How polycentric is a monocentric city? The role of agglomeration economies

Ahlfeldt, Gabriel M. and Wendland, Nicolai

LSE, TU-Berlin

July 2010

How Polycentric is a Monocentric City? The Role of Agglomeration Economies

Gabriel M. Ahlfeldt[a] and Nicolai Wendland[b]

[a] *Address for correspondence*: London School of Economics and Political Sciences, Department of Geography and Environment, Houghton Street, London WC2A 2AE, phone [44] (0)20 78523785, fax [44] (0)20 7955 7412, g.ahlfeldt@lse.ac.uk, http://personal.lse.ac.uk/ahlfeldg

[b] Darmstadt University of Technology, Department of Law and Economics, Residenzschloss, Marktplatz 15, 64283 Darmstadt, Germany
phone [49] (0)6151 166506, fax [49] (0)6151 165652, wendland@vwl.tu-darmstadt.de

Abstract: Can the demise of the monocentric economy across cities during the 20th century be explained by decreasing transport costs to the city center or are other fundamental forces at work? Taking a hybrid perspective of classical bid-rent theory and a world where clustering of economic activity is driven by (knowledge) spillovers, Berlin, Germany, from 1890 to 1936 serves as a case in point. We assess the extent to which firms in an environment of decreasing transport costs and industrial transformation face a trade-off between distance to the CBD and land rents and how agglomeration economies come into play in shaping their location decisions. Our results suggest that an observable flattening of the traditional distance to the CBD gradient may mask the emergence of significant agglomeration economies, especially within predominantly service-based inner city districts.

Keywords: Transport Innovations, Land Values, Location Productivity, Agglomeration Economies, Economic History, Berlin

JEL classification: N7, N9 R33, O12

Version: July 2010

1. Introduction

The traditional models of urban economics view cities as aligned around a single, exogenously defined “mono”-center, the so called central business district (CBD). The value of urban land emerges from a tradeoff of access and transport cost to this center (e.g. Alonso, 1964; Mills, 1969; Muth, 1969). More recent models, in contrast, have acknowledged the polycentric structure of many cities in the world and attempted to explain the emergence of more complex patterns through the interplay of various forces of agglomeration and dispersion (e.g. Anas & Kim, 1996; e.g. Lucas & Rossi-Hansberg, 2002). Monocentric and polycentric views on the spatial structure of cities, therefore, feature very distinct but not necessarily mutually exclusive underlying mechanisms that generate economic densities.

The traditional view of a firm’s bid-rent function is that bid-rents have to diminish as transport costs to the exogenous centre increase. In order to understand why goods need to be transported to the city centre, one may think of a central market place and/or export hub where goods and services are traded and/or shipped. It is, of course, questionable to which degree this rationale applies to modern service-based (urban) economies. Alternative explications for the evident spatial clustering of firms have instead built on the idea of scale-economies and spatial interactions that drive productivity for firms in close proximity through knowledge spillovers, for example, and mutual access to intermediate inputs.

A common approach in the literature to empirically test the predictions of the traditional (moncentric) models has been to look at the relationship between distance to city centers and observed land values. Although in the historical context it has been somewhat difficult to find appropriate data, the empirical literature has provided evidence for negative rent gradients, mostly for residential, but also for commercial land (McMillen, 1996). The magnitude of the gradients, thereby, has been found to diminish considerably over time, a phenomenon that is widely interpreted as urban decentralization. Based on these findings, however, it is hardly possible to draw conclusions on the origin of the spatial pull that drives firms into the center in the first place. Do firms discount their bids for land on the transport cost for shipping goods to the centre or do they take advantage of locating close to other businesses to enjoy a productivity externality? Thus, it is not clear whether rent gradients that diminish over time reflect a reduction in transport costs to the city center or the increase in agglomeration economies as the fundamental determinant of productivity of commercial land, and, hence, its market price. Clearly, if strong agglomeration economies are present, they offer the potential for increasingly larger sub-centers and edge cities to emerge, which would reduce the magnitude of (negative) CBD gradients.[1]

Against this background, we examine transport costs to the city center and the mutual attraction of economic activity as alternative determinants for the value of commercial land. We chose Berlin, Germany, during the late period of industrial revolution as a case since anecdotal evidence records the beginning of a gradual breaking-up of the monocentric city structure during the early 20th century. During our study period from 1890-1936, the city underwent a major transformation in the industry structure towards a predominantly service-based economy and developed a dense network of intra-urban rapid transit. Both incidents should have generated driving forces that amplified spatial interactions among economic agents, thereby stimulating the relevance of agglomeration economies. To account for the fundamental change in accessibility due to the creation of a dense intra-city transport network, we model the effective travel time among each pair of commercial locations in the city for each observation year. In order to allow the spatial pull driving firms´ bid-rents to originate from various locations we make use of a gravity-type variable, which previously had been employed to explain the impact of labor market accessibility on residential property prices (Adair, McGreal, Smyth, Cooper, & Ryley, 2000; Ahlfeldt, in press; Osland & Thorsen, 2008), but has not yet been applied to commercial land. Since it could reasonably be argued that in the spirit of the monocentric model the CBD is only a proxy for a central transport hub to which goods have to be carried, we employ robustness checks where we consider rail hubs and water ways as alternatives to the standard definition of the CBD. Briefly summarized, we evaluate the sensitivity of the estimated rent gradient to the inclusion of controls for agglomeration effects as well as location and environmental features, which all might act as noticeable determinants. Our empirical strategy thus aims at separating the true effect of

---

[1] A prominent example is LA, where sub-centres dominate the CBD so that even a positive gradient was found (Heikkila et al., 1989).

proximity to an exogenous city centre from correlated effects, triggered first of all by agglomeration economies, but also by or environmental quality.

Our results indicate a flattening of the CBD gradient over time, which is in line with previous evidence on historic land gradient evolution (Abelson, 1997; Atack & Margo, 1998; McMillen, 1996; Smith, 2003). Even by the end of our observation period, we observe a significantly negative gradient, which is still large compared to previous findings. A closer look, however, reveals a fundamental change in the city structure over the study period. While conditioning on agglomeration effects hardly affects the magnitude of the gradient estimate in 1890, it almost entirely explains the CBD gradient roughly 50 years later. Overall, our results indicate that by the end of our study period, the large and significantly negative CBD gradient masked the presence of agglomeration economies and a considerable degree of polycentricity, which contradicts the standard view of the monocentric city. We conclude that the frequent result of a small but significant gradient estimate can be indicative of a fundamental change in the determinants of urban land value, rather than simply very low transport costs to the city center. Hence, a differentiated view is required when interpreting monocentric gradient estimates.

2. Background

2.1 Theoretical Framework

The uneven distribution of clusters of economic activity across the planet is a striking regularity. One explanation is that firms receive a productivity premium due to agglomeration benefits (Andersson, Burgess, & Lane, 2007), which seemingly applies to all levels of geographical disaggregation, such as countries, cities and even municipalities and districts. Productivity gains amongst spatially concentrated firms which are engaged in similar activities are usually referred to as *localization economies*. *Urbanization economies* emanate if the firms benefit from diversity in production or from the total amount of economic activity in close proximity. Both forces are external to the firm. The discussion of how and why economic densities emerge has for a long time been dominated by the idea of two different forms of agglomeration economies. So called *first nature geography* may be responsible for individual firms' initial location decisions

(Berliant & Konishi, 2000; Ellison & Glaeser, 1999; Kim, 1995, 1999).[2] Comparative advantages provided by certain locations create incentives for firms and industries to cluster around focal points of interest. In many cases, these might have offered perfect conditions for cities and CBDs to emerge in the first place, e.g. if those locational advantages were represented by well accessible points like ports. Via intense interactions between producers at the same location, *urbanization* and *localization economies* eventually arise and generate additional benefits derived from *second nature geography* (Berliant, Peng, & Wang, 2002; Fujita & Ogawa, 1982; Henderson, 1974, 1977, 1988; Jacobs, 1969). An important factor for productivity gains derived from spatial proximity to other firms consists of potential knowledge spillovers due to formal and informal communication. These receive enhanced importance in service-dominated cities and industries as these specifically rely on the exchange of information amongst economic agents. Given that firms benefit from face-to-face contacts and the cost of maintaining contacts increases with distance, spatial clustering will yield either higher revenues or lower cost. Rosenthal and Strange (2001) show that the effects of information spillovers might be assessed well at micro-levels of an urban economy, thereby underlining their specific relevance in explaining location patterns within cities.

Based on this concept, Fujita and Ogawa (1982) construct a "locational potential function", where firms directly benefit from spatial proximity to other producers. They show how externalities can account for different urban configurations ranging from simple monocentric to polycentric outcomes. Notably, their model exclusively attributes location decisions to the existence of externalities. Similarly, Helsley (1990) relates his research directly to the fact that agglomeration economies might be strongest within the CBD and are most likely to decline with distance. Compared to the view that goods and services need to be transported to the city centre, these models represent an opposite extreme case, emphasizing *second nature* at the expense of *first nature geography*.

In contrast, our view of urban configurations is a hybrid of both perspectives: a simple monocentric economy where goods still have to be shipped to an exogenous centre in

---

[2] For a comprehensive overview of the nature of agglomeration economies see (Rosenthal & Strange, 2004)

order to be traded or exported and a Fujita & Ogawa (1982) world where firms are exposed to an agglomeration economy that arises from nearby economic activity. We note that only the firm side of Fujita & Ogawa (1982) is considered in this study. For simplicity, we assume that each firm produces some kind of goods, information or services. Firms use fixed production inputs of capital *(K),* which includes labor costs, and land *(L)*.[3] There are no market restrictions, which results in free entrance and exit of all producers leading to zero economic profits in equilibrium.

Inputs of all firms enter our production function symmetrically, which is of a Cobb-Douglas type:

$$Q(K_b, L_b) = K^{\beta} L^{1-\beta}, \qquad [1]$$

Note that, for clarity of the exposition, we assume that agglomeration benefits $A(x)$ do not impact on output $Q(K_b, L_b)$, but directly impact on firms' profits. As shown in the appendix, however, all qualitative implications of the models remain unchanged if a multiplicative production function is assumed where output increases in the presence of agglomeration benefits.

In either case, firms are subject to increasingly positive externalities as the distance to surrounding firms decreases:

$$A(x) = \int M\,(y) e^{-\alpha d(x,y)} \mathrm{d}(y), \qquad [2]$$

with *M(y)* being the density of firms at point *y*, and α being the distance-decay parameter;[4] $d(x,y)=|x-y|$ is the distance between two firms located at *x* and *y*. Given that Berlin, and even more so its central area, was characterized by a high proportion of service-based industries (see Tab. 1), we assume benefits to be predominantly driven by knowledge spillovers. Since these involve a high degree of face-to-face contacts, economic distance is assumed to be expressed in terms of effective travel times amongst agents, as will be modeled in our empirical analysis.

---

[3] Firms are identical in their behavior regarding the location choice. They may differ in the types of services or goods they produce.

[4] Note that the benefits of locating at *x* do not only depend on the value of α, but also on the relative distribution of economic activity over the space.

We extend the model provided by Fujita and Ogawa (1982) by the idea that goods still have to be exported via central export hubs or that services still have to be sold at central market places. Consequently, distance to the traditional CBD still matters as a location factor in itself. Related transport costs *(t)* depend on distance (*D*) as well as on the amount of transported goods or services.

$$T(x, K_b, L_b) = tD(x)Q(K_b, L_b) \qquad [3]$$

We assume an additive production equation, where clustering yields pecuniary benefits (side-benefits or cost reductions) and drives profits upwards.[5] Firms take constant wages across the city as given. The price of the good serves as numeráire, *p* is the monetary conversion rate of benefits derived from locating at *x,* and *R* and *C* are the cost for using land and capital.

$$\max_x \pi = Q(K_b, L_b) + pA(x) - R(x)L_b - CK_b - T(x, K_b, L_b) \qquad [4]$$

The zero profit condition yields:

$$R(x) = \frac{1}{L_b}[(1 - tD(x))Q(L_b, K_b) + pA(x) - CK_b] \qquad [5]$$

$$\frac{\partial R(x)}{\partial D(x)} = -\frac{t}{L_b}Q(L_b, K_b) < 0 \qquad [6]$$

where $f(L_b, K_b)$ is constant across firms. As equilibrium rents must be higher at close distances to the centre, firms substitute away from land, thus yielding the negative and convex land gradient known from classic land theory. To show that land rents also decrease at increasing rates as a firm moves away from the source of production externalities, we calculate the first order condition.

$$\frac{\partial R(x)}{\partial A(x)} = \frac{p}{L_b} > 0 \qquad [7]$$

It is evident that firms will substitute away from land as agglomeration benefits, and thus rents, increase, generating a bid-rent curve which is convex in the location of ag-

---

[5] Another way of incorporating agglomeration economies would be to assume multiplicative effects. Both forms are mathematically equivalent, while the multiplicative form suggests that the effect raises productivity in the presence of agglomeration economies. The derivation of the above arguments using a multiplicative production function is provided in the appendix.

glomeration benefits. In equilibrium, the marginal effect of distance to the centre hence decreases in distance, while the marginal effect of agglomerations economies increases in the density of economic activity. It is obvious that if physical transport cost $t = 0$, or the market place loses its role, equation (5) collapses to the Fujita & Ogawa world where bid-rents are solely shaped by agglomeration economies, facilitating a range of spatial outcomes depending on parameter values. If $p = 0$ and solely transport costs to the city centre dominate, the mills map will emerge instead.

2.2 Berlin 1881-1936

Our study period covers the second phase of industrialization in Berlin. As is typical for this stage of development, the period was characterized by rapid population growth and technological innovations. This era is of particular interest for the purposes of this article for a number of reasons.

First, anecdotal evidence suggests that a traditional monocentric city structure began to break up and new, specialized sub-centers started to attract commercial activity by the beginning of the 20th century (Krause, 1958). Plazas such as Potsdamer Platz and Alexanderplatz, located alongside the former tariff-wall (Zollmauer) that had marked the former city boundaries for centuries and became primary locations for businesses. While these were located within relative proximity around the very center, new business agglomerations emerged even at remote locations .[6] The area around the Kurfürstendamm is probably one of the most prominent examples. After rising to become a major entertainment and luxury retail centre in the 1920s, it grew to be the CBD of West-Berlin during the years of division and has maintained its status until today.

Second, this development was accompanied by the transformation from a craftsman-dominated economy into a service-based one (Bergmann, 1973). Holding the status of

[6] The commercial center of Berlin had been formed by the Berlin City Palace (Stadtschloss) for centuries. Alexanderplatz is located approximately 770 meters to the northeast and Potsdamer Platz lies about 2km to the southwest. However, accounting for spatial changes within the city, we define the CBD as the metro station "Stadtmitte".

capital for both Prussia and the German Reich since the end of the French-Prussian War in 1871, this new prestige and various administrative and political entities drew firms and service-oriented industries like banks and the media into the city. Table 1 shows how sustainably the industry structure of the city changed over our observation period. Note that most of the large manufacturing firms were located at remote districts such that this change was even more fundamental for the central business district investigated here than the city-average depicted in Table 1.

Tab. 1 Industry Structure in 1890 and 1933

Year	Manufacturing	Share of total employment	Trade and Services	Share of total employment
1890	310.251	38.01%	178.380	22.02%
1933	1.056.683	46.60%	1.064.300	46.90%

Notes: Figures are taken from the Statistical Yearbook of Berlin for 1890 and 1936, respectively. The yearbook from 1936 provides data based on the 1933 census. Manufacturing numbers also include mining and construction, whereas trade and services include trade, transportation, communication and utilities, business services and FIRE industries. Private services are excluded.

Third, a dense network of intra-urban transport emerged. In 1877, the circular line, which connected Berlin to its surroundings and to several regional lines, was inaugurated. Then, in 1882, an east-west connection joined several inner-city stations with the circular line (Borchert, Starck, Götz, & Müller, 1987). This, however, was only a first step in generating inner-city travel systems and it was not for several decades that gradually added stations created a highly developed and very dense network that fundamentally changed the pattern of urban accessibility.

Both the change in industry structure towards a service based economy and the reduction of effective transport costs due to the emerging transport network should have amplified spatial interactions among economic agents and should have given rise to an increasing importance of agglomeration economies, simultaneously reducing the relative importance of physical distance to the CBD as the major determinant of the value of land.

During our study period, an ambitious planning agenda was to become a major driving force, the so called Hobrecht Plan. Taking the famous Parisien Haussman Plan as its precedent, the new development aimed at establishing a new setting of dense five to six-storey block developments and representative boulevards within the "Wilhelminian Ring", which roughly corresponds to the area inside the circular rail line.[7] It is important to note, however, that the allocation of economic activity within that area was not explicitly influenced by zoning policies (Richter, 1987), except a general ban of buildings that exceeded a height of 24m, the so called "Traufhöhe". Some remarks must, of course, be directed towards WWI and the Great Depression, both of which fall within our study period. While the depressing effects on the urban economy are clearly visible in our data for 1928, and to a smaller degree also for 1936, it is not that clear why the relative within-city distribution of economic activity should have been affected. It is important to note that the epicenter of the fighting was far away and the city did not suffer major war damage. Also, our study area ends before Hitler imposed a general price stop by the end of 1936 to prevent a further inflation that would have been the natural consequence of an economic downturn and increased government spending.

3. Empirical Analysis

3.1 Data

Our data encompasses a sample of land values for commercial areas as defined in the historical land value map drawn up by Bruno Aust (1986), which shows real land uses at the individual plot level for a large part of Berlin in 1940. For the empirical analyses we use a balanced panel of 1470 commercial plots where land values were continuously available from 1881 to 1936. We thereby cover an area of approx. 9 kilometer radius around the city center, which we define as the present-day subway station "Stadtmitte" (Downtown). Due to the huge loss of raw data caused by the two wars, the identification of reliable information on land values covering a sufficiently long time period proved to

---

[7] For details see Hegemann (1930)

be challenging. However, two valuable sources could be retrieved from Berlin's historical archives. The first was created by the renowned technician Gustav Müller (1881-1910). In cooperation with official planning authorities he published a collection of very detailed colored maps. These maps were presented in a similar way to Olcott's land values, which contributed to Chicago becoming a unique laboratory for Urban Economics in an historical context. Müller's maps provide data at an astonishingly disaggregated level of individual plots. The stated objective was to provide official and representative guides for both private and public investors participating in Berlin's real estate market. While Müller himself did not explicitly reveal the exact procedure of land valuation, the imperial valuation law (Reichsbewertungsgesetz) of the German Reich contained a strict order to use capital values for the assessment of commercial plots based on fair market prices. In line with the valuation laws for commercial land, Müller claims that his assessment refers to the pure value of land, which is adjusted for all building and even for garden characteristics. He also corrects for specific location characteristics such as single and double corner lots, subsoil and courtyard properties. The maps cover an area of similar scope to Bruno Aust's (1986) map of land uses.

The second source was created by Ferdinand Kalweit (1928; 1936). He was the first to provide detailed information on land prices in Berlin after Müller. In his function as a chartered building surveyor ("gerichtlich beeideter Bausachverständiger"), he offered great expertise regarding land valuation procedures, and received a government assignment in order to overcome the lack of documentation created by the troubled environment of WWI and hyperinflation. Kalweit´s work resulted in two books containing land values for all streets in the city in 1928 and 1936. Like Müller, he followed the explicit rules of the imperial valuation law. He additionally considered information on real sales as a basis for local adjustments. After controlling for subsoil property and location characteristics, he assigned representative minimum and maximum values of the pure land value to each street. These street stretches were frequently larger than single commercial areas and often contained non-commercial uses. To the maximum extent possible, we applied consistent rules in order to identify the provided land value information as precisely as possible. First, we assume that within residentially and commercially used streets, Kalweit's upper bound estimate refers to commercial use. Second, if provided values referred to very long road stretches, land values at sub-stretch level were gathered by considering values assigned to crossing roads. In addition, a colored map for 1938, prepared by Runge (1950), which shows many similarities to the Müller maps, served as a guidance. Runge received an official assignment from authorities after WWII in order to provide an overview of land values based on the pre-WWII situation. Due to a lack of comprehensive documentation, this map was not considered a primary source in the analyses but nevertheless provided valuable information and crosschecks on the spatial structure during the inter-war period.

A number of spatial variables were calculated using GIS: great circle distances to a) the CBD, defined as the subway station "Stadtmitte" (Downtown), b) to the next major park or forest area and c) distance to the nearest body of water, which are all time-invariant. Further, we calculate great-circle distances to the next mainline station and next industrial area based on available historical maps that fit the respective years as closely as possible.[8] Table 2 provides descriptive statistics for the discussed data. Bilateral travel times are discussed in the next subsection. Note that throughout our empirical analysis we land that are normalized values to mean. As discussed below, 1881 and 1928 data will only be used in auxiliary regressions.

8 Distance to the nearest mainline station changes only after 1890. For distance to the industrial areas we match 1880 to 1890, 1900 and 1910 to 1910 and 1936 to 1940. Location of industrial areas are all identified from Aust´s (1986) land use maps discussed in the main text.

Tab. 2 Descriptive statistics

	Obs.	*Min*	*Max*	*Mean*	*Median*	*Std*
LNLV 1890	1470	-4.08	2.35	-0.72	-0.57	1.36
LNLV 1900	1470	-3.29	2.02	-0.31	-0.30	0.93
LNLV 1910	1470	-3.04	1.73	-0.22	-0.23	0.80
LNLV 1936	1470	-4.23	2.50	-0.41	-0.61	0.91
Distance to the CBD	1470	0.06	8.16	3.20	3.21	0.91
Distance to industry 1880	1470	0.00	2.02	0.33	0.22	0.33
Distance to industry 1910	1470	0.00	1.14	0.26	0.20	0.22
Distance to industry 1940	1470	0.00	1.35	0.33	0.24	0.29
Distance to water	1470	0.00	3.20	0.88	0.69	0.71
Distance to green spaces	1470	0.50	4.88	1.75	1.62	1.05

Notes: Distances are calculated in kilometres. LNLV is log of normalized land values. More information on the data is available from the authors.

Networks

In our empirical analyses we connect all city areas based on a bilateral travel time matrix that incorporates the present rail transport infrastructure (subway and suburban rail) for the respective year. Therefore, the evolution of the city's complete public railway network, including up to 222 stations, has been traced back over the course of our study period in order to create digital maps.[9] Note that the total length of the network, which was calculated within a GIS environment, varied as much as from about 186 km in 1890 to more than 410 kilometers in 1936, which is close to the same size of the contemporary network (475 km). Once the bilateral network distances between rail stations were calculated using GIS, the total trip length in terms of travel time was estimated based on a simple transport decision model as used in Ahlfeldt (in press). Accordingly, passengers choose the closest station in terms of distance D as the start of their train journey (station s) and the closest station to their final destination as the endpoint (station e).

[9] For all following arguments, relevant information and network plans can be found at: http://www.bahnstrecken.de/indexf.htm; http://www.bahnstrecken.de/bse.htm; http://berlineruntergrundbahn.de/; www.stadtschnellbahn-berlin.de; www.berliner-verkehr.de.

Between these stations they choose the shortest network path. Passengers walk to stations at waking speed (V^{walk} = 4 km/h) while trains run at a velocity of V^{train} = 33.8 km/h, which could be determined from historic train schedules. A buffer time of 2.5 minutes is added to account for the average waiting time at the station of departure, based on an average five minute train frequency. Passengers will choose to walk, instead of taking the train, strictly on the basis of travel time minimization. Travel time between areas *i* and *j* in year *t* therefore can be described as follows.

$$TT_{ijt} = \min\left(\frac{D_{ijt}}{V^{walk}}; \min\frac{D_{ist}}{V^{walk}} + \min\frac{D_{set}}{V^{train}} + \min\frac{D_{ejt}}{V^{walk}}\right) \tag{8}$$

Internal travel times are discounted at walking speed. Internal distances are calculated as in Redding & Venables (2004) as two thirds of the radius of a circle with the same surface area (A) as area *i*.

$$TT_{ii} = \frac{2}{3}\frac{\left({}^{A_i}/_{Pi}\right)^{1/2}}{V^{walk}} \tag{9}$$

3.2 Empirical Strategy

Our baseline specification is an established log-linear CBD gradient specification that models the value of urban land as a function of distance to an exogenous city centre, which we define as the subway station "Stadtmitte" (Downtown). As noted in the theoretical background section, the standard monocentric city model assumes that firms' bid rents diminish with distance to the CBD as transport costs to the centre increase (Alonso, 1964; Mills, 1969; Muth, 1969). Since firms substitute land for other input factors at close locations to the CBD due to higher land prices, the gradient takes a convex form, which is accounted for by the log-linear functional form with a presumably negative sign. Evidence suggesting that land values may be satisfactorily described by such an exponential function is available for the cities of Chicago, Cleveland, New York and Sydney (Atack & Margo, 1998; Kau & Sirmans, 1979; McDonald & McMillen, 1990; McMillen, 1990, 1996; McMillen, Jarmin, & Thorsnes, 1992; Mills, 1969; Smith, 2003).

Obviously, the assumption of a featureless plain ground, which underlies standard rent theory, is very rigid and unrealistic in light of most of the real-world settings. There is a range of location and environmental features which potentially affect firm's bid rents.

The slope of a firm's bid-rent *dR/dD* is then a composite effect of transport cost *t* and a (dis)amenity effect as distance to downtown increases. Since identical firm behavior is assumed, the production function does not enter equation (10).

$$\frac{dR}{dD} = -\frac{t}{L} + \frac{dR}{dE}\frac{dE}{dD}, \tag{10}$$

where *dR/dE* is the marginal effect of the environmental externality on the bid-rent and *dE/dD* reflects the change in the amount of the (dis)amenity as one moves out of the city centre. If externalities impact on firms' bid-rents and are correlated with distance to the CBD, thus $dR/dE \neq 0$ and $dE/dD \neq 0$, the estimated gradient will be biased if (dis)amenities are not controlled for appropriately.

We therefore extend the bivariate gradient model by a vector of location control variables that are assumed to impact log-linearly on the value of urban land. Berlin is crossed by two rivers, the Spree and the Havel, which are also connected by a system of channels. Proximity to the water spaces may impact positively on firms' bid rents mainly for two reasons. Following the argument that firms trade the transport cost of shipping goods to an export node in the city centre, they would also be willing to pay for access to waterways that serve as transport routes out of the city. Note that for a similar argument we conduct robustness checks using *distance to the nearest mainline station* instead of the CBD.[10] The second reason why we expect a negative impact of *distance to the nearest water body* on the value of land is that water bodies represent a widely accepted location amenity, making areas in their proximity more desirable and prestigious. A similar argument applies to *distance to the nearest green space*. A good example is the central park area "Tiergarten" that has attracted embassies and headquarters. In contrast to these natural amenities, we expect *distance to the nearest industrial area* to impact negatively on the value of commercial land due to the correlated environmental disamenties, e.g. noise and pollution. Our (extended) baseline specification thus takes following form.

$$\log(NLV_{it}) = \alpha_t + \beta_t DCBD_{it} + X_{it} b_t + \varepsilon_{it} \tag{11}$$

---

[10] Due to the high correlation, both variables do not enter our models at the same time.

where NLV_{it} is the per-square-meter land value at location i in time t, normalized to the mean in the respective year, *DCBD* is the distance to the CBD in km and X is a vector of hedonic controls. Parameters are α, β and the vector b, while ε is an error term. The percentage effect of a 1 km increase in distance to the CBD on the value of land is given by β. Note that we find a spatial structure in the error term when estimating specification (11), which is typical for micro level spatial analyses. We use spatial autoregressive (SAR) models to obtain unbiased and efficient estimates in the presence of spatial dependency. LM tests reject a spatial-lag model in favor of an error-corrections model (Anselin, 1995), which corrects for the spatial structure as follows:

$$\varepsilon = \lambda W \varepsilon + \mu, \tag{12}$$

where W is a binary row standardized weights matrix indicating transactions that are neighbors, λ is a parameter and μ is a random error term.[11]

In the next step, we extend our baseline specification (11) in order to relax the assumption of an exogenous city center and to test for a significant effect of access to the surrounding economic mass, which would be in line with the presence of agglomeration economies. We now assume bid-rents to depend on transport costs to the CBD, environmental disamenities as in equation (10) and, analogically, an agglomeration benefit from locating close to existing economic agglomerations (A).

$$\frac{dR}{dD} = -\frac{t}{L} + \frac{dR}{dE}\frac{dE}{dD} + \frac{dR}{dA}\frac{dA}{dD}, \tag{13}$$

As for the environmental (dis)amenities, a gradient estimate will be biased if firms value the presence of agglomeration economies ($dR/dA \neq 0$) and the distribution of economic activity is correlated with the distance to the CBD ($dA/dD \neq 0$), a condition that quite naturally will be true in reality. For an unbiased estimate of the effect of transport

---

[11] We chose a row-standardized weights matrix (W), where transactions within a distance band of 300 meters are treated as neighbors. This weights matrix provides the best fit compared to alternative specifications and minimizes the Akaike and Schwarz criteria across all years. Exemplarily, LM test scores (p-values) for specification [11] including location controls in 1910 are: $LM_{lag} = 0.000$, $LM_{error} = 0.000$, robust $LM_{lag} = 0.948$ robust $LM_{error} = 0.000$, which clearly indicate the appropriateness of estimating a spatial error model. Results are available from the authors.

costs to the CBD on the value of urban location, we therefore need to hold constant both environmental effects as well as agglomeration spillovers. The surface area A_j of commercial areas, multiplied by the (normalized) per square meter land value, serves as an indicator of economic activity. It reflects the capitalized location productivity and is assumed to emanate productivity spillovers that benefit neighboring firms. A potentiality equation similar to that in Ahlfeldt (in press) is used to allow the spatial pull that drives bid-rents to originate from various locations. Applications of similar gravity-type variables in the realm of the real estate economics literature include Adair, et al. (2000), Osland & Thorson (2008) and Ahlfeldt & Maennig (2010).

$$\log(NLV_{it}) = \alpha_t + \beta_t DCBD_{it} + \gamma_t\left[\sum_j \left(A_j \times NLV_{jt}\right) e^{-\tau \times TT_{ijt}}\right] + X_{it} b_t + \mu_{it} \qquad (14)$$

In equation (14), which is estimated using non-linear least squares (NLS), spillovers from a neighboring area *j* discount on travel time (*TT*) defined in (8 and 9). Parameter τ reflects the slope of the spatial decay function and parameter γ the magnitude of the marginal price effect of the spillover potentiality. Feasible parameter values for γ and τ are positive. The log-linear specification with positive coefficient satisfies the convexity requirement laid out in the theory section. Robustness-checks for spatial dependency are conducted based on a linearized version of equation (14), where τ is hold-constant.

There is an obvious endogeneity problem in equation (14), as the dependent variable shows up in the right-hand-side potentiality, even though multiplied by surface area and discounted by travel time. To avoid a correlation of the error term with the exogenous regressor, we instrument normalized land values with lagged values. Precisely, we run auxiliary first stage regressions of normalized land values on lagged land values as well as on a second order polynomial of distance to the CBD and use the predicted values in the second stage equation (14). Intuitively, the two stage procedure may be thought of as modeling an equilibrium where firms bid for locations under a limited degree of uncertainty. Firms do not know exactly the current distribution of economic activity by the time they bid for land, but base their decisions on past observations, adjusted for a general change in the city structure (CBD gradient), which is observable. We lag land values by ten years, with the exception of 1890 and 1936, where we instrument with 1881 and 1928 values. Note that due to the requirement of instrumenting land values with feasible lags, the 1881 and 1928 values are only used in the first-stage regressions. First-stage results are presented in Table A1.

Our empirical analyses are structured into three basic steps. First, we run bivariate land gradient models to compare how the value of locating closer to the CBD changed over time. As the existing evidence for Chicago (1996), Cleveland (2003), New York (1998) and Sydney (1997) uniformly suggests a process of urban decentralization during our study period, we expect the marginal price effect of distance to the CBD to constantly diminish. Second, we extend the bivariate gradient models by our hedonic controls to evaluate whether a potential decentralization was driven by an increase in the value (cost) of (dis)amenities in the urban periphery (core). Third, and most importantly, we include our agglomeration variable to test for significant productivity spillover effects and to disentangle the effects of transport cost to an exogenous centre from correlated agglomeration effects. Given the transformation into a service-based economy and the improvement in transport infrastructure, which should have promoted spatial interactions between different commercial areas, we expect the explanatory power of the agglomeration variable to increase at the expense of the CBD gradient over our study period. Note that if a significant CBD gradient masked the benefits of good access to the whole economic mass of the city, transport costs to a single market place or transport hub, the gradient parameter would be reduced (close) to zero when estimated conditional on our agglomeration variable.

3.3 Empirical Results

Table 3 shows the results of a series of bivariate gradient models corresponding to equation (11), where the vector *X* is omitted. Throughout our study period, we find negative and statistically highly significant land gradients, which are in line with the predictions for a monocentric urban economy. As expected, the marginal value of locating 1 km closer to the city center diminishes constantly over the study period, a phenomenon widely described as urban decentralization. While in 1890 land values decrease by as much as about 77% per 1 km increase in distance to the CBD, this figure more than halves to 37% in 1936. Still, the magnitude of the point estimate is large in comparison with previous evidence. Note that the most comparable results available in the literature are provided by McMillen (1996) for commercial land values in Chicago, a city of roughly the same size as Berlin. McMillen´s gradient estimates for the same period, however, are much lower, ranging from 0.31 in 1892 to 0.12 in 1928.[12] The explanatory power of our bivariate gradient models diminishes over time, although even by the end of our study period a considerable proportion of variation in land values is explained by the simple model and the explanatory power exceeds McMillan´s findings for Chicago in all years. From 1890 to 1936 we find a reduction in the R^2 from 0.74 to 0.39 compared to 0.58 and 0.24 in the case of Chicago 1892 and 1928.

Tab. 3 Bivariate gradient estimates

	(1)	(2)	(3)	(4)
	1890	1900	1910	1936
Distance to the CBD	-0.768**	-0.532**	-0.432**	-0.370**
(km)	(0.015)	(0.009)	(0.009)	(0.015)
Constant	1.737**	1.390**	1.162**	0.779**
	(0.039)	(0.026)	(0.028)	(0.05)
Observations	1470	1470	1470	1470
R-squared	0.74	0.77	0.69	0.39

Notes: Dependent variable is land value normalized to mean in all models. Robust standard errors are in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

Taking these results as a basis, it would seem fair to state that, despite a pronounced process of decentralization, Berlin remained a monocentric city throughout the study period. The results, while replicating previous evidence for other cities, do not, however, allow for an evaluation of the origins of the spatial pull that drives businesses to the city center nor do they allow for an assessment of why the decentralization actually happened and why the explanatory power of standard gradient models diminishes so markedly over time. In the remainder of this section we turn our attention to these open questions.

In the next step, we estimate a series of equation-(11)-type extended land gradient models. If decentralization was driven by an increasing response of firms' bid-rents to (dis)amenities rather than a reduction of transport costs to the city centre, we would expect the reduction in the point estimates of the land gradient to be less pronounced

[12] Note that for the purposes of comparability, McMillan´s estimates have been rescaled from miles to km.

than in the bivariate models of Table (3). Empirical results corresponding to equation (11) are presented in Table (4). The environmental control variables add to the explanatory power of the baseline models, most notably in 1936. They show the expected signs, with water spaces and green spaces acting as amenities and with industrial areas emanating negative (net)externalities in all years, except the first year. The reason for the exception in 1890 might be that at the beginning of industrial transformation there were complementarities among commerce and heavy industry that dominated the negative environmental effects. The point estimate for the CBD gradient is reduced in all years, indicating that the attractiveness of central areas was partly due to (exogenous) amenities. Notably, the reduction of the gradient estimates over time, however, remains roughly the same size in relative terms as the results in Table (3).

As the estimated gradient coefficients are all reduced following the inclusion of the hedonic controls, Table (4) results further indicate that the steep decline in land values when moving out of the city center was partially attributable to the presence of amenities in the centre. Central areas befitted from the ease of access to the Spree river and proximity to prestigious parks, e.g. the “Tiergarten”, while more peripheral areas seem to have suffered from (increasingly costly) negative externalities emanating from heavy industries in the industrial belt outside the “Wilhelminian” ring. However, despite their reduction compared to Table (3), the magnitudes of the gradient coefficients are still large. It remains questionable whether the idea of physical transport costs to a central market place in the city center could explain a reduction in land value of close to 30% for every 1 km increase in distance, at least within the service-based economy into which Berlin had transformed itself into by the end of the observation period.

Tab. 4 Gradient estimates with (dis)amenities

	(1)	(2)	(3)	(4)
	1890	1900	1910	1936
Distance to the CBD	-0.649**	-0.490**	-0.405**	-0.286**
(km)	(0.014)	(0.01)	(0.01)	(0.015)
Distance to the nearest	-0.433**	-0.101**	-0.022	-0.061*
water body (km)	(0.036)	(0.023)	(0.02)	(0.026)
Distance to the nearest	-0.103**	-0.036**	-0.046**	-0.105**
green space (km)	(0.018)	(0.011)	(0.011)	(0.017)
Distance to the nearest	-0.133*	0.474**	0.550**	1.006**
industrial area (km)	(0.057)	(0.056)	(0.054)	(0.067)
Constant	1.965**	1.282**	1.028**	0.414**
	(0.047)	(0.037)	(0.038)	(0.061)
Observations	1470	1470	1470	1470
R-squared	0.8	0.79	0.72	0.52

Notes: Dependent variable is land value normalized to mean in all models. Robust standard errors are in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%

To address these doubts, in the third step of our analysis we further extend the model to allow equilibrium land values to depend on the access to the whole economic mass of the city. As discussed above, our specification aims at empirically disentangling the effects of agglomeration spillovers, including those that are correlated with the distance to the CBD, from the effects of physical transport costs to the CBD as well as the effects of natural and environmental (dis)amenities. We run the extended specifications both with and without (Table 4) (dis)amenitiy controls to maintain comparability with the baseline versions of Tables 3 and 4. While both Tables yield qualitatively similar results, our quantitative interpretations focus on Table (4) since we believe that the inclusion of hedonic controls adds to the validity of the model.

The results yield a number of interesting insights. First, the magnitude and spatial decay parameters are positive and estimated at high levels of statistical significance in all models, which supports the presence of significant agglomeration economies. Second, the explanatory power of the models is increased considerably following the introduction of the agglomeration variable. The increases are particularly large for the late years. Third, the point estimate on the marginal price effect of the distance to the CBD is reduced considerably. In 1936, the gradient coefficient, despite still being statistically significant, is reduced by almost by 90% compared to the bivariate gradient model. A 1 km increase in distance to the city center yields a reduction of no more than about 8%, conditional on our control for agglomeration economies. The point estimates for the CBD gradient, conditional on spillover effects, are not very sensitive to the inclusion of hedonic controls, except for 1890, when the gradient estimate is reduced remarkably once hedonic controls are included. Figure 1(left) illustrates the point estimates of the CBD gradients from Tables 3-6, highlighting that the inclusion of the agglomeration variable not only reduces the estimated CBD gradient, but also that the magnitude of the reduction increases over time.

Tab. 5 Gradient estimates with spillover effects (2SNLS)

	(1)	(2)	(3)	(4)
	1890	1900	1910	1936
Distance to the CBD	-0.666**	-0.422**	-0.295**	-0.082**
(km)	(0.016)	(0.012)	(0.011)	(0.015)
	[0.795]	[0.696]	[0.564]	[0.138]
Spillover Potentiality	0.030**	0.021**	0.022**	0.056**
(γ)	(0.016)	(0.005)	(0.003)	(0.004)
	[0.093]	[0.239]	[0.346]	[0.680]
Spillover decay	0.665**	0.366**	0.325**	0.407**
(τ)	(0.235)	(0.055)	(0.026)	(0.018)
Constant	1.462**	0.871**	0.475**	-0.617
	(0.075)	(0.053)	(0.050)	(0.068)
Observations	1470	1470	1470	1470
R-squared	0.75	0.80	0.74	0.62

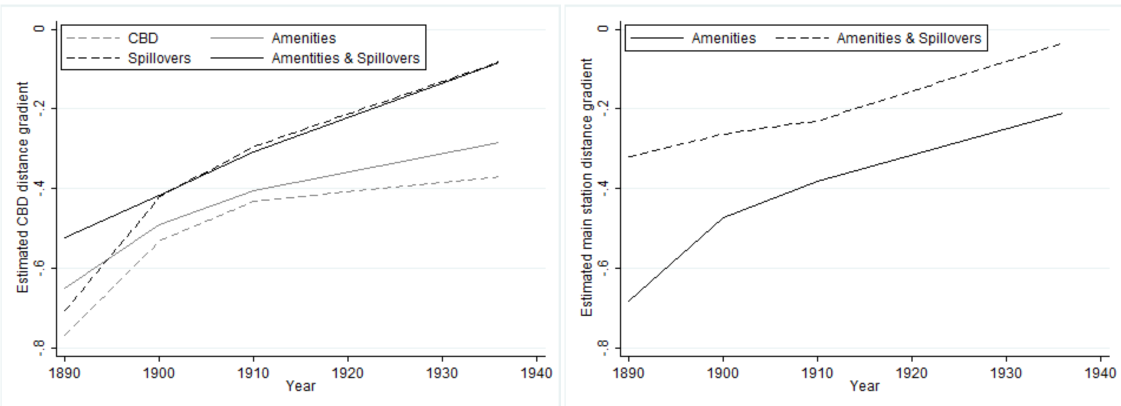
Notes: Dependent variable is land value normalized to mean in all models. Robust standard errors are in parentheses. Standardized coefficients are in brackets. + significant at 10%; * significant at 5%; ** significant at 1%

Tab. 6 Gradient estimates with (dis)amenities and spillover effects (2SNLS)

	(1)	(2)	(3)	(4)
	1890	1900	1910	1936
Distance to the CBD	-0.523**	-0.417**	-0.309**	-0.084**
(km)	(0.023)	(0.0126)	(0.0119)	(0.015)
	[-0.588]	[-0.688]	[-0.591]	[-0.140]
Spillover Potentiality	0.028**	0.020**	0.023**	0.049**
(γ)	(0.009)	(0.006)	(0.004)	(0.005)
	[0.174]	[0.182]	[0.274]	[0.560]
Spillover decay	0.433**	0.423**	0.379**	0.423**
(τ)	(0.094)	(0.076)	(0.042)	(0.022)
Distance to the nearest	-0.404**	-0.098**	-0.020	-0.072**
water body (km)	(0.027)	(0.018)	(0.018)	(0.024)
Distance to the nearest	-0.101**	-0.033**	-0.038**	-0.067**
green space (km)	(0.016)	(0.012)	(0.012)	(0.015)
Distance to the nearest	-0.433**	0.195**	0.216**	0.462**
industrial area (km)	(0.067)	(0.063)	(0.061)	(0.061)
Constant	1.468**	0.988**	0.610**	-0.492**
	(0.088)	(0.056)	(0.056)	(0.072)
Observations	1470	1470	1470	1470
R-squared	0.81	0.80	0.74	0.65

Notes: Dependent variable is land value normalized to mean in all models. Robust standard errors are in parentheses. Standardized coefficients are in brackets. + significant at 10%; * significant at 5%; ** significant at 1%

Fig. 1 Estimated gradient effects

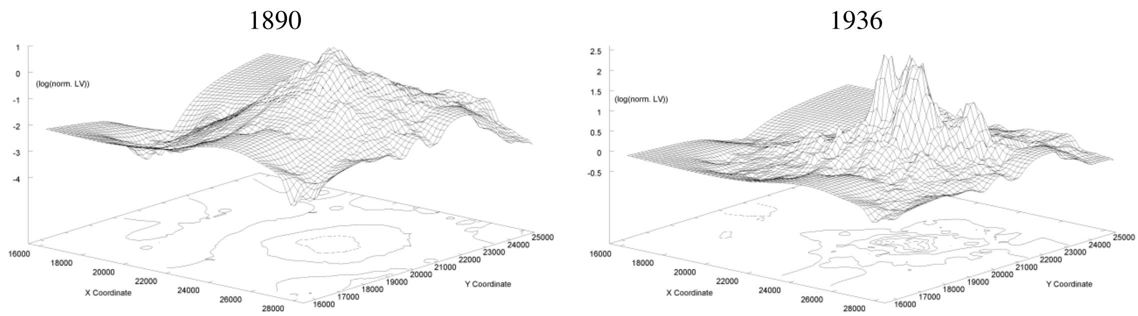


Notes: Figures illustrate point estimates on the effects of distance to the CBD (left) and distance to the nearest mainline station (right) from Tables 5-6 and A1.

Besides the change in the magnitude of the distance to CBD effect, we are interested in the relative contribution to the explanatory power of *spillover potentiality* and *distance to CBD*. For the coefficients of interest, Tables 5 and 6 show standardized coefficients [in brackets] which express the impact of the explanatory variables on the dependent variable in units of standard deviations (SD). From the results, it is evident that at the beginning of our study period, physical distance to the CBD was a strong determinant of land value, even conditional on our agglomeration variable and the hedonic controls. While an increase in distance to the center by 1 SD yields a reduction in the log of normalized land value by 0.588 SD, the respective increase is no more than 0.17 SD if we increase the spillover potentiality by 1 SD, holding all other factors constant. Very interestingly, over the study period this relationship nearly perfectly reverses. By the end of the observation period, we find the magnitude of the standardized coefficient to clearly exceed the one on the distance gradient (0.56 vs. 0.14) as well as any other variable in the model. Thus, our results confirm that the city had undergone a fundamental change in its spatial structure over our study period, with access to other businesses clearly becoming the more important determinant for firms´ bid-rents compared to transport costs to the central market place or transport hub.

The changes become clearly visible when plotting the price component (in log of normalized land values) that is jointly attributable to the distance to the CBD and the spillover potentiality into three dimensional space ($\hat{\beta}_t DCBD_{it} + \hat{\gamma}_t\left[\sum_j\left(A_j \times NLV_{jt}\right)\exp\left(-\hat{\tau} \times TT_{ijt}\right)\right]$). Figure 2 clearly shows a monocentric pattern for 1890 with a single peak in the CBD and smoothly and constantly descending values in all directions. By 1936, the pattern had become much more complex. While it is still the case that predicted values are generally much higher within the downtown locations than in the periphery, the surface shows a number of agglomerations that exhibit a pronounced influence in their proximity. Among them are Potzdamer Platz and a part of Leipziger Strasse, the Government district around Brandenburg Gate, the banking district around the central bank and, with a smaller magnitude, Alexanderplatz at the eastern end of the downtown section. All together, these results demonstrate that, while the simple bivariate gradient model for 1936 would still support the existence of a monocentric equilibrium, the effective city structure already exhibited a considerable degree of polycentricity by the end of our study period. Perhaps more crucially, by masking the polycentric structure, the bivariate gradient model supports a monocentric rent theory prediction of bid-rent functions that are simply shaped by transport costs to a single, dimensionless point, while the relevance of this concept is, in reality, much smaller than suggested by the naïve gradient models.

Fig. 2 Joint effect of distance to the CBD and spillover potentiality



Notes: Figures illustrate the joint effect of distance to the CBD and spillover potentiality based on Table 6 estimates.

Finally, one might argue that our empirical specifications would not reflect the true spirit of rent theory if bid-rents were assumed to reflect firms´ transport costs to an export hub. The CBD may, or may not, be a feasible approximation for this export hub, depending on whether or not the centre had grown around an important port or rail station. In the case of Berlin during our study period, the CBD has to be considered a poor approximation in these terms. Besides the use of waterways accounted for in our models, haulage of goods during the study period took place mainly via rail. Central mainline stations that served as origins and destinations of freight transport, however, were developed just outside the historical tariff-wall (Zollmauer) rather than within the densely developed CBD. In order to accommodate this particular geography, we rerun Table 5 and 6 specifications using the distance to the nearest mainline station instead of the distance to the CBD. The resulting point estimates presented in Figure 1 (right) very much confirm all findings derived from our benchmark specifications. The point estimate for the distance-to-nearest-mainline-station effect is reduced even closer to zero.[13]

4. Conclusion

This study evaluates the change in the spatial city structure of Berlin during the second era of industrialization vis-à-vis the traditional monocentric city model and an alternative approach that allows firms to value access to the whole economic mass of the city rather than to a single, dimensionless point, named CBD. As expected, the city´s trans-

[13] Full estimation results are available from the authors upon request.

formation into a modern, service-based economy together with the creation of a dense rapid transport network gave rise to increasing spatial interactions across space. While in 1890 the city closely followed a monocentric pattern, by 1936 the spatial structure had broken up into a much more complex construct, resembling present-day polycentric cities. Rather than discounting the value of location on transport costs to a dimensionless central market place or export hub, approaching the 1930s, firms valued access to the whole economic mass of the city, which had clustered into numerous agglomerations. A gravity-type variable, which to our knowledge is used for the first time to explain the spillover component in commercial land values, explains close to 90% of the CBD gradient in 1936. At the same time, a simple bivariate gradient model still performs satisfactorily since the agglomeration economies are still correlated with the distance to the CBD.

These finding highlight the fact that a differentiated view is required when interpreting rent gradients for commercial properties. Although a significantly negative CBD gradient may be in line with the early rent theory prediction for a monocentric urban economy rather than simply reflecting transport costs to the CBD, it may be masking a) a considerable degree of polycentricity and b) that the true determinant of concentration in the urban core is a productivity gain from locating close to other businesses. The idea of firms being drawn into an exogenous centre seems to apply, if at all, only to cities in an early state of industrial evolution, but to a much lesser extent to the service-based economies which have dominated the central areas of cities since at least the mid 20th century.

It is important to note, however, that our findings do not dismiss the basic assumptions of rent theory entirely. Our results still support the view that firms discount the value of a location on transport costs. Rather than distance to a virtual, dimensionless CBD, however, access to other economic activities in a city seems to have become the most important determinant of commercial rent in a service-based economy.

Appendix

In the following we provide the derivation of F.O.C. analogically to section 2.1 for the multiplicative production function, which is mathematically equivalent to the additive form presented above. The assumptions are exactly as noted before. In this case, however, the argument differs slightly. Given the production function

$$Q(x, K_b, L_b) = A(x)K^{\alpha}L^{1-\alpha}$$

with

$$\max_{x} \pi = Q(x) - R(x)L_b - C\, K_b - tD(x)Q(x, K_b, L_b)$$

we assume that agglomeration economies raise productivity at locations which are in close proximity to high economic densities. The zero profit condition yields:

$$R(x) = \frac{1}{L_b}\left[\left(1 - tD(x)\right)Q(x) - C(K_b)\right]$$

$$\frac{\partial R(x)}{\partial D(x)} = -\frac{t}{L_b} Q(x, K_b, L_b) < 0,$$

where *Q(x)* is strictly positive and the same for all firms. Agglomeration economies strictly raise location productivity as the distance to surrounding firms decreases.

$$\frac{\partial R(x)}{\partial A(x)} = \left(1 - tD(x)\right)\frac{1}{S_b}\frac{\partial Q(x, K_b, L_b)}{\partial A(x)} > 0$$

Note that by definition $\partial Q(x, K_b, L_b)/\partial A(x) = K^{\alpha}L^{1-\alpha}$ must be positive and $\left(1 - tD(x)\right)$ must be non-negative, as transport costs will otherwise exceed revenues.

Tab A1 1st stage regressions

	(1)	(2)	(3)	(4)
	1890	1900	1910	1936
Lagged Land Value	1.852**	1.131**	1.177**	0.735**
(Reichsmark)	(0.07)	(0.018)	(0.018)	(0.014)
Distance to CBD	-116.948**	-67.411**	-19.720+	-94.254**
(km)	(9.823)	(7.769)	(10.583)	(10.09)
Distance to CBD	12.658**	5.959**	1.062	10.970**
squared	(1.13)	(0.934)	(1.262)	(1.34)
Constant	283.203**	236.627**	137.919**	205.606**
	(22.11)	(16.828)	(24.048)	(19.556)
Observations	1470	1470	1470	1470
F-stat	1871.76	5644.34	5045.95	1856.77
R-squared	0.79	0.92	0.91	0.79

Notes: Dependent variable is land value in Reichsmark per square meter in all models. Lagged land values refer to 1881 (1), 1890 (2), 1900 (3), 1928 (4). Standard errors are in parenthesis. + significant at 10%; * significant at 5%; ** significant at 1%

Literature

Abelson, P. (1997). House and Land Prices in Sydney from 1931 to 1989. *Urban Studies, 9*, 1381-1400.

Adair, A., McGreal, S., Smyth, A., Cooper, J., & Ryley, T. (2000). House Prices and Accessibility: The Testing of Relationships within the Belfast Urban Area *Housing Studies, 15*(5), 699-716.

Ahlfeldt, G. M. (in press). If Alonso was right: Modeling Accessibility and Explaining the Residential Land Gradient. *Journal of Regional Science, forthcoming*.

Ahlfeldt, G. M., & Maennig, W. (2010). Substitutability and Complementarity of Urban Amenities: External Effects of Built Heritage in Berlin. *Real Estate Economics, 38*(2), 285-323.

Alonso, W. (1964). *Location and Land Use: Toward a general Theory of Land Rent*. Cambridge, Massachusetts: Harvard University Press.

Anas, A., & Kim, I. (1996). General Equilibrium Models of Polycentric Urban Land Use with Endogenous Congestion and Job Agglomeration. *Journal of Urban Economics, 40*(2), 232-256.

Andersson, F., Burgess, S., & Lane, J. I. (2007). Cities, matching, and the productivity gains of agglomeration. *Journal of Urban Economics, 61*, 112-128.

Anselin, L. (1995). *Simple Diagnostic Tests for Spatial Dependence*. Urbana-Champaign.

Atack, J., & Margo, R. A. (1998). Location, Location, Location! The Price Gradient for Vacant Urban Land: New York, 1835 to 1900. *Journal of Real Estate Finance & Economics, 16*(2), 151-172.

Aust, B. (Cartographer). (1986). *Die städtebauliche Entwicklung Berlins.*

Bergmann, J. (1973). *Das Berliner Handwerk in den Frühphasen der Industrialisierung* (Vol. 11). Berlin: Colloquium Verlag.

Berliant, M., & Konishi, H. (2000). The endogenous formation of a city: Population agglomeration and market places in a location-specific production economy. *Regional Science & Urban Economics, 30*(3), 289-324.

Berliant, M., Peng, S., & Wang, P. (2002). Production externalities and urban configuration. *Journal of Economic Theory, 104*, 275-303.

Borchert, F., Starck, T., Götz, G., & Müller, H. (1987). *Berlin und seine S-Bahn*. Berlin: transpress VEB Verlag für Verkehrswesen

Ellison, G., & Glaeser, E. L. (1999). The geographic concentration of industry: Does natural advantage explain agglomeration? *American Economic Review, 89*(2), 311-316.

Fujita, M., & Ogawa, H. (1982). Multiple equilibria and structural transition of non-monocentric urban configurations. *Regional Science and Urban Economics, 12*(2), 161-196.

Hegemann, W. (1930). *1930 - Das Steinerne Berlin. Geschichte der grössten Mietskasernenstadt der Welt* (Vol. 3). G. Kiepenheuer: Berlin.

Heikkila, E., Gordon, P., Kim, J. I., Peiser, R. B., Richardson, H. W., & Dale-Johnson, D. (1989). What Happened to the CBD-Distance Gradient?: Land Values in a Policentric City. *Environment and Planning, 21*(2), 221–232.

Helsley, R. W. (1990). Knowledge and Production in the CBD. *Journal of Urban Economics, 28*, 391-403.

Henderson, J. V. (1974). The sizes and types of cities. *American Economic Review, 64*, 1640-1656.

Henderson, J. V. (1977). *Economic Theory and the Cities*. New York: Academic Press.

Henderson, J. V. (1988). *Urban Development: Theory, Fact, and Illusion*. New York: Oxford University Press.

Jacobs, J. (1969). *The Economy of Cities*. New York: Random House.

Kalweit, F. (1928). *Die Baustellenwerte in Berlin*. Berlin: Ermo Verlagsgesellschaft.

Kalweit, F. (1936). *Die Baustellenwerte in Berlin*. Berlin: Carl Heymanns Verlag.
Kau, J. B., & Sirmans, C. F. (1979). Urban Land Value Functions and the Price Elasticity of Demand for Housing. *Journal of Urban Economics, 6*(1), 112.
Kim, S. (1995). Expansion of markets and the geographic distribution of economic activities: The trends in US regional manufacturing structure, 1860–1987. *Quarterly Journal of Economics, 110*(4), 881-908.
Kim, S. (1999). Regions, ressources, and economic geography: Sources of US regional comparative advantage, 1880-1987. *Regional Science & Urban Economics, 29*, 1-32.
Krause, R. (1958). *Die Berliner City. Frühere Entwicklung/ Gegenwärtige Situation/ Mögliche Perspektiven.* Berlin: Dissertation der Freien Universität Berlin.
Lucas, R. E., Jr., & Rossi-Hansberg, E. (2002). On the Internal Structure of Cities. *Econometrica, 70*(4), 1445-1476.
McDonald, J. F., & McMillen, D. P. (1990). Employment subcenters and land values in a polycentric urban area: the case of Chicago. *Environment and Planning A, 22*, 1561-1574.
McMillen, D. P. (1990). Consistent estimation of the urban land value function. *Journal of Urban Economics, 27*(3), 285-293.
McMillen, D. P. (1996). One Hundred Fifty Years of Land Values in Chicago: A Nonparametric Approach. *Journal of Urban Economics, 40*(1), 100-124.
McMillen, D. P., Jarmin, R., & Thorsnes, P. (1992). Selection bias and land development in the monocentric city model. *Journal of Urban Economics, 31*(3), 273-284.
Mills, E. S. (1969). The value of urban land. In H. Perloff (Ed.), *The quality of urban environment*. Baltimore, MA: Resources for the Future, Inc.
Müller, G. (Cartographer). (1881-1910). *Karte zur Berechnung des Grund- und Bodenwerthes in Berlin*
Muth, R. F. (1969). *Cities and Housing: The Spatial Pattern of Urban Residential Land Use*. Chicago: University of Chicago Press.
Osland, L., & Thorsen, I. (2008). Effects on housing prices of urban attraction and labor-market accessibility. *Environment and Planning A, 40*, 2490-2509.
Redding, S. J., & Venables, A. J. (2004). Economic geography and international inequality. *Journal of International Economics, 62*(1), 53-82.
Richter, G. (1987). Zwischen Revolution und Reichsgründung. In W. Ribbe (Ed.), *Geschichte Berlins*. München: Verlag C.H.Beck.
Rosenthal, S. S., & Strange, W. C. (2001). The Determinants of Agglomeration. *Journal of Urban Economics, 50*(2), 191-229.
Rosenthal, S. S., & Strange, W. C. (2004). Evidence on the nature and sources of agglomeration economies. In J. V. Henderson & J.-F. Thisse (Eds.), *Handbook of Regional and Urban Economics* (Vol. 4): North-Holland.
Runge, E. (Cartographer). (1950). *Bodenwertkarte Gross-Berlin (1938)*
Smith, F. H. (2003). Historical evidence on the monocentric urban model: a case study of Cleveland, 1915-1980. *Applied Economics Letters, 10*(11), 729.