by all T_j^* ($j \in \mathbf{J}^*$) global rent gradient functions. It represents both the magnitude of the benefits the subcenter "receives" from all major centers through commuting and spillovers of agglomeration economies, and the magnitude of agglomeration economies the subcenter generates itself. The underlying rationale is essentially that a subcenter's ability to generate agglomeration economies will be the higher the more it benefits from the metropolitan centers.²² The agglomeration economies generated by a subcenter affect the regions in its neighborhood. The subcenter attracts commuting from other regions, and there may be spillovers. To account for commuting costs or spillover losses, the quantity in brackets in (3) has to be discounted geographically in order to measure the benefits from subcenter s arriving at region n . This is done by the exponential distance-decay term $e^{-\delta D_{ns}}$ which decreases in the distance between s and n . For simplicity, the distance decay parameter is assumed to be $\delta = 0.02$ for all local land price gradient functions.²³ The weight for the subcenter itself ($n = s$) is taken to be the average intra-regional distance, approximated by $\frac{2}{3} \sqrt{AREA_s / \pi}$, where $AREA_s$ denotes the subcenter's area in km². The value of B_{sn} is consequently highest for the subcenter itself ($n = s$), and decreases with increasing distance from the subcenter. The effects of commuting to, or spillovers from the s^{th} subcenter

²¹ To qualify as a potential subcenter, at least 10% of a region's area must fall into global gradient functions.

²² This specification is fairly restrictive. A more general specification would be to measure the magnitude of the benefits the subcenter receives from major centers by the magnitude of the land price effects, i.e., by $\sum_{j \in \mathbf{J}^*} \sum_{\tau=1}^{T_j^*} \gamma_{j\tau} A_{j\tau}$. In addition, spillovers from other subcenters nearby may be taken into account. These extensions which result in a non-linear regression model are left to the future. The specification preferred here implies that a subcenter covered entirely by a global function is assigned a higher value than one that is covered only partly by a global function. And a subcenter situated in overlapping global functions of several metropolitan centers is, ceteris paribus, assigned a higher value than one that is covered by just one global function.

²³ A decay parameter of 0.02 implies a half-life distance of about 35km. A 'one-size-fits-all' decay parameter is fairly restrictive. It accounts neither for wage differences between subcenters, nor for the fact that subcenters may generate different forms of agglomeration economies with different attenuation rates. Estimating subcenter-specific distance decay parameters is left to future research.

on the land price at region n are captured by the subcenter-specific parameters ρ_s . Again, the selection procedure is employed to select the subset of actual subcenters, $\mathbf{S}^* \subseteq \mathbf{S}$, $\mathbf{S}^* = \{1, \dots, S^*\}$, from the set of all potential subcenters.

The effects of agglomeration economies on land prices cannot be assessed appropriately without detailed information on the land prices arising from non-urban land uses (henceforth labeled “rural” land prices for short). For a metropolitan location, the land price actually attributable to urban agglomeration is just the fraction of the observed land price that exceeds the (hypothetical) rural land price, i.e., the land price that would prevail if the metropolitan center did not exist. Rather than fixing the rural land prices exogenously, based on some information on the average prices of agricultural land, they are estimated from a set of indicators of first-nature geography in the present paper. The determinants of the rural land prices that will be described in Section IV.3 are denoted by X ; the corresponding parameters by α .

Finally, the model comprises two sets of control variables, denoted by Z . The first set accounts for border effects, i.e., the effects on land prices in border regions originating from neighboring countries. A dummy variable is specified for each neighboring country (including East Germany). An additional dummy variable reflects the specific land-price effects of the three larger cities just beyond the border, Basel, Strasbourg, and Innsbruck, on their direct neighbors in Germany. The second set controls for expected of future increases of land prices that may monetize in the current land prices (e.g., Miyao 1987; Berliant and Wang 2004). If not controlled for effectively, the effects of expectations on land prices at the fringes of dynamically growing metropolitan areas may be attributed to the effects of contemporary agglomeration economies. The two determinants of growth emphasized most prominently by the theory of endogenous growth (Lucas 1988; Romer 1990) are specified as control variables: The innovativeness of the centers in the recent past, proxied by the log-transformed number of patent applications granted to inventors from the metropolitan center, and the human-capital intensity of the center, proxied by the (logged) share of workers with university degree in the total labor force of the metropolitan center. To capture their effects on the metropolitan hinterlands, both variables are spatially lagged, using an inverse exponential distance decay function with a decay parameter of 0.01.

A variety of factors that may impact on land prices in metropolitan areas are not explicitly controlled for because they are considered endogenous to urban agglomeration. One such factor is the effects of restrictive local zoning policies or other local regulations that reduce the supply of land or restrict its use. These policies are considered as reflecting the voters’ preferences for a more tightly regulated land use in urbanized area. Another factor is the supply of typically urban public goods related to consumption or production. Cultural institutions such as operas, theatres, or museums, that raise the urban residents’ utility and bid rent, or the supply and quality of the urban infrastructure (e.g., transport hubs, universities) that raise the

firms' or workers' productivity and bid rent are considered inherently endogenous to urban agglomeration.

In summary, assuming the different groups of determinants of a region's land price just introduced to be additively separable in a semi-logarithmic specification, the empirical model can be written as

$$\ln P_n = \sum_{j \in \mathbf{J}^*} \beta_j C_{jn} + \sum_{j \in \mathbf{J}^*} \sum_{\tau=1}^{T_j^*} \gamma_{j\tau} A_{j\tau n} + \sum_{s \in \mathbf{S}^*} \rho_s B_{sn} + \sum_{k=1}^K \alpha_k X_{kn} + \sum_{l=1}^L \phi_l Z_{ln} + u_n \quad (4)$$

P_n denotes the land price in $N = 326$ West-German *Landkreise* and *kreisfreie Städte* at a given point in time; the C_{jn} are dummy variables for the main metropolitan centers; the $A_{j\tau n}$ reflect the global land price gradient functions around the metropolitan centers which are made up by consecutive, circularly symmetric rings of 10km width (innermost ring 20km); B_{sn} reflects the local land price gradient functions around metropolitan subcenters; and the X_{kn} and Z_{ln} are indicators of first-nature geography which determine the rural land prices, and control variables that account for border effects and future expected growth. u_n , is an i.i.d. error term; the β_j , $\gamma_{j\tau}$, ρ_s , α_k and ϕ_l are parameters to be estimated; and \mathbf{J}^* , \mathbf{S}^* and T_j^* are the sets of actual metropolitan centers and subcenters within metropolitan areas as well as the optimal lag lengths of the global land price gradient functions by metropolitan center.

2. Selection procedure

The selection procedure is used to identify simultaneously the set of actual metropolitan centers and subcenters, \mathbf{J}^* and \mathbf{S}^* , from the sets of potential centers and subcenters, \mathbf{J} and \mathbf{S} , and the optimal lag lengths of all global land price gradient functions, T_j^* .²⁴ The objective function is chosen to be

$$\begin{aligned} & \max R^2(\text{adj.}) \\ & \text{s.t. } \beta_j > 0 \quad \forall j \in \mathbf{J}^*; \\ & \quad \gamma_{j\tau} > 0 \quad \forall j \in \mathbf{J}^* \wedge \tau=1, \dots, T_j^*; \\ & \quad \rho_s > 0 \quad \forall s \in \mathbf{S}^*. \end{aligned}$$

The restrictions forcing the parameters of all urban variables (metropolitan center dummies, ring variables, subcenter variables) to be strictly positive are established to exclude (i) *kreisfreie Städte* from the set of metropolitan centers where diseconomies of agglomeration dominate the economies; (ii) rings from the global land price gradient functions that cover agglom-

²⁴ The SAS code is available from the author upon request.

eration shadows (Fujita and Krugman 1995; Mori et al 2005); and (iii) metropolitan locations from the set of subcenters that are not affected by agglomeration economies originating from close-by metropolitan centers at all. With a few exceptions that will be detailed below, the procedure adds or removes one variable to/from the model in each iteration, depending on the value of the objective function. It takes fully into account the hierarchy of locations: It does not consider adding a ring around a metropolitan center that is not in the actual model; or a ring the next lower-order ring of which is not in the model; or a subcenter that is not covered by any ring actually in the model. Likewise, it does not remove an inner ring from the model without removing simultaneously all higher-order rings as well as all subcenters actually covered only by those rings.

The procedure works with two groups of variables which are updated after each iteration:²⁵ the $J^*+S^*+T_j^*$ variables in the model,²⁶ and the group of potential entrants. Potential entrants are all next higher-order rings to the metropolitan center dummies (ring 0) and the rings currently in the model, and regions are considered potential subcenters. In each iteration, the procedure performs one auxiliary regression for each variable potentially to be added to or removed from the model selected in the previous iteration, and one for the baseline model. It selects the variable that yields the highest value of the objective function (subject to the restrictions).²⁷ If the objective function suggests removing a ring or a center while associated higher-order rings and/or subcenters are in the actual model, the option of removing that ring or center together with all associated higher-order rings and subcenters is evaluated instead. And if the parameter of an incumbent variable turns negative in response to adding or removing another variable, the option of simultaneously removing the variable with the negative parameter is evaluated instead.

3. Data

The 326 West German *Landkreise und kreisfreie Städte* (regions for short) chosen as the observational units in the present study are the smallest local administrative units in Germany for which detailed statistical data on land prices is available. Their average size is 781.3

²⁵ The update may include re-calculating the variables of the local gradient functions which depend on the set of rings actually in the model.

²⁶ Rather than just the highest-order rings and/or subcenters, all urban variables are challenged in each iteration to reduce the probability of lock-ins which is a standard problem in any selection procedure. The determinants of rural land prices are forced into the model.

²⁷ The procedure starts with a model that comprises only the determinants of the rural land prices and the control variables. In the first iteration, only the metropolitan centers are consequently considered for being added. The procedure stops if the model preferred in the previous iteration maximizes the objective function.

sqkm; their average population density 518 inhabitants per sqkm. 91 of them are *kreisfreie Städte* (city-counties), separate local administrative (and statistical) units comprising a single urban community.²⁸ In Germany, almost all bigger cities are *kreisfreie Städte*. While they are much smaller in geographic terms than the *Landkreise* (148.2 sqkm, compared to 1,001.3 sqkm), their average population density is much higher (1 366.4 inhabitants per sqkm, compared to 223.3). In the present study, the 32 *kreisfreie Städte* with a population of more than 200,000 (average over the period 1976–1980) are considered potential metropolitan centers, i.e., members of the set **J**. To assess the sensitivity of the regression results to the choice of the set of potential metropolitan centers, an alternative regression will be run for the 57 *kreisfreie Städte* with a population of more than 100,000.

The land prices (P_n in equation 4) are measured by the price (in constant 2000 prices) paid per square meter of unimproved residential land on average over the period 1995 to 2001, drawn from annual land sales statistics.²⁹ Unimproved residential sites are, except for their neighborhood characteristics which are unobservable here, a fairly homogeneous good. The observed price differences between locations should be attributable mainly to first- or second-nature geography. From a theoretical point of view, the indicator should reflect the equilibrium land price emerging from the demand by both households and firms who compete for land in the city. In practice, the land markets for residential and commercial purposes are divided sharply. The equilibrium prices of commercial sites are actually unobservable. Being a preferred instrument in the competition among local authorities for firms, they are biased downward heavily by public subsidies. Although not being unaffected by local authorities, the prices of residential land can be expected to be a more reliable indicator of the scarcity of land in the local environment.

To obtain the fraction of a region's area covered by any ring of a global gradient function (A_{jm}), first, a system of regular grid points is created covering the entire surface of West Germany (excluding the islands), such that one grid point represents one km², using the dataset of *Landkreis* boundary coordinates supplied by the SAS software package. Second, rings are defined as distance bands around the midpoints of all metropolitan centers (or the location of

²⁸ There is only one exception, the city of Hannover, which was merged with its hinterland in the public statistics.

²⁹ The land sales statistics, available from the GENESIS database of the German federal statistical office (downloaded from <http://www.statistik-portal.de/Statistik-Portal/GenesisUebersicht.asp>), report numbers of transactions, lot sizes and total amounts paid by *Landkreis/kreisfreie Stadt*. To obtain a sufficient number of transactions for each *Landkreis*, the annual transactions are aggregated across the years 1995 to 2001 after deflating them by the national consumer price index. The number of transactions varies considerably across the *Landkreis/kreisfreie Städte*, with a minimum of 6 and a maximum of 11 868 (average 1 384). The land price in Hamburg which is not available from the statistic is set to 600€.

their downtown centers; source: Bundesanstalt für Bauwesen und Raumordnung), using Euclidean distances. The fraction of a region's area covered by a ring is then the number of grid points in the overlap of the region and the distance band around the center, divided by the total number of grid points in the region.

A variety of exogenous determinants of rural land prices is tested:³⁰ The first group of determinants is local amenities which may affect land prices through their valuation by consumers: Irrespective of agglomeration economies, land prices should, *ceteris paribus*, be higher at places with more favorable geographic and climatic conditions as well as a richer cultural heritage (Roback 1982). For Germany, Rehdanz and Maddison (2004) find a positive relationship between climatic conditions (temperature, precipitation) and housing prices. An index of the variation of altitudes (relief intensity),³¹ and dummy variables for locations in the Alps, on the seashore, and at larger lakes are used as proxies of amenities from natural conditions. The mean annual sunshine radiation in kWh/m² in the respective NUTS2 region used as proxies of amenities from climatic conditions. The ancient cultural heritages is proxied by an index of the concentration of ancient cultural sites.³²

The second group of determinants of rural land prices is geographic, climatic and cultural factors which may affect land prices through agricultural productivity or industrial specialization. Rural land prices may be higher at locations with more fertile soil which raises agricultural productivity. The fertility of soil is measured by the official index which ranges from 0 (worst quality) to 100 (loess). For essentially the same reason, the ancient form of inheritance may affect land prices: Still today, the agricultural productivity may be lower in areas where partible inheritance divided farms and fields into smaller units in the past. The form of inheritance is proxied by a variable which is 1 for primogeniture as the dominant form of inheritance, -1 for partible inheritance, and 0 for mixed or other forms of inheritance. A positive parameter consequently reflects the land price effects of higher agricultural productivity due to larger farm and field sizes. Finally, the rural land prices may be higher at locations with mineral deposits the exploitation of which generates additional income. Roos (2005) finds the availability of coal and lignite deposits to be correlated positively with labor pro-

³⁰ Determinants that do not exhibit a significant effect on land prices are excluded.

³¹ A high relief intensity may, in addition, limit the supply of arable land which will, *ceteris paribus*, also tend to raise land prices.

³² The data on sunshine radiation and the concentration of cultural sites is from the 'Study Programme on European Spatial Planning' (SPESP) data set, downloaded from http://www.mcrit.com/SPESP/spesp_report/BBR_download.htm. The data on the relief intensity were kindly made available by the Bundesanstalt für Bauwesen und Raumordnung.

ductivity in Germany. The availability of significant mineral deposits, coal and lignite, is indicated by two dummy variables.³³

V. Regression results

This section presents and discusses the results of a regression that is based on the assumption that the 32 largest West German *kreisfreie Städte* (population > 200,000) qualify as potential metropolitan centers. The smaller *kreisfreie Städte* may be subcenters but not metropolitan centers. For this setting, the selection procedure selects 50 urban variables: 22 metropolitan center dummies, 15 ring variables that constitute the global land price gradient functions, and 13 subcenter variables that constitute the local gradient functions. To save space, the detailed regression results are given in column (i) of Table A1 in the Appendix. Before discussing the parameter estimates for the control variables and the urban variables in more detail, a view at the summary statistics at the bottom of Table A1 shows that the model accounts for no less than 80% of the variance of the land prices across regions. This high R^2 is not just due to the center dummies. The R^2 net of the contribution of the center dummies is about 70%.³⁴ Figure A1 which compares the land prices predicted by the model to the actual land prices by region illustrates that the model does, indeed, fit the actual land prices very well. Taking into account that – apart from the center dummies and control variables – the only piece of information entering the model is the distances to the centers and subcenters, this result suggests that the preferences of economic agents for being situated close to other agents must be a powerful economic force, indeed. It confirms Rosenthal and Strange who state that “Understanding the economy is not possible without understanding cities.” (Rosenthal and Strange 2005: 1).

Among the control variables, three consumption and two production-related variables are estimated to affect rural land prices positively: Households appear to value the intensity of sunshine radiation (SUNSHINE), and the scenic landscape (RELIEF_INTENS; MOUNTAIN); agricultural productivity is higher in regions with better soil (SOIL, SOILSQ)³⁵ as primogeniture as the dominant form of inheritance in the past (INHERIT). The estimates for the border controls indicate that the regions along the former iron curtain, i.e., at the borders

³³ The data on soil quality were kindly provided by the Bundesanstalt für Bauwesen und Raumordnung. The data on the forms of inheritance in the past are inferred from Figure 1 in Abel (1955). The dummies for the availability of coal and lignite deposits in the West German *Landkreise* are constructed from a map provided by the Bundesanstalt für Geowissenschaften und Rohstoffe (2005).

³⁴ The value is calculated as $R^{2*} = 1 - \text{var}(\mathbf{u} + \mathbf{C}\boldsymbol{\beta}) / \text{var}(\ln \mathbf{P})$, where \mathbf{u} , \mathbf{C} , $\boldsymbol{\beta}$ and \mathbf{P} denote the vectors or matrices of the respective variables in (4). The correlation between the center dummies and the other variables in the model is ignored for simplicity. It is fairly low.

³⁵ The joint effects of the quality of soil and its square on absolute land prices are positive for the entire range of the quality index (0–100) an increasing continuously in the index.

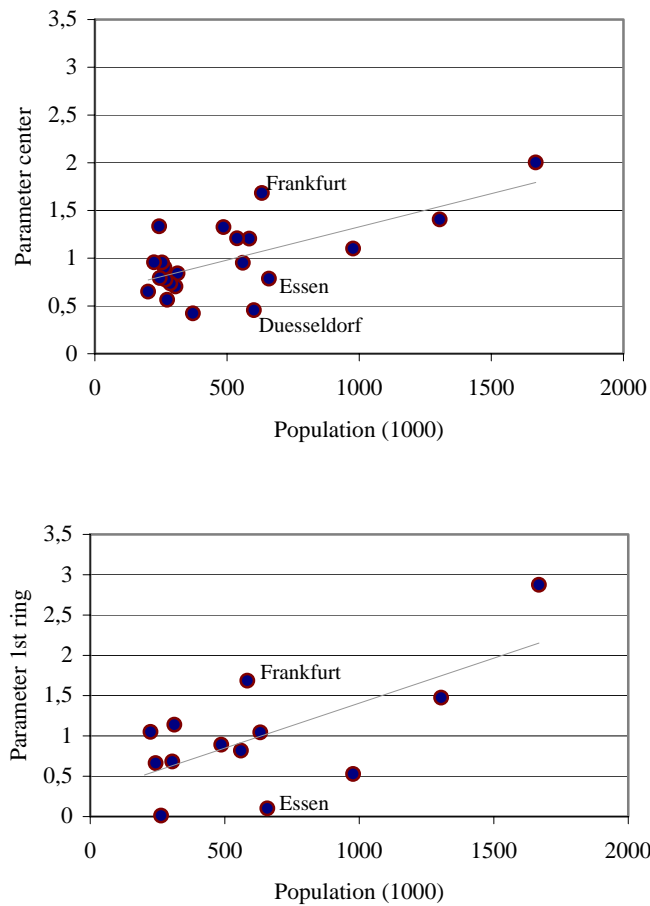
to the Czech republic and Eastern Germany (DUM_CZ, DUM_DE), still suffer from their peripherality. The variables on the effects of the nearby centers' human-capital intensity and innovativeness that are supposed to control for the effects of expected future growth on land prices are highly insignificant. The measure of innovativeness has even a negative parameter. This is taken as an indication that expectations do not affect the land prices at the metropolitan fringes too seriously. Virtually all metropolitan areas, as defined from commuting intensities, have in fact been losing some population and employment to rural areas in Germany over the last decades (Bade et al. 2002). In addition, the public regulations of the land markets in Germany limit the opportunities for speculative purchases of land that is expected to be upgraded in the near future.

Turning to the results for the urban variables, 22 of the 32 potential metropolitan centers are identified as actual metropolitan centers by the selection procedure. Of the 22 metropolitan centers, 9 are estimated to not affect land prices in their neighborhood significantly. 12 affect land prices of regions within a distance of up to 20km (1st ring), and only one metropolitan center, Frankfurt, generates significant spillovers over distances of up to 40km (3rd ring). Figure 1 plots the parameters estimates for the metropolitan center dummies (upper graph) and the 1st rings of the global land price gradient functions (lower graph) against the centers' population sizes.³⁶ In line with the urban theory, the parameters tend to increase with increasing size of the center, although there is some variation among the metropolitan centers with just above 500,000 inhabitants, and although the correlation for the parameters of the global gradient functions is rather weak. In summary, the results obtained for the global gradient functions are broadly in line with those obtained by Brakman et al (2004) from a market potential approach: Similar to those of market potentials, the direct effects of commuting to metropolitan centers, and of spillovers of externalities from the centers on the land prices elsewhere generally appear to decay very rapidly with increasing distance.

In addition to the metropolitan centers and the global land price gradient functions, the selection procedure identifies 13 subcenters, however. Most of them are situated in the metropolitan areas around the largest cities, Hamburg, Munich, Essen, Frankfurt and Stuttgart. Using the metropolitan areas of Frankfurt and Stuttgart as an example, the next section will show by

³⁶ For the centers, a value of $\beta = 1.5$ indicates that, *ceteris paribus*, agglomeration economies raise the land price in the respective metropolitan center by $100(\exp(1.5)-1) = 348\%$ over a (hypothetical) rural land price that would prevail at that place if the metropolitan center would just not exist. For a ring of a global gradient function, a value of $\gamma = 0.35$ indicates that having an additional metropolitan center of the same size at the same distance raises a region's land price by $100(\exp(0.35)-1) = 52\%$, *ceteris paribus*, provided the ring covers the region's entire area.

Figure 1 – Population sizes and estimated parameters of metropolitan center dummies and 1st rings of the global land rent gradient functions^a



^a Regression based on 32 pre-determined potential metropolitan centers, see column (i) of Table A1 for details.

means of a simulation that the metropolitan areas are actually larger than suggested by the global land price gradient functions alone.

Before turning to the simulations, it is necessary to emphasize that the regression results are not invariant to the choice of the set of pre-specified potential metropolitan centers. Further refinements and extensions are warranted to increase, in particular, the precision of identifying subcenters. Table A1 in the Appendix depicts, in addition to the results for the 32 pre-specified centers discussed above (column i), those the 57 pre-specified centers with more than 100,000 inhabitants (column ii). A comparison of the results suggests that, first, the parameter estimates differ not too much for those variables that enter both models. Second, there are some differences in the sets of selected metropolitan centers, and the optimal lag lengths of global gradient functions. Third, only 12 of the 25 *kreisfreie Städte* with 100,000–200,000 inhabitants are actually selected as actual metropolitan centers in regression (ii).

Most of them do not affect land prices in their neighborhood significantly, according to the estimates. And finally, the sets of subcenters identified by the selection routine differs quite considerably between the two regressions. In some instances, the subcenters in the two models are just neighbors within the same metropolitan area, such as Harburg in (i) and Stade in (ii), both of which belong to the Hamburg metropolitan area. In other instances, a subcenter in (i) becomes a center in (ii) (Wolfsburg).

VI. Rural and urban components of land prices

To get an idea of the spatial patterns of land prices predicted by the global and local land price gradient functions, this section maps the rural and urban components of the land prices predicted by equation (4), using the parameters estimated from the regression with 32 potential metropolitan centers (column i in Table A1). Setting the residuals to zero, the absolute land prices predicted by (4), \hat{P}_n , can be calculated as

$$\begin{aligned} \hat{P}_n &= \exp \left[\sum_{k=1}^K \hat{\alpha}_k X_{kn} + \sum_{l=1}^L \hat{\phi}_l Z_{ln} \right] \exp \left[\sum_{j \in \mathbf{J}^*} \hat{\beta}_j C_{jn} + \sum_{j \in \mathbf{J}^*} \sum_{\tau \in \mathbf{T}_j^*} \hat{\gamma}_{j\tau} A_{j\tau n} + \sum_{s \in \mathbf{S}^*} \hat{\rho}_s B_{sn} \right] \\ &= \hat{P}_n^{rural} \hat{\Pi}_n^{urban}, \end{aligned} \quad (5)$$

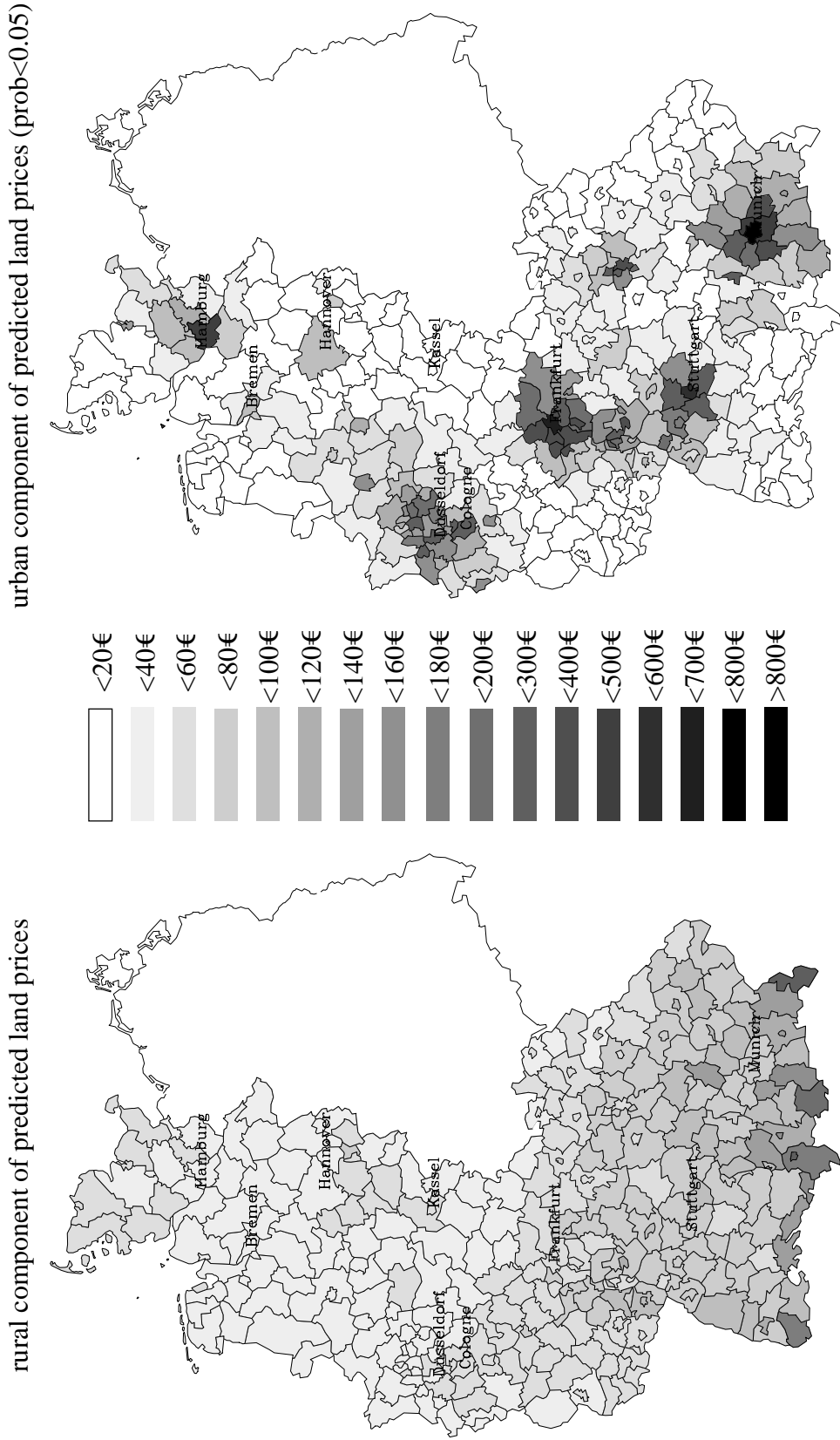
using the same notation as in (4). Hats (^) indicate estimated or predicted variables. \hat{P} denotes absolute land prices in €, $\hat{\Pi}$ multipliers (markups). \hat{P}_n^{rural} is the land price net of all agglomeration effects predicted by the model for region n ; $\hat{\Pi}_n^{urban}$ is the estimated markup over the rural land price in region n attributed to urban agglomeration. The corresponding € land prices are calculated as $\hat{P}_n^{urban} = \hat{P}_n - \hat{P}_n^{rural} = \hat{P}_n^{rural} (\hat{\Pi}_n^{urban} - 1)$.

Figure 2 maps the rural (\hat{P}_n^{rural}) and urban (\hat{P}_n^{urban}) components of the predicted land prices. Predicted values not significantly different from zero at the 95% level are set to zero.³⁷ The predicted rural land prices (left-hand side map) which change fairly smoothly over space reflect, among others, the effects of the more fertile soil on the land prices in the northern part (Schleswig-Holstein), the Rhine valley, and the mid-east between Hannover and Kassel; and those of the favorable climate and the attractive landscape in the south.

Commuting and economies of urban agglomeration are estimated to contribute to raise land prices significantly in large parts of the country (right-hand side map). While the Hamburg area in the north and the Munich and Nuernberg areas in the south appear to be dominated by

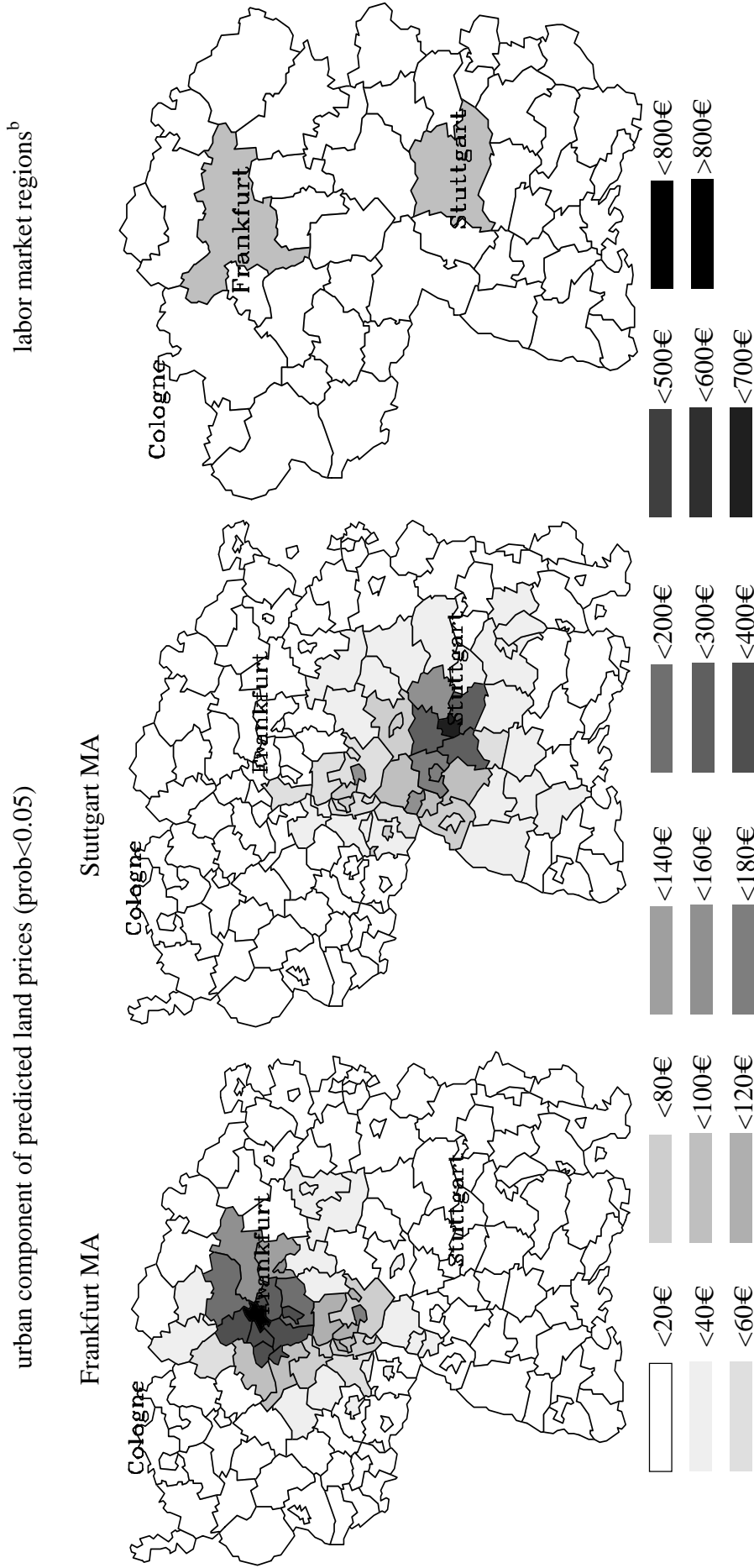
³⁷ The prediction errors were estimated using the delta method.

Figure 2 — Rural and urban components of predicted land prices for West German Landkreise^a



^a Regression based on 32 pre-determined potential metropolitan centers, see column (i) of Table A1 for the underlying parameter estimates.

Figure 3 — Comparing urban components of predicted land prices attributed to Frankfurt and Stuttgart to labor market regions^a



^a Regression based on 32 pre-determined potential metropolitan centers, see column (i) of Table A1 for the underlying parameter estimates.

^b Source: Eckey et al. (2006).

single centers, possibly with a few subcenters, the Ruhr area in the mid-west and the corridor from Frankfurt to Stuttgart in the south west are actually characterized by a polycentric metropolitan system. Splitting up such a systems of overlapping and interdependent metropolitan areas into non-overlapping MSA aggregates is certainly a challenge. Figure 3 illustrates this by comparing the sizes of the Frankfurt and Stuttgart metropolitan areas to the sizes of their labor market regions, determined from commuting intensities (Eckey et al. 2006). While the commuting intensities suggest classifying Frankfurt and Stuttgart as 3rd-order neighbors, with two labor-market regions in-between, the estimates here suggest the Frankfurt and Stuttgart metropolitan areas are clearly overlapping.

VII. Conclusions

The economics discipline has shown very little interest in conceptual issues of defining metropolitan areas, although the concepts may be outdated. Focusing on commuting patterns in the first line, they are not suited too well for taking into account the growing interactions and interdependencies among firms in metropolitan centers and suburbs. Theoretical urban models show that the extensive interactions and interdependencies between those firms work as a channel for spillovers of agglomeration economies from the centers to the suburbs. Commuting intensities cannot be expected to be good proxies of the intensities of such spillovers. What is warranted is a more general conceptual framework for defining metropolitan areas.

The present paper goes one step into the direction towards a more general framework. It proposes an empirical approach for quantifying jointly the geographical scope of commuting as well as all forms of agglomeration economies originating from metropolitan centers. Adopting an urban economics perspective, the empirical approach uses land prices as a universal indicator of the benefits diffusing from the center to the suburbs. It estimates the effects of commuting to, and spillovers from metropolitan centers and subcenters on land prices at all locations from a hierarchical system of metropolitan area-wide and subcenter-specific land price gradient functions. In addition, it uses indicators of first-nature geography to determine simultaneously the (hypothetical) land prices arising from non-urban (rural) land uses. Explaining the rural and urban components of land prices simultaneously allows to determine the fringes of metropolitan areas where the urban components turn insignificant. The estimation is done using a model selection strategy that takes explicitly into account the hierarchy of urban locations, selects metropolitan centers and subcenters, and determines the optimum geographical scope of the land price effects of urban agglomeration.

The empirical results for West German NUTS3 regions (*Landkreise, kreisfreie Städte*) indicate that metropolitan areas may be significantly larger than suggested by classifications based on commuting intensities. One reason is found to be subcenters that, on the one hand, benefit from the proximity to larger metropolitan centers, and, on the other hand, generate

agglomeration economies (and commuting) themselves to the benefit of their neighboring regions. In doing so, they shift the metropolitan fringes beyond the geographical reach of the main centers.

Several simplifying assumptions offer ample scope for future refinements and extensions. First, the specification of the suburban land rent gradient functions is fairly restrictive. A more general specification and a non-linear estimation strategy is warranted to identify subcenters with greater precision. Second, the approach requires pre-determining a set of potential metropolitan centers, the choice of which may affect the results. A strategy for identifying the metropolitan centers endogenously is warranted. Third, using land rents rather than land prices as the response variables reduces possible biases from expected future developments that, if monetized in the land prices, may be attributed to contemporary urban externalities. And finally, a finer spatial grid of observations offers the opportunity for refining of the empirical methodology, and for determining metropolitan fringes more precisely.

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Appendix

Table A1 — Regression results for equation (4) – regressions based on 32 or 57 pre-determined potential metropolitan centers^a

dependent variable: ln(land price)	(i) 32 centers (pop>200K)		(ii) 57 centers (pop>100K)	
Variable	coeff	prob	coeff	prob
Metropolitan centers (parameters β in eq. 4) & global land rent gradient functions (“rings”; parameters γ)				
Center 1 (Hamburg)	2.002	0.000	2.080	0.000
Ring 1	2.875	0.113	2.851	0.084
Center 2 (München)	1.407	0.001	1.048	0.014
Ring 1	1.475	0.008	0.889	0.132
Center 3 (Köln)	1.102	0.005	1.144	0.001
Ring 1	0.529	0.118	0.492	0.103
Center 4 (Essen)	0.785	0.043	0.792	0.025
Ring 1	0.102	0.614	0.083	0.687
Center 5 (Frankfurt/Main)	1.683	0.000	1.884	0.000
Ring 1	1.045	0.004	1.443	0.000
Ring 2	1.352	0.002	0.789	0.184
Ring 3	0.986	0.012	1.171	0.001
Ring 4			0.720	0.102
Center 7 (Düsseldorf)	0.456	0.263	0.722	0.047
Ring 1			0.054	0.869
Center 8 (Stuttgart)	1.205	0.007	1.146	0.005
Ring 1	1.685	0.004	1.723	0.002
Center 9 (Duisburg)			0.613	0.093
Center 10 (Bremen)	0.951	0.015	1.085	0.003
Ring 1	0.817	0.022	0.911	0.006
Center 11 (Hannover)	1.209	0.002	1.256	0.001
Center 12 (Nürnberg)	1.326	0.001	1.306	0.000
Ring 1	0.892	0.000	0.892	0.000
Center 15 (Saarbrücken)	0.423	0.287	0.708	0.058
Ring 1			0.421	0.240
Center 16 (Bielefeld)	0.841	0.029	0.681	0.066
Ring 1	1.140	0.034	0.610	0.329
Center 18 (Mannheim)	0.704	0.079		
Ring 1	0.683	0.007		
Center 19 (Bonn)	0.737	0.055	0.832	0.018
Center 20 (Karlsruhe)	0.564	0.159		
Center 21 (Wiesbaden)			0.844	0.069
Center 22 (Münster)	0.775	0.046	0.820	0.021
Center 23 (Braunschweig)	0.903	0.028	0.876	0.021
Ring 1	0.011	0.984		
Center 25 (Kiel)	0.956	0.013	1.075	0.002
Center 26 (Augsburg)	0.792	0.039	0.711	0.043
Center 27 (Aachen)	1.334	0.003	1.440	0.000
Ring 1	0.663	0.298	0.888	0.128
Center 30 (Krefeld)	0.958	0.021	0.794	0.040
Ring 1	1.050	0.038		
Center 32 (Kassel)	0.651	0.091	0.805	0.023

to be continued

Table A1 continued

Variable	(i) 32 centers (pop>200K)		(ii) 57 centers (pop>100K)		
	coeff	prob	coeff	prob	
Centers & global gradient functions cont'd					
Center 35 (Mülheim/Ruhr)			0.505	0.209	
Center 36 (Freiburg/Breisgau)			1.448	0.000	
Ring 1			1.289	0.043	
Center 42 (Bremerhaven)			0.435	0.226	
Center 43 (Darmstadt)			0.525	0.287	
Center 44 (Oldenburg)			0.876	0.013	
Ring 1			0.493	0.309	
Center 45 (Regensburg)			0.474	0.171	
Center 47 (Heidelberg)			0.929	0.013	
Ring 1			0.536	0.183	
Ring 2			0.629	0.017	
Center 48 (Wolfsburg)			0.593	0.135	
Ring 1			0.376	0.568	
Center 49 (Würzburg)			1.444	0.000	
Ring 1			0.637	0.130	
Center 51 (Koblenz)			1.163	0.001	
Center 54 (Heilbronn)			0.650	0.085	
Center 57 (Wilhelmshaven)			0.557	0.122	
Ring 1			0.655	0.145	
Local land rent gradient functions for subcenters (parameters ρ in eq. 4; associated centers in parentheses)					
Stormarn	(Hamburg)	1.338	0.000	1.505	0.000
Harburg	(Hamburg)	0.478	0.240		
Ebersberg	(München)	1.587	0.000	1.119	0.061
Starnberg	(München)	0.710	0.113	0.891	0.073
Ennepe-Ruhr-Kreis	(Essen)	2.068	0.000	2.175	0.000
Darmstadt	(Frankfurt)	0.699	0.089		
Main-Kinzig-Kreis	(Frankfurt)	0.872	0.040		
Enzkreis	(Stuttgart)	1.256	0.000		
Rems-Murr-Kreis	(Stuttgart)	0.490	0.273	0.874	0.017
Forchheim	(Nürnberg)	0.992	0.000	1.072	0.000
Osnabrück (LK)	(Bielefeld)	1.187	0.000	0.950	0.002
Wolfsburg	(Braunschweig)	0.587	0.088		
Viersen	(Krefeld)	0.691	0.098	1.392	0.000
Stade	(Hamburg)			0.687	0.101
München (LK)	(München)			0.771	0.285
Hochtaunuskreis	(Frankfurt)			1.401	0.000
Reutlingen	(Stuttgart)			0.395	0.166
Lippe	(Bielefeld)			0.748	0.075
Karlsruhe (LK)	(Karlsruhe)			1.702	0.000
Gifhorn	(Braunschweig)			0.651	0.067

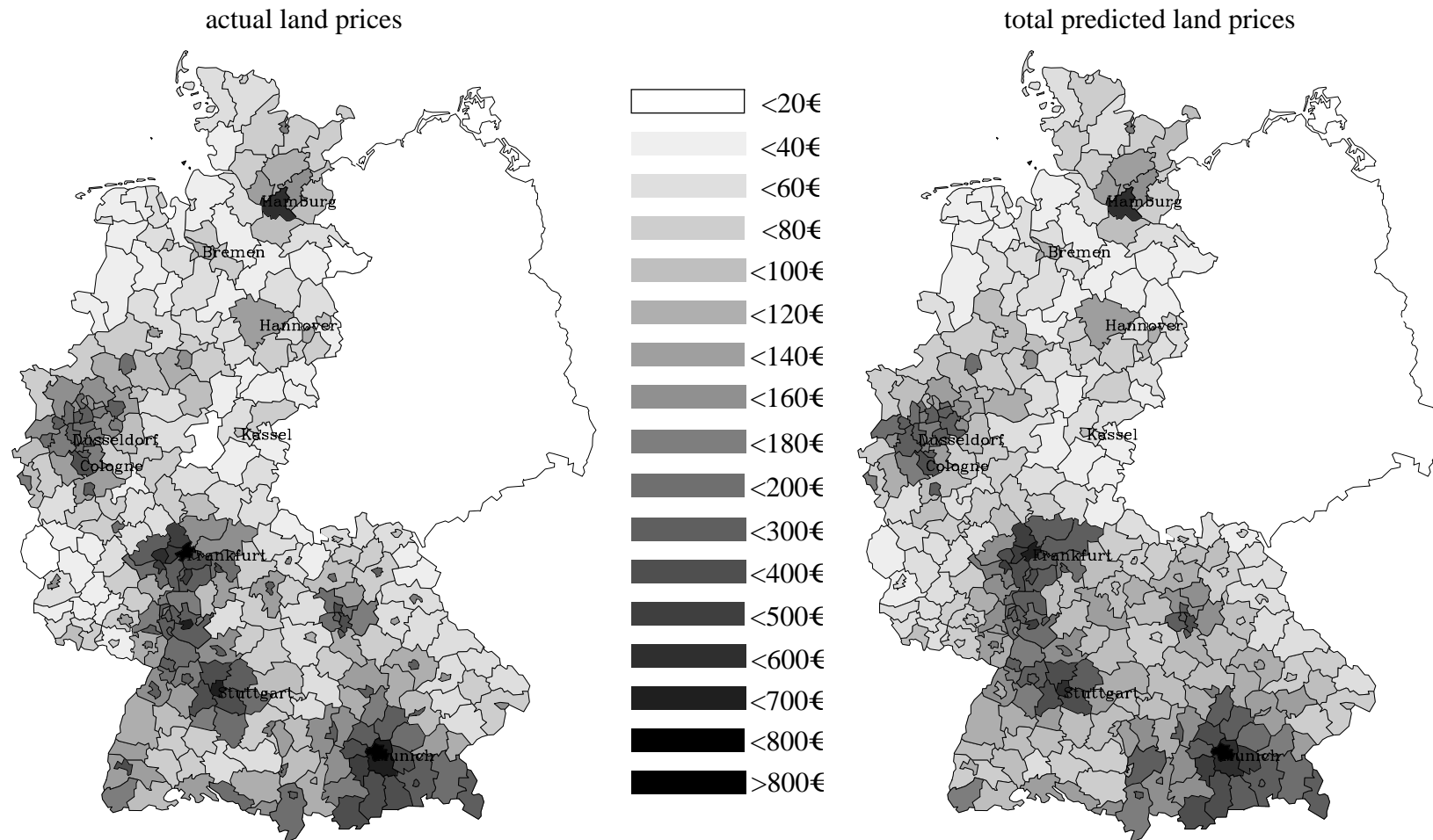
to be continued

Table A1 continued

Variable	(i) 32 centers (pop>200K)		(ii) 57 centers (pop>100K)	
	coeff	prob	coeff	prob
First-nature geography				
Intercept	-0.600	0.390	-0.662	0.359
SUNSHINE	1.295	0.000	1.431	0.000
RELIEF_INTENS	0.002	0.000	0.002	0.000
MOUNTAIN	0.493	0.000	0.319	0.012
SOIL	0.005	0.763	-0.003	0.857
SOILSQ	0.000	0.558	0.000	0.429
INHERIT	0.112	0.006	0.162	0.000
Border controls				
DUM_AT	-0.201	0.147	-0.189	0.151
DUM_BE	-0.424	0.087	-0.491	0.027
DUM_CH	0.085	0.695	0.223	0.266
DUM_CZ	-0.431	0.007	-0.477	0.001
DUM_DE	-0.318	0.002	-0.243	0.015
DUM_DK	0.188	0.415	0.222	0.288
DUM_FR	0.048	0.724	-0.083	0.573
DUM_LU	-0.396	0.103	-0.194	0.387
DUM_NL	0.106	0.491	0.221	0.156
Future growth prospects ^b				
Wln(1+share high-skilled 1993)	1.661	0.708	-1.057	0.810
Wln(1+no. of patents \emptyset 1991,1993)	-0.009	0.784	-0.222	0.575
R ² / R ² (adj.)	0.817 / 0.769		0.861 / 0.810	
R ² without center dummies	0.691		0.679	
lnL / AIC	-141 / 420		-110 / 400	
degrees of freedom / observations	257 / 326		236 / 326	
number of iterations of selection proc.	57		88	

^a Results obtained from a selection procedure (see Section IV.2), based on cross-section OLS regressions for West German *Landkreise*; dependent variable: $\ln(\emptyset$ real land price/sqm 1995-2001).

^b The variables are defined as spatially lagged shares of high-skilled workers (university degree), resp. numbers of patents in 91 *kreisfreie Städte*, using inverse exponential distances (decay parameter: 0.01). W denotes the spatial weights matrix.

Figure A1 — Observed and predicted land prices for West German Landkreise^a

^a Regression based on 32 pre-determined potential metropolitan centers, see column (i) of Table A1 for the underlying parameter estimates.