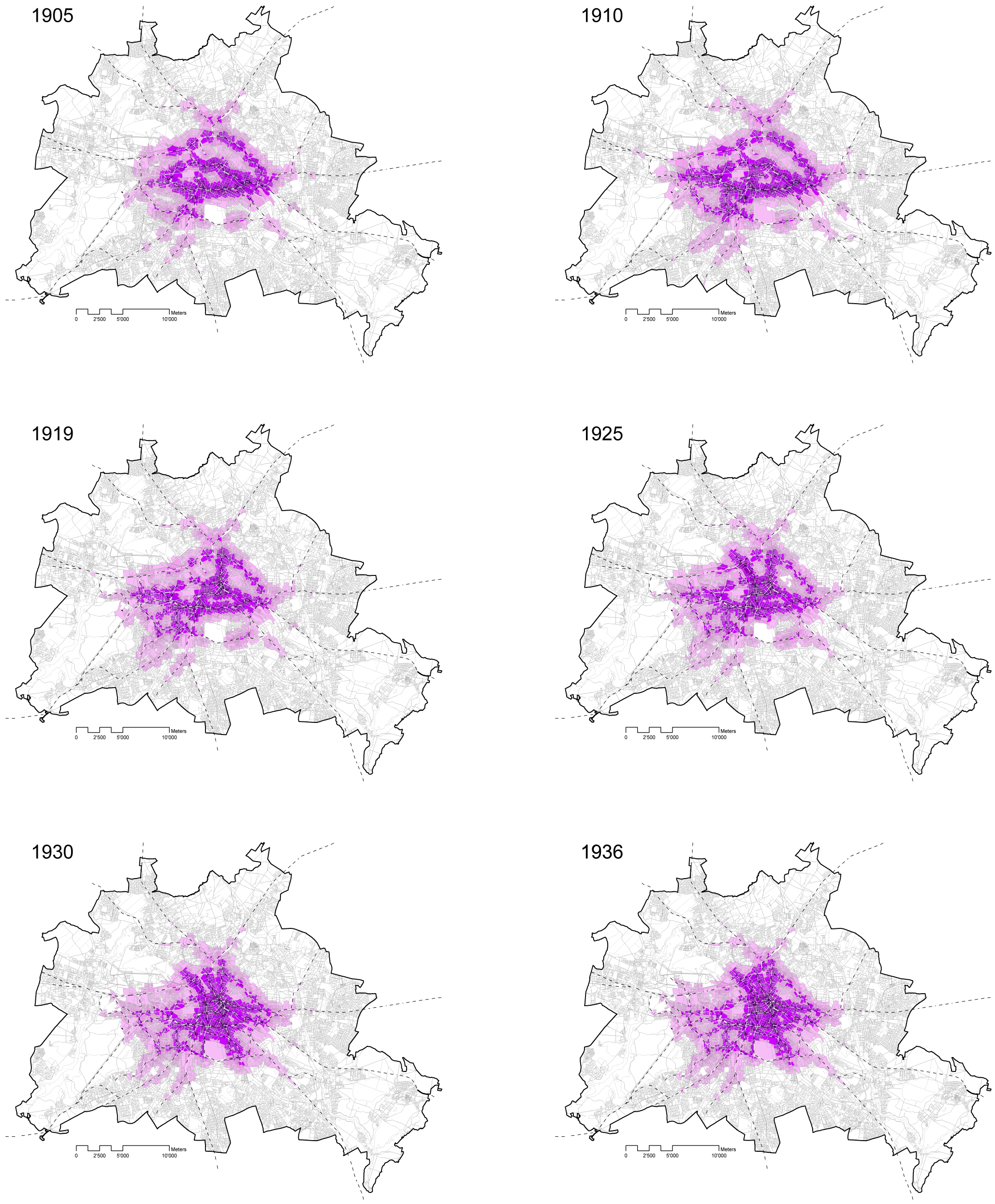
Fig. 7 Market Potential Generated by Rail-Based Urban Transport 1905-1935



Source: Author's own calculations, Urban and Environmental Information System of the Senate Department Berlin (2006), Leyden (1933), Statistical Yearbooks (Statistisches Amt der Stadt Berlin, 1878-1939).

Notes: Classes have been calculated applying the Jenks algorithm (natural-breaks method) that aims at minimizing the differences within and maximizing the differences between classes.

This generated the major prerequisites for a general movement of – especially high-income – households towards the west. The intended representative character of the Kurfürstendamm in combination with improved accessibility exerted a strong attraction. However, although increasing activity and investments clearly affected that area by the beginning of the 20th century, its era of prosperity, which was accompanied by a rapid increase in relative land values, did not begin until the beginning of the 1920s (see 5.2). Nonetheless, the visualized quantitative market access indicators precede this development by about two decades. Interestingly, high expectations regarding returns on investment fostered the connection of an area which had been almost completely undeveloped prior to 1890 and thus did not exert any economic attraction(Bohm, 1980).[34] Hence, a possible endogeneity of described construction efforts can be rejected. Large investments in the rail infrastructure generated the additional benefit of high market access, which was indispensable for the subsequent emergence of strong and localized agglomeration forces.

In 1910, the expanding network had generated an area of preeminent centrality, which could not be matched by any other newly connected area across Berlin. Since the historical center had been densely developed decades ago, it had not offered location opportunities for expanding industries. Setting the focus on an

[34] See 5.2.2 for a more detailed discussion.

area, which was largely undeveloped but with high levels of accessibility was a decisive step for further urban development and in line with theoretical expectations. Interestingly, this initiated location advantages that could not even be reversed by a strong battery of exogenous shocks, such as the economic crisis and the two wars. The triggered agglomeration forces and the created location advantages proved to be sustainable even when during the 1920s and 1930s the area lost some of its formerly gained relative centrality within the network due to gradually increasing network density within the old CBD.

Conclusion

This section presented the contribution of rail-based public infrastructure to increasing centrality and, hence, increasing agglomeration forces, which also implies decreasing costs of transport and commuting. The developed multi-level market potential indicator connects all of Berlin's 15,937 statistical blocks with each other and with the infrastructure network and assesses effective accessibility within the entire urban area. This generates the base for further analyses in section 5.2. It could be shown that the inauguration of the first two east-west connections (inner-city line and first metro) significantly fostered a general shift of population and market access towards the western districts. This may have substantially influenced the rapid transformation of the Kurfürstendamm area from a representative residential area into the fastest growing sub-center of the city. Obviously, the emergence of location advantages preceded the increase in economic development by years if not decades and proved to be sustainable even after being challenged by a strong battery of exogenous shocks.

5.2. Decentralization and Sub-Centers: A Micro Study

This section will provide a detailed micro study on the emergence and development of the Kurfürstendamm area as Berlins strongest sub-center. Within a quasi-experimental environment, which explores the first signs of agglomeration until the establishment of an area of major economic activity, I investigate how areas in immediate proximity to new major transport nodes may become subject to initial advantages, whereupon agglomeration forces and cumulative causation lead to the emergence of strong activity clusters, or even alternative CBDs.

Firms tend to outbid households in competition for central locations since the attractiveness of commercial areas critically depends on access to consumer and labor markets. In equilibrium markets, any increase in location attractiveness perceived by market participants due to improved accessibility will capitalize into land values of designated business areas, and hence become observable. For the purposes of this empirical analysis, it was indispensable to meet both requirements, identifying designated business blocks within the observation area (see 3.3) and collecting the corresponding land values assigned to them (see 3.4). The work is based on calculated centrality indicators (5.1).

5.2.1. Data and Methodology

The empirical strategy basically consists of comparing the evolution of land valuation and access to markets within the study area in order to allow for conclusions on a causal relationship. Given that firms outbid each other for locations and generate steeper bid-rent curves than do households, designated business blocks or areas are assumed to represent a feasible indicator of their attractiveness and an increased level of economic activity. By relying on historical data on standard land values (see 3.4), I can show that over the course of the observation period the location of Berlin's City-West experienced an impressive increase in significance compared to the historical urban core as well as to the next strongest sub-centers. To identify at what time the new center emerged as a strong core, I track land valuation over time.

The relevance of market access for the emergence of the new center is investigated at two stages. First I employ accessibility indicators as already described in section 5.1.1 to test whether preceding the concentration of economic activity the area exhibited an initial advantage in terms of accessibility compared to alternative locations that may explain the emergence of the new urban core. Second, I focus on the heart of the new urban core around Breitscheidplatz to analyze the role of accessibility at a micro-level. Therefore, different observation areas had to be defined and compared over time. Consulting historical sources which illustrated and described the economic structure of the city (Hofmeister, 1990; Leyden, 1933; Lipmann, 1933;

Louis, 1936) allowed for feasibly defining three areas which represented the core regions of economic activity within the research area. Due to its spatial and historical significance, the Kaiser-Wilhelm-Gedächtniskirche represents the center of the core region and, extending to about 700 m towards east (Wittenbergplatz; location of the KaDeWe) and 700 m to the west, forms Area 1. The second region additionally comprises the highly colorful Hardenbergstrasse towards the Technical University in the north, the Olivaer Platz in the west and Nollendorfplatz in the east. The third area is represented by a wider range of what was still considered the center, and also includes the shopping area along the Wilmersdorfer Strasse (see Figure A 1).

I track differences over time by the application of simple difference estimations:

$$\log(Y_{bt}) = d_t\ a + Kudamm1 \times d_t\ b + Kudamm2 \times d_t\ \mathrm{c} + \varepsilon_{bt}, \tag{8}$$

where Y_{bt} stands either for standard land values (*SLV*), population potentiality (*PP*) or rail-based population potentiality (*RPP*) of business block *b* in period *t*, d_t is a full set of time dummies and *a, b* and *c* represent the sets of coefficients to be estimated. ε_{bt} is an error term satisfying the usual conditions. *Kudamm1* and *Kudamm2* are dummy variables denoting business blocks within Kudamm Area 1 and Kudamm Area 2 respectively. A pooled sample of data on *SLV* for the years 1890, 1896, 1900, 1905, 1910, 1929 and 1936 is used, while *RPP* data is available for five-year intervals from 1875 to 1930 with the exception of 1915. 1936 data was constructed using the 1936 railway network and the linearly interpolated population of 1933 and 1939. For *PP*, which corresponds to the indicator of market access (*MA)* in the traditional sense (Harris, 1954), additional data is available for 1871 when the whole area had not yet been connected to an inner-city railway network.

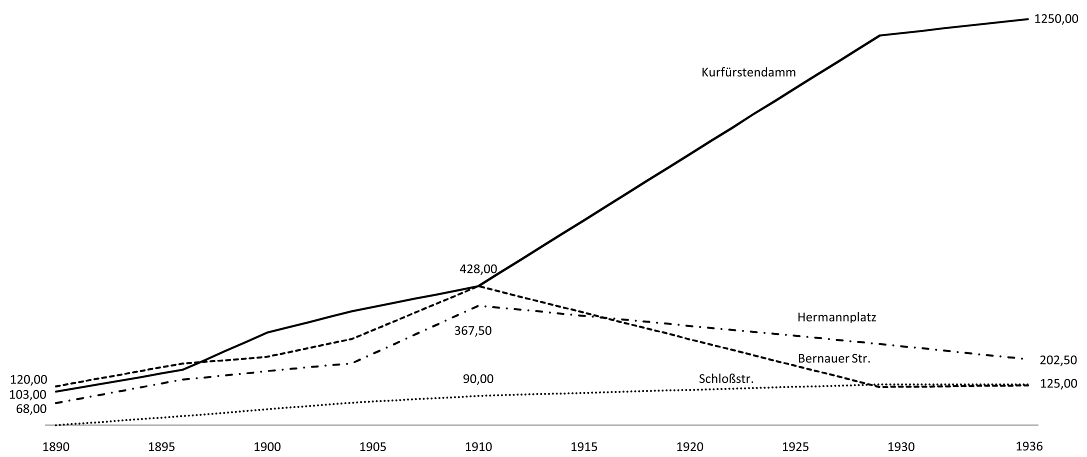
Since the sample is restricted to Kudamm Area 3, coefficients on interactive terms give average block differences between Kudamm Area 1 and Kudamm Area 2 and Kudamm Area 2 vs. Kudamm Area 3, respectively, for all available years. As a log-linear specification is used, estimated dummy coefficients *d* can be interpreted as percentage differences (*PD)* according to a well-established formula (Halvorsen and Palmquist, 1980; Kennedy, 1981):

$$PD = 100\exp((d - \frac{\mathrm{var}(d)}{2}) - 1), \tag{9}$$

5.2.2. Results and Conclusion

The empirical findings regarding the emergence of the Kudamm area as a self-sufficient center tell a clear story and support anecdotal evidence provided by many historians. A general population movement towards the west and southwest in combination with continuous investments in public infrastructure and real estate led to a gradual establishment of the City-West accompanied by a relative decline in the importance of the historical CBD, particularly during the 1920s (Krause, 1958; Leyden, 1933). This development started off the ongoing tendency towards Berlin's duo-centricity. The powerful dynamics of spatial reorganization triggered by a rapid population growth during the 19th century led to a general gain in the importance of slightly decentralized sub-centers in Berlin. Figure(8) shows the general land value development for representative business blocks within the most important sub-centers. The sub-centers used were taken from Lipmann (1933), who conducted a detailed analysis on Berlin's economic activity. Here, the development of each of the corresponding areas is represented by the one business block that had experienced the strongest increase in terms of both land values and rail potentiality up to 1936.

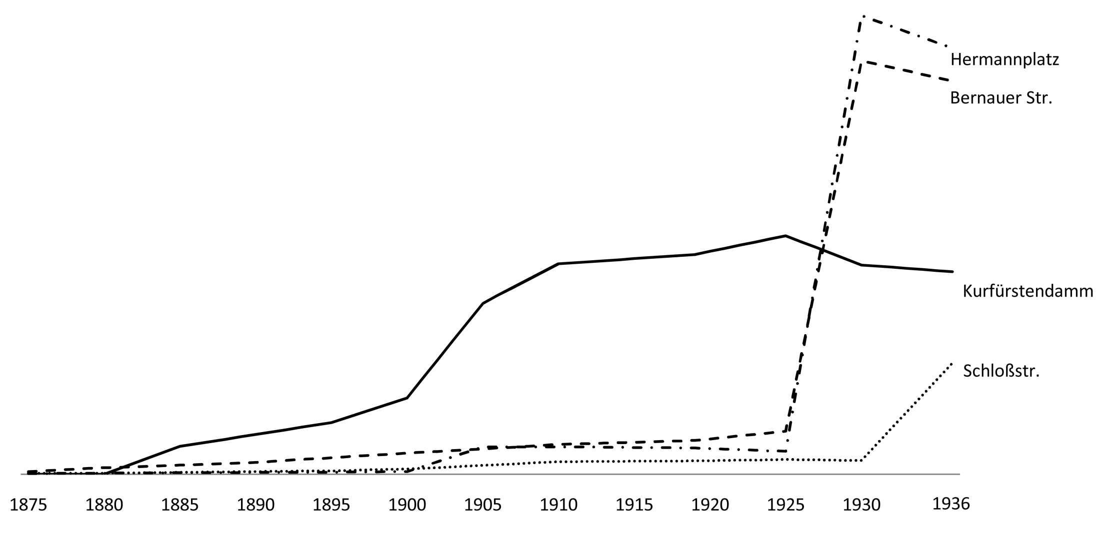
Fig. 8 Standard Land Values of the Most Important Sub-Centers (1890-1936)



Notes: Author's own calculations. Figure is taken from Ahlfeldt and Wendland (2008b).

While in 1890, when spatial reorganization had not yet unleashed its full power, the area around Bernauer Strasse was even higher valuated than the then almost undeveloped Kurfürstendamm area. After 1895 the Kudamm began to overtake the other sub-centers and extended its lead from 1910 onwards. Given its evident dominance regarding land value development, one can easily confirm common assumptions, which name this area as the most thriving during the entire research period. Consequently, the objective will be to unravel the relevant determinants for the emergence of economic activity clusters restricted to that area. In terms of relative centrality quantified by the abovementioned indicator (*RPP*) it demonstrated a remarkable initial advantage (see also 5.1), which emerged after 1880 and was strengthened during the first decade after the turn of the century owing to far-reaching extensions of the railway network (Figure 9).

Fig. 9 Rail Potentiality for the Most Important Sub-Centers (1875-1936)



Notes: Author's own calculations. Figure is taken from Ahlfeldt and Wendland (2008b).

Apparently, emerging agglomeration forces together with cumulative causation, accompanied by supplementary amplifications of the network, established a path-dependent development so that the Kudamm area maintained its role as the most important center besides the historical CBD, despite a considerable decline in relative accessibility after 1925.

The importance of the Kudamm region within the whole area of Berlin can be even better demonstrated by directly comparing it to the old CBD, which by the beginning of the observation period had already been the center of economic activity for hundreds of years. Figure (10) visualizes trends in *PP, RPP*, and *SLV* for the Kudamm area relative to the historical CBD.[35]

[35] In order to represent the CBD's performance, the same strategy was applied as for the representation of sub-centers. The one business block with the best performance regarding its land value and railway potentiality until 1936 was chosen.

Fig. 10 PP, RPP, LV: Kurfürstendamm vs. Historical CBD (1875-1936)

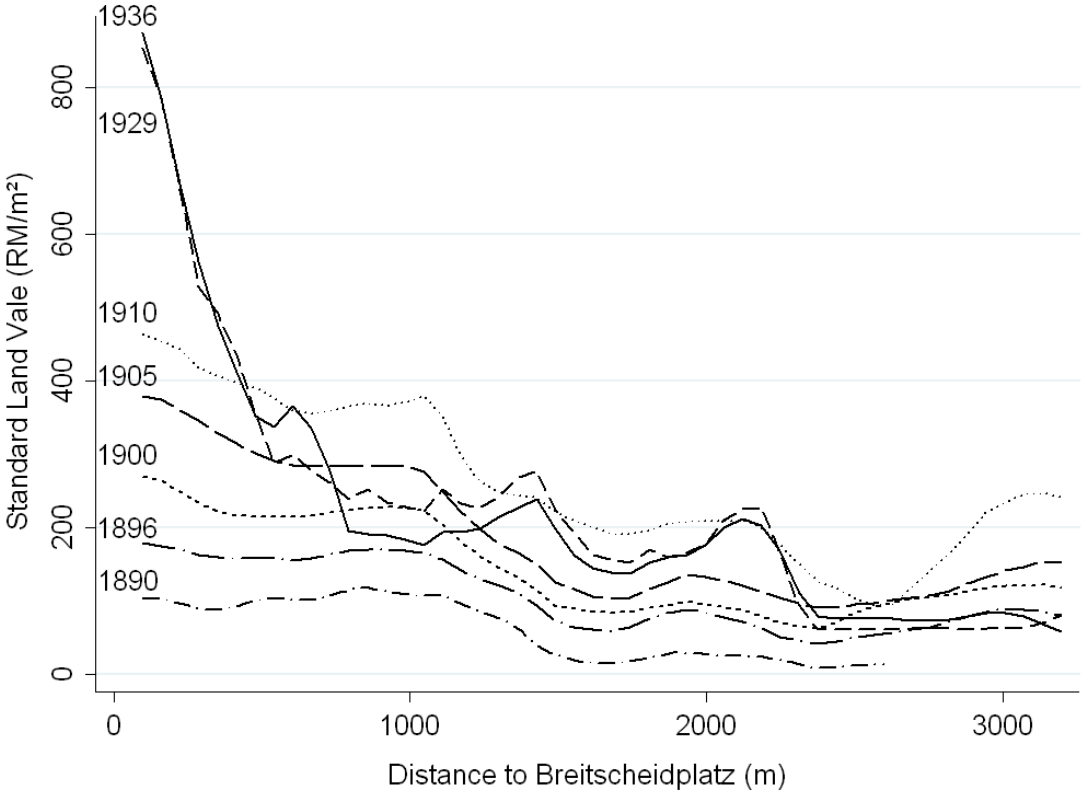
Notes: Indices represent ratios of Kudamm values to the respective values in the historical CBD. Author's own calculations. Figure is taken from Ahlfeldt and Wendland (2008b).

While the general shift in market access is owed to the increasing population of western and southwestern districts, the investments undertaken regarding public infrastructure further benefited the Kurfürstendamm area, exposing remarkable location advantages and therefore attracting business to a large extent. In 1910 it even represented the most benefited area in terms of network-based market access. The perceived attractiveness and high expectations regarding future returns on investment apparently capitalized directly into land values. Agglomeration forces may have led to spillover effects, which at least supported the impressive economic growth within the Kudamm3 region until the end of the 1920s.

Considering land value trends until 1910, which were very similar to those of the other major sub-centers, the large investments into connectivity of the Kudamm area are surprising. Intuitively, one would expect the focal node of a transport network within existing cores of economic activity and not within only scarcely developed areas. From the historical center, the other major sub-centers, Hermannplatz and Bernauer Strasse, could also have been connected more easily. However, despite their shorter distance from the historical center, these centers were not connected until the end of the 1920s, almost 30 years after the Kurfürstendamm. Metro lines would have run through very densely populated areas, which would have met demand structures more appropriately. Even the obviously needed underground line below the traditionally most important retail and commercial boulevard (Friedrichstrasse) was not developed until the mid 1920s. Anecdotal evidence also shows that the selection of the first metro rail paths was determined exogenously to urban economic development (Erbe, 1987). The extension of pre-existing railway tracks took place through widely undeveloped areas, which led to the effect of a perceived increasing attractiveness created by improved accessibility. The declared intention of property developers was to promote further investments and building activity (Bohm, 1980). Taking these indications together with the evident time lag, it appears more likely that, in this case, causality runs from accessibility to economic development rather than *vice versa*.

Over the study period it can be observed how a former widely undeveloped area unexpectedly became perfectly integrated into the existing public infrastructure network. The good accessibility provided initial location advantages that led to a path-dependent development, which was not reversed by a relative decline in centrality during the 1920s. This is completely in line with theoretical implications that highlight the role of initial advantage and cumulative causation for economic development (see 4). The Kernel regressions depicted in Figure (11) show how, by 1936, a small sub-center had transformed into a self-sufficient main-center with precise land gradients around the very core. Thus, this provides strong evidence for the roots of Berlin's existing duo-centric structure dating back to the period of urban railway network construction, proving division not to be the causal determinant for its emergence.

Fig. 11 Kernel Smoothed Gradients for the Kurfürstendamm Area (1890-1936)



Notes: Author’s own calculations. Kernel is Epanechnikov. Land values are restricted to all identified business blocks within the designated *Kudamm3* area. Figure is taken from Ahlfeldt and Wendland (2008b).

Initial Advantage in Market Access: A Micro Study

From comparison with other major sub-centers and the traditional CBD we know that during the early years of the 20thcentury the Kudamm area experienced a strong increase in significance, first in terms of market access and connectivity, then also in terms of economic activity, which was reflected in higher land values. Now, a detailed analysis of the Kudamm neighborhood as a sub-sample will be conducted in order to reveal whether the mechanisms discussed in the sections above also apply to a micro-level scale. In particular, it shall be explored whether the new economic core incidentally emerged after economic activity in the neighborhood exceeded a critical mass or if the new center developed around a small core (perhaps only two or three blocks) that benefited from an initial advantage from the very beginning. In 1890, agglomerations of high-price areas existed along the Potsdamer Straße, a radial street leading from the CBD, and the Kurfürstenstraße, both located to the east of the Kudamm area. This area clearly expanded further to the west implying that the development of economic activity may be attributed to spill-over effects towards the Kurfürstendamm. Conducting simple difference estimations (8) will allow assessing the causalities by retrieving indices of relative *PP, RPP* and *SLV* for the Kudamm areas 1 and 2 as defined in the Appendix. Table (2) shows the estimation results, which are visualized in Figure (12).

Note that the sample is now restricted to all business blocks within Kudamm Area 3. Consequently, all blocks within Area 1 also belong to Area 2. Estimates therefore yield differences between Areas 3 and 2 and areas 2 and 1 respectively.

Tab. 2 The Emergence of the Sub-Center Kurfürstendamm: SLV, PP, RPP

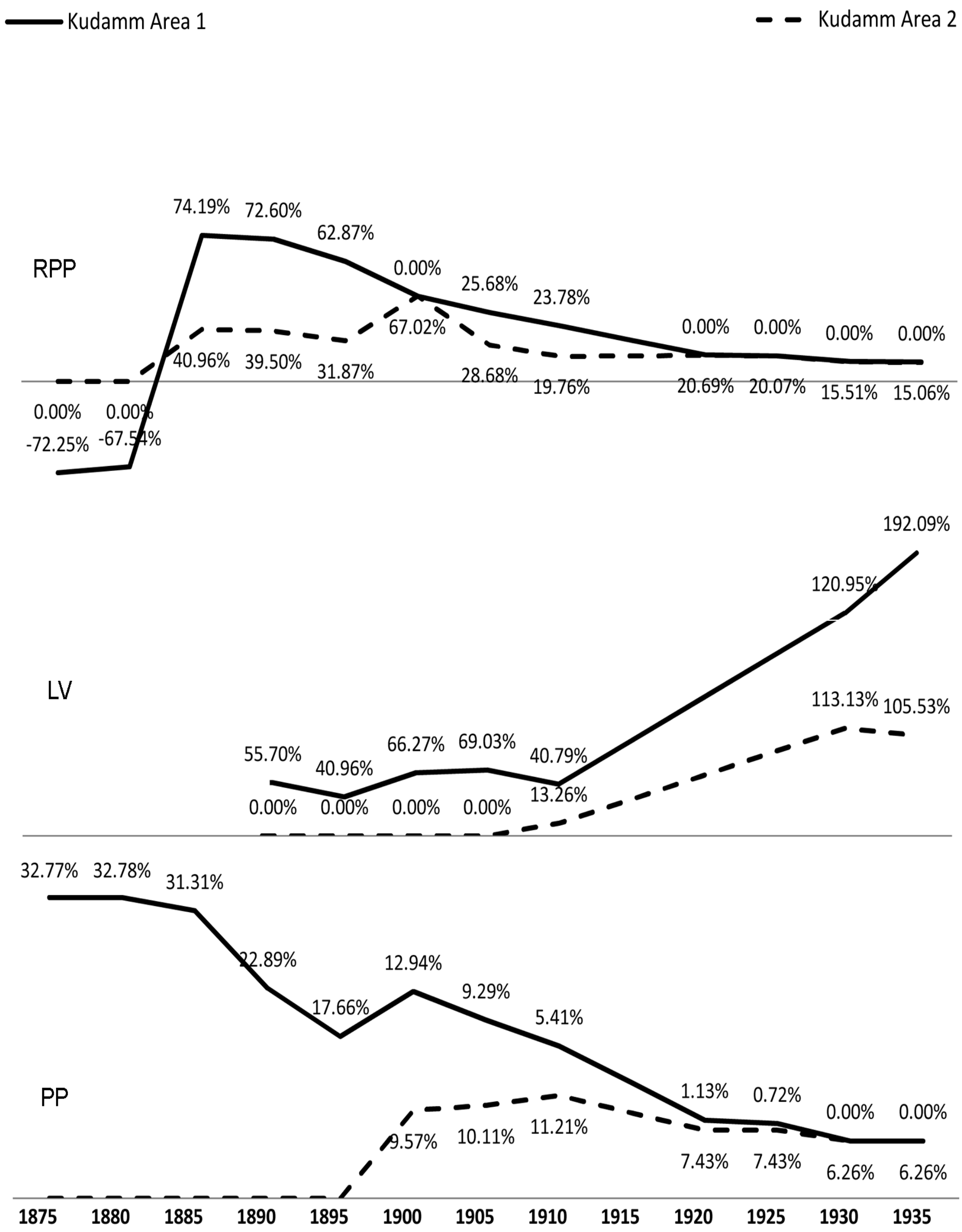
	(1) Log(SLV)	(2) Log(PP)	(3) Log(RPP)
Kudamm1 x 1871		0.2985***	
		(3.97)	
Kudamm1 x 1875		0.2834***	-1.2536***
		(5.52)	(-5.29)
Kudamm1 x 1880		0.2834***	-1.0913***
		(3.89)	(-4.2)
Kudamm1 x 1885		0.2723***	0.5651***
		(3.84)	(3.96)
Kudamm1 x 1890	0.4474***	0.2061***	0.5558***
	(4.65)	(3.42)	(3.93)
Kudamm1 x 1895/1896	0.3448***	0.1626***	0.4969***
	(6.18)	(4.32)	(3.68)
Kudamm1 x 1900	0.5107***	0.1217***	0.1005
	(7.5)	(4.29)	(0.85)
Kudamm1 x 1905	0.5274***	0.0888***	0.2338**
	(7.37)	(4.49)	(2.29)
Kudamm1 x 1910	0.3438***	0.0527***	0.2191**
	(5.91)	(4.79)	(2.04)
Kudamm1 x 1919		0.0112*	0.1644
		(2.93)	(1.44)
Kudamm1 x 1925		0.0072	0.1668
		(1.83)	(1.46)
Kudamm1 x 1929/1930	0.8022***	0.0035	0.1750
	(5.82)	(1.24)	(1.55)
Kudamm1 x 1936	1.080***	-0.0005	0.1725
	(8.11)	(-0.16)	(1.52)
Kudamm2 x 1871		0.0402	
		(0.36)	
Kudamm2 x 1875		0.0365	-0.0379
		(0.48)	(-0.22)
Kudamm2 x 1880		0.0368	-0.3335
		(0.34)	(-1.18)

Kudamm2 x 1885		0.0417	0.3495***
		(0.39)	(3.12)
Kudamm2 x 1890	0.1324	0.0505	0.3390***
	(0.81)	(0.55)	(3.06)
Kudamm2 x 1895	0.0822	0.0872*	0.2820***
	(0.99)	(1.43)	(2.71)
Kudamm2 x 1900	-0.0403	0.0914**	0.5170***
	(-0.47)	(1.86)	(5.7)
Kudamm2 x 1905	0.0880	0.0963***	0.2561***
	(1.01)	(2.53)	(2.85)
Kudamm2 x 1910	0.1269*	0.1062***	0.1842**
	(1.8)	(3.99)	(2.09)
Kudamm2 x 1919		0.0716***	0.1917**
		(5.68)	(2.24)
Kudamm2 x 1925		0.0716***	0.1866**
		(6.16)	(2.16)
Kudamm2 x 1929/1930	0.7239***	0.0606***	0.1478*
	(8.58)	(5.88)	(1.73)
Kudamm2 x 1936	3.916***	0.0606***	0.1438*
	(27.62)	(6.4)	(1.7)
Observations	1109	2254	1932
Sample	Kudamm Area 3	Kudamm Area 3	Kudamm Area 3
R^2	0.5212	0.7766	0.9465

Notes: Endogenous variables in Models (1), (2) and (3) are the log of standard land values (SLV), the log of population potentiality (PP) and the log of rail population potentiality (RPP). Ku-damm1 and Kudamm2 are dummy variables denoting business blocks within Ku-damm Area 1 and Kudamm Area 2 respectively. 1871 – 1936 similarly represent year dummies. The sample is restricted to business blocks within Kudamm Area 3 in all models. All models include a full set of year dummies. T-statistics (in parenthesis) are heteroscedasticity-robust. * denotes significance at the 10% level; ** denotes significance at the 5% level; *** denotes significance at the 1% level.

While in 1875 *PP* already showed a remarkable advantage for Area 1, it still did not capitalize into corresponding *SLV*. Up until the late 1880s, most parts of the Kudamm area were still not developed and the land was mainly of agricultural use, which implied only marginal land values (Bohm, 1980; Müller, 1881-1910). As visualized by Figure (12), the continuously decreasing *PP* of Area 1 relative to Area 3 until 1936 is due to a rapid population growth within the broader area, which was previously unpopulated in most parts. In 1890 land values of Kudamm Area 1 had exceeded Area 2 and Area 3 by 55.7%, which underlines a relatively high attractiveness from the beginning of the Kudamm development. Formerly, the core region had gained an advantage in *RPP* of 115.1% in 1885 compared to Area 3, following the inauguration of the east-west suburban railway line in 1882 (Stadtbahn).

Fig. 12 Micro-Level Market Access and Land Value Development



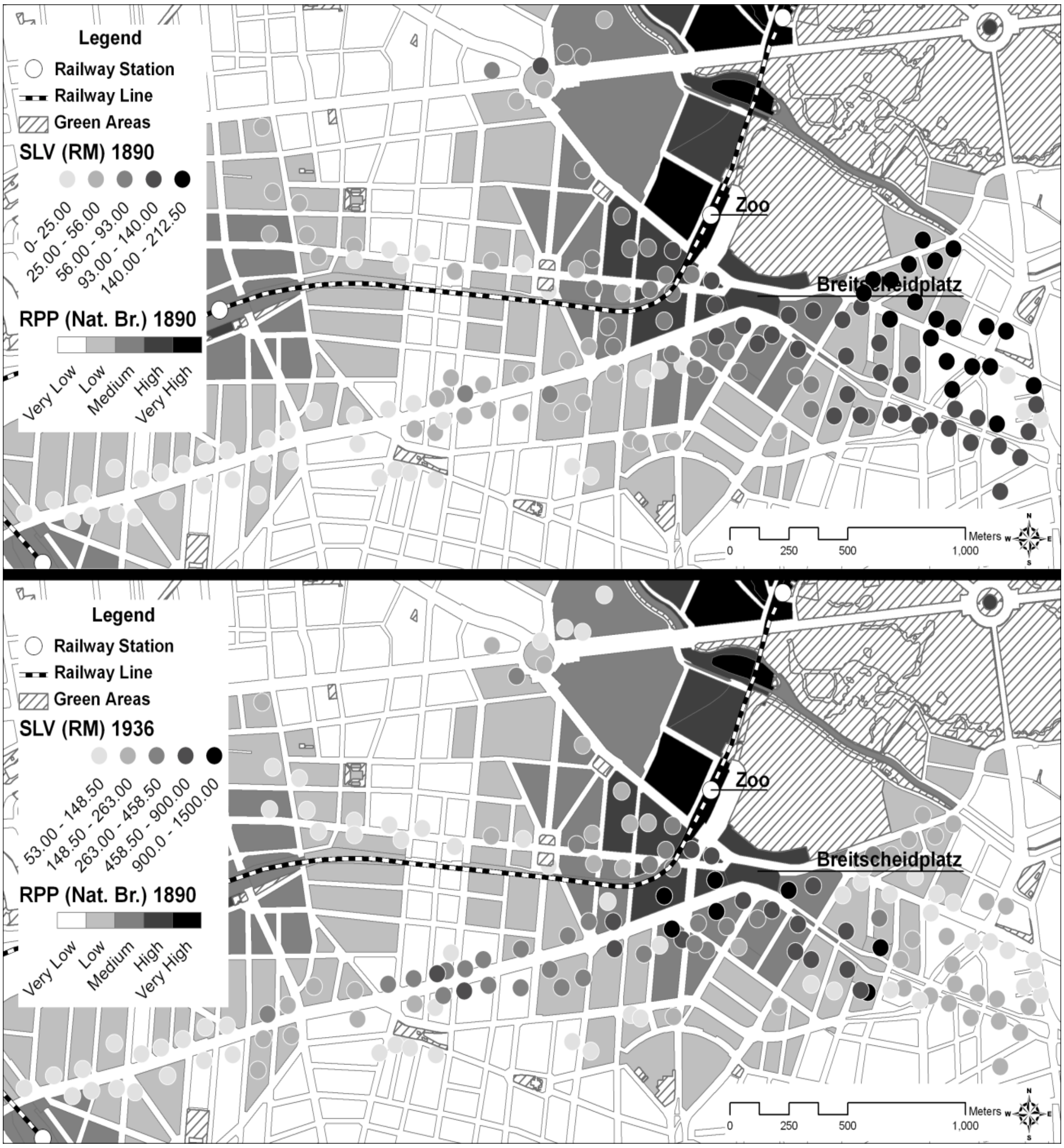
Source: Author's own calculations. Relative development of the indicators RPP, LV, and PP for Kudamm Area 3 against Kudamm Area 2 and Kudamm Area 2 against Kudamm Area 1, respectively. Figure is taken from Ahlfeldt and Wendland (2008b).

These results suggest that public infrastructure not only accounts for a large proportion of the whole area's gains, but also considerably contributes to the core region's emergence and growth. It is evident that the remarkable increase in relative land values around the inner core from 1910 on follows a period when the area demonstrated the highest *RPP* values not only within its neighborhood, but even compared to the other sub-centers and the CBD (see Figures 9-10). The simultaneous increase within Area 2 may be attributable to spill-over effects owing to an overall positive and expansive development of that area.

Figures (13) and (14) stress the role of *RPP* in forming an area of high accessibility and, after some time lag, correspondingly adjusting attractiveness capitalized into land values. Figure (13) compares *SLV* and *RPP* within Kudamm Area 3 for the first (1890) and the last (1936) year for which *SLV* were available. By 1890 a certain pattern of rail accessibility had been formed within the area. However, block values had still not adapted to that pattern. Higher plot prices were still realized along the radials towards the traditional CBD to the east of the Kudamm area (upper picture). Interestingly, in 1936 the highest values had regrouped around the initially more accessible blocks and hence had adapted to a pattern, which was generated 46 years earlier.[36]

[36] The Breitscheidplatz also exhibited a certain prestige from a town planning perspective. However, Wittenbergplatz, much closer to the high priced areas in 1890, had similar pre-existing features

Fig. 13 Pattern of Land Valuation 1890 and 1936



Source: Urban and Environmental Information System of the Senate Department of Berlin (2006).

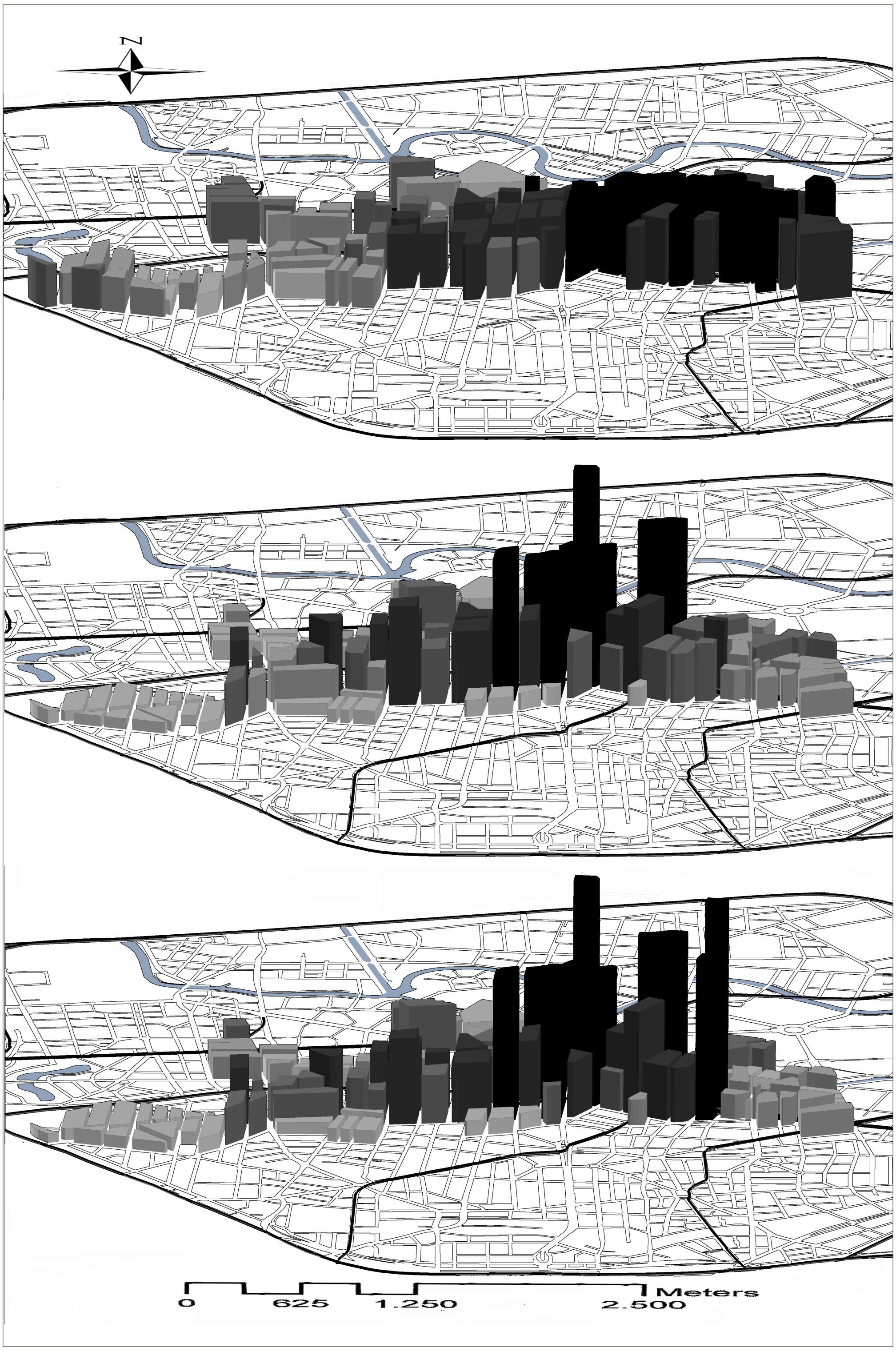
Notes: Classes have been calculated applying the Jenks algorithm (natural-breaks method), which aims at minimizing the differences within and maximizing the differences between classes. Figure is taken from Ahlfeldt and Wendland (2008b).

The formerly small sub-center originated at an exposed position within the boundaries shaped by the initial market access advantage. Apparently, owing to this advantage, a core of economic activity emerged around Breitscheidplatz, which became the center of forces of agglomeration and consolidated its position as a new urban core in the course of typical processes of cumulative causation.

The magnitude of adaptation becomes even more evident when looking at Figure (14), which visualizes *SLV* of the whole Kudamm Area 3 in 3D. The height of extrusion corresponds to the blocks' average *SLV* presented in map units (meter).

In 1910, the clear trend of a higher valuation towards the east is still visible, but had already decreased when compared to 1890. The second picture (1929) is capable of visualizing the processes and shows how the high-priced values had grouped around the formerly described core of the area. Interestingly, spill-over effects seem to work, again towards the eastern part of the street by 1936, implying further expansion and a possibly not finalized development. This development was halted in subsequent years, when economic environments completely changed during World War II.

Fig. 14 Block Averaged *SLV* 1910,1929 and 1936



Source: Authors' own calculations. Urban and Environmental Information System of the Senate Department of Berlin (2006).

Notes: The solid black lines represent the rapid transit tracks existent in corresponding years.

5.3. Decentralization and Rapid Transit Systems: The Marginal Value of Transport Innovations

While the former sections were dedicated to the rail-based public infrastructure's contribution to creating initial advantages and to promoting the emergence of sub-centers, this section will use a significantly extended data set in order to investigate the impact of transport innovations on productivity for commercially used plots across the city. As indicated by the previous chapters, attractiveness of urban locations is capitalized into property prices. Hence, locations offering better accessibility to major centers of economic activity decrease transport costs and tilt the commercial bid-rent curve upwards. By tracking the rail network as well as land use and land value records over time, the marginal effects of decreasing transport costs can be directly observed.

A growing body of literature studies the impact of newly built or extended rapid transit lines on property prices (see 4) but, until the present, there have been no analyses doing so by turning to the very beginning of their implementation. Analyzing the period of industrialization offers the opportunity to get closer to the net value of expanding networks, since in growing and widely undeveloped environments other urban amenities, such as entertainment, cultural or shopping opportunities, most probably reveal only marginal effects on urban attractiveness.[37] A quasi-experimental time-difference estimation strategy will

[37] However, it may be reasonably assumed that within a gradually congesting and growing city decentralized natural amenities such as bodies of water, free spaces, and forests also

assess two major issues regarding the expansion of intra-urban railway networks. First, the marginal value of decreasing distance to railway stations across the city between 1890 and 1936 will be assessed. This reflects the general willingness to pay more for plots of land, which are located closer to railway or metro stations. The second issue will follow the question of whether reduced travel times to the CBD trigger positive price effects. In this setting, the changing travel times from any given business plot to the CBD along the network are assessed over the years to infer the marginal value per minute time reduction.

5.3.1. Data and Methodology

Proximity to Stations

In this section, the previously used data on land values is extended considerably. First, the data on land use as described in 3.3 is used to identify all commercially used plots. Next, the corresponding land values for the years 1890, 1910, and 1936 are taken for the subsequent analysis.

In a first step, straight-line distances of all commercial plots to the next stations are calculated for each year. This provides the necessary information indicating whether the extension of the network led to declining distances to stations for individual plots. From 1890 to 1910, 871 of 1473 considered commercial areas

experience increasing attractiveness. Unfortunately, in this setting this point has to be ignored but is to be assessed in subsequent works.

experienced a decline in distance to a station, while from 1910 to 1936 679 of 1678 locations were affected. Considering the far-reaching expansions throughout this period as described in 2.2, this is not surprising. Distance only increased at very few locations where stations were disconnected or slightly moved along the network.

The starting point of the empirical analysis is the monocentric city model (Alonso, 1964; Mills, 1972; Muth, 1969), estimated by using the well-established log-linear specification. The standard setup assumes the value of urban land (LV) to be an exponential function of distance to the city center (*distCBD*).

$$\log(LV_{it}) = \alpha - \beta \, distCBD_{it} + \varepsilon_{it} \,. \tag{10}$$

Parameter α corresponds to the log of land value in the city center while β gives the percentage change in land value as one moves 1 km away from the CBD and ε is an error term satisfying the usual conditions.

Since it cannot be rejected that the center of gravity does not move over time, it was endogenously defined for each year by applying a strategy developed by Plaut and Plaut (1998). Accordingly, *distCBD* is replaced by a function of CBD coordinates relative to location *i*.

$$\log(LV_{ti}) = \alpha \; - \beta \; ((X^{CBD} - X_{it})^2 + (Y^{CBD} - Y_{ti})^2)^{0.5} + \varepsilon_{ti} \,, \tag{11}$$

where X^{CBD} (east/west) and Y^{CBD} (north/south) describe the location of the CBD as coordinates given in units of projected km and X_i and Y_i are the same referring to location *i.* During the research period, the CBD moved approximately 0.6 km to the west and 0.4 km to the south from 1890 to 1936. In 1936, the CBD is located between Pariser Platz and the intersection of the boulevards Friedrichstrasse and Unter den Linden.

Next, I extend the basic monocentric model by distance to the nearest railway station *(distST)* and allow for unobserved location effects *(f).*

$$\log(LV_{it}) = \alpha_t + \beta_t\, distCBD_i + \gamma_t\, distST_{it} + f_i + \varepsilon_{it}\,, \tag{12}$$

Assuming that the marginal benefit of having a railway station close by remained unchanged over time (γ = γt = γt-1), the following time-difference form is obtained:

$$\begin{aligned}\log(LV_{it}) - \log(LV_{it-1}) = (\alpha_t - \alpha_{t-1}) + (\beta_t - \beta_{t-1})\ distCBD_i \\ + \gamma\ (distST_{it} - distST_{it-1}) + (\varepsilon_{ti} - \varepsilon_{ti-1})\end{aligned} \tag{13}$$

Existing evidence suggests a flattening of the land gradient over time, owing to changes in production and transportation technology (Ahlfeldt and Wendland, 2008a; Atack and Margo, 1998; Margo, 1996; McMillen, 1996; Smith, 2003). This specification therefore allows the gradient to vary over time. Periods t-1 and t refer either to 1890-1936, 1890-1910 or 1910-1936.

It can be shown that the first difference estimate satisfies quasi-experimental conditions. Considering a control group (C) of locations that remain unaffected by transport innovations, parameter γ provides a difference-in-difference estimate distinguishing between time as well as control and treatment (T) locations.

$$(\log(LV_{it}) - \log(LV_{it-1}))^{T} - (\log(LV_{it}) - \log(LV_{it-1}))^{C} = \gamma \ (distST_{it} - distST_{it-1}) \quad (14)$$

Travel Time

One direct goal of this section is to model travel times to the CBD to be able to infer precisely the marginal value of improved transport networks. Three steps had to be applied in order to generate first intermediate results.

First, the evolution of the city's complete railway network had to be traced back and digitized, including all corresponding stations. Details on the procedure are presented in 3.2.

Second, the adequate bilateral travel velocities between all stations had to be calculated. Consulting historical network plans which indicated travel times between stations allowed for reasonably assuming an average train velocity of 33.8 km/h over the complete period. After careful consultation of several different sources, the speed of non train-related trips was set to 1/3 of the train velocity. This assumption should approximately reflect a combined average speed of walking, bus and streetcar rides, while at the same time keeping the models as simple and comprehensive as possible.[38]

[38] The very dense network of streetcars and buses – even in peripheral areas – suggests relatively high non-train velocities. In 1934, 72 streetcar lines covered 638 km and bus lines

Third, the actual travel time for all agents from the predefined commercial areas to the endogenously identified CBD (see above) had to be calculated by taking into account the abovementioned velocities. The applied methodology is as follows: Agents are free to choose whether to take a rapid train service or not in order to arrive at the city center. Their decision is solely based on the minimum time spent on the whole trip. If they choose rapid rail transit, their journey consists of a combined network path consisting of three steps. First, a non-train trip to the next station, second a combination of train rides along the network to the station, which is closest to the CBD, and third, a final non-train trip to the city center, which minimizes travel time.

The results of section 5.4 suggest a positive impact of reduced travel time to the CBD since the flattening land gradient found on the basis of straight-line distances was not accompanied by a respective change in the travel time gradient. Over the course of the observation period, one would therefore expect an increase in land values, particularly at those locations that experienced a major reduction in travel time. As in the previous section, I employ an approach similar to Gibbons and Machin (2005) in order to reveal the marginal impact of travel time reduction on the value of urban land. Starting from equation (10), I replace distance to CBD by travel time to CBD (*ttCBD*) and, again, allow for unobserved fixed location effects *f*.

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summed up to 343 km. Since I use straight-line distances and not actual pathways, the velocity may be slightly overestimated. For references see (Beier, 1990; Bley, 2003; Borchert *et al.*, 1987; Dittfurth, 1993; Hoffmann-Axthelm, 1982).

$$\log(LV_{it}) = \alpha_t - \beta\ ttCBD_{it} + f_i + \varepsilon_{ti} \tag{15}$$

Assuming that the marginal benefit of travel time does not change over time, the time-difference form is as follows:

$$\log(LV_{it}) - \log(LV_{it-1}) = (\alpha_t - \alpha_{t-1}) - \beta\ (ttCBD_{it} - ttCBD_{it-1}) + (\varepsilon_{ti} - \varepsilon_{t-1}), \tag{16}$$

where *t* refers to 1936 and *t-1* to 1890.

5.3.2.The Marginal Value of Proximity to Stations

Results corresponding to equation (13) are presented in column (1) of Table (3) for the long difference 1890 – 1936. The positive coefficient on *distCBD* indicates the typical process of decentralization during the period of late industrialization, which is reflected in a flattening land gradient. Accordingly, the marginal cost of locating farther away from the CBD is reduced by almost 40 percentage points over time. As suggested previously, this is due to a general improvement in transport and production technology, which triggers a general upward-shift of urban bid-rent curves. Hence, the willingness to pay increases due to decreasing transport and production costs.

In the standard specification, the negative coefficient on *distST* points to a marginal increase in land value by approximately 22.3% per km reduction in distance to a station. In order to capture land value decentralization more flexibly, binomial and trinomial forms of distance to the endogenous CBD (columns 2 and 3) as well as mutually exclusive 1 km rings up to a distance of 7 km (column 5 and 6) are introduced (cbd1-7). While the parametric approach proved to significantly increase the model fit in former research by allowing for more heterogeneity of the corresponding gradients (e.g. McMillen, 1996), the non-parametric strategy serves as a robustness check and shows more explicitly how plots at different distances adapt to the explored innovations.

The previously explored emergence and development of the strong sub-center along the boulevards Kurfürstendamm and Tauentzienstrasse at the beginning of the 20th century (see 5.2) is accounted for by introducing an additional dummy variable. It captures all plots within a 1 km distance radius around the Breitscheidplatz. The respective coefficient (*KU*) indicates a relative increase of more than 50% (columns 4 and 6) within its impact area. The key coefficient of interest on *distST* is estimated consistently in all specifications.

The changing signs of the binomial and trinomial *distCBD* coefficients reveal an interesting pattern by showing how values close to the center decrease, then steadily increase while moving outwards and finally decrease again at the city fringe. The improved model fit indicates the feasibility of the functions. Functions of higher order did not provide any additional explanatory power.

Tab. 3 Time Difference Estimates 1890 – 1936

	(1)	(2)	(3)	(4)	(5)	(6)
const	-0.843***	-0.566***	-0.566***	0.403***	1.508***	1.509***
	(0.0524)	(0.0794)	(0.0794)	(0.0894)	(0.1330)	(0.1330)
distST	-0.223***	-0.220***	-0.221***	-0.219***	-0.243***	-0.241***
	(0.0480)	(0.0484)	(0.0463)	(0.0461)	(0.0484)	(0.0483)
distCBD	0.374***	0.170***	-1.017***	-1.043***		
	(0.0149)	(0.0579)	(0.0941)	(0.0941)		
distCBD^2		0.298***	0.402***	0.400***		
		(0.0092)	(0.0291)	(0.0293)		
distCBD^3			-0.032***	-0.032***		
			(0.0025)	(0.0026)		
KU				0.446***		0.415***
				(0.0739)		(0.081)
Distance Rings					Yes	Yes
Obs.	1478	1478	1478	1478	1478	1478
R^2	0.341	0.350	0.410	0423	0.405	0.415

Notes: Endogenous variable is log of land value (*LV*) in RM/sqm in all models. *Distance Rings* is a set of dummies denoting properties within mutually exclusive 1 km distance rings around the CBD. Standard errors (in parenthesis) are heteroscedasticity-robust. *** denotes significance at the 1% level.

Tables (4) and (5) repeat Table (3) estimations for 1890-1910 and 1910-1936 respectively. Interestingly, the relevant processes of adjustment and decentralization appear to have taken place almost exclusively during the first period until 1910. As reported in section 2.2, the suburban railway network was almost fully introduced until 1910. The underground network reached the major part of its extensions by 1913, only a few years later. This strongly points to a very dynamic environment involving large investments and already capitalized expected profits within that period. The coefficient estimates on *distST* are very similar in Table (3) and (4), providing strong evidence for this theory. Additionally, the coefficient on *distCBD* acts the same way, suggesting that the major part of commercial decentralization, which reflects in increasing land values further away from the CBD, took place until 1910.

The distance rings show this process more explicitly. They reveal a relative decline in land prices up to a distance of 3 km around the CBD. Reaching the 4 km ring, values increase. The KU coefficient is insignificant, supporting both the conveyed historical evidence and the results obtained in section 5.2.

Tab. 4 Time Difference Estimates 1890 – 1910

Const.	0.258***	0.00908	0.826***	0.826***	1.195***	1.193***
	(0.0450)	(0.0634)	(0.0564)	(0.0563)	(0.172)	(0.172)
distST	-0.202***	-0.220***	-0.239***	-0.239***	-0.265***	-0.267***
	(0.0481)	(0.0466)	(0.0455)	(0.0456)	(0.0458)	(0.0458)
distCBD	0.306***	0.487***	-0.577***	-0.577***		
	(0.0141)	(0.0477)	(0.0699)	(0.0696)		
distCBD^2		-0.0267***	0.312***	0.312***		
		(0.00773)	(0.0234)	(0.0235)		
distCBD^3			-0.030***	-0.030***		
			(0.00215)	(0.00218)		
KU				-0.000388		-0.0499
				(0.0473)		(0.0575)
cbd1					-0.619***	-0.619***
					(0.170)	(0.170)
cbd2					-0.523***	-0.522***
					(0.171)	(0.171)
cbd3					-0.468***	-0.467***
					(0.170)	(0.170)
cbd4					0.202	0.212
					(0.175)	(0.177)
cbd5					0.598***	0.606***
					(0.176)	(0.177)
cbd6					0.867***	0.868***
					(0.190)	(0.190)
cbd7					0.584**	0.585**
					(0.233)	(0.233)
Obs.	1473	1473	1473	1473	1473	1473
R^2	0.328	0.338	0.407	0.407	0.396	0.396

Notes: Endogenous variable is log of land value (*LV*) in RM/sqm in all models. *Distance Rings* is a set of dummies denoting properties within mutually exclusive 1 km distance rings around the CBD. Standard errors (in parenthesis) are heteroscedasticity-robust. *** denotes significance at the 1% level.

Table 5 reveals no significant impact of a distance to station effect at all. Results also indicate that the emergence of the Kurfürstendamm area as a strong sub-center took place after 1910. In this period it is highly significant and similar to Table 3. While the distance rings have negative signs, they still uncover a relatively weaker decline in the outer parts of the city, indicating that decentralizing movements were still apparent.

Tab. 5 Time Difference Estimates 1910–1936

	(1)	(2)	(3)	(4)	(5)	(6)
Const	-1.054***	-0.679***	-0.464***	-0.415***	-0.157	-0.161
	(0.0355)	(0.0536)	(0.0735)	(0.0741)	(0.136)	(0.136)
distST	0.0545	0.00956	0.0114	-0.00451	0.0331	0.0117
	(0.0416)	(0.0375)	(0.0388)	(0.0382)	(0.0397)	(0.0394)
distCBD	0.0661***	-0.190***	-0.446***	-0.497***		
	(0.0098)	(0.0345)	(0.0757)	(0.0762)		
$distCBD^2$		0.0336***	0.109***	0.116***		
		(0.0049)	(0.0227)	(0.0229)		
$distCBD^3$			-0.0062***	-0.0062***		
			(0.002)	(0.002)		
KU				0.439***		0.449***
				(0.0702)		(0.07)
cbd1					-0.566***	-0.565***
					(0.142)	(0.142)
cbd2					-0.690***	-0.689***
					(0.141)	(0.140)
cbd3					-0.857***	-0.859***
					(0.138)	(0.138)
cbd4					-0.842***	-0.921***
					(0.138)	(0.137)
cbd5					-0.571***	-0.646***
					(0.139)	(0.138)
cbd6					-0.497***	-0.497***
					(0.141)	(0.141)
cbd7					-0.447***	-0.446***
					(0.149)	(0.148)
Obs.	1678	1678	1678	1678	1678	1678
R^2	0.039	0.088	0.098	0.132	0.106	0.140

Notes: Endogenous variable is log of land value (*LV*) in RM/sqm in all models. *Distance Rings* is a set of dummies denoting properties within mutually exclusive 1 km distance rings around the CBD. Standard errors (in parenthesis) are heteroscedasticity robust. *** denotes significance at the 1% level.

Building on the work of Gibbons and Machin (2005), this section provides the first archival evidence for the value of transport innovations during European industrialization. The results reflect the willingness of landlords to bid higher prices for commercial properties due to infrastructural improvements. The estimated effect is a net effect of travel-time savings to and from the respective locations and environmental changes arising, e.g. from increased noise.

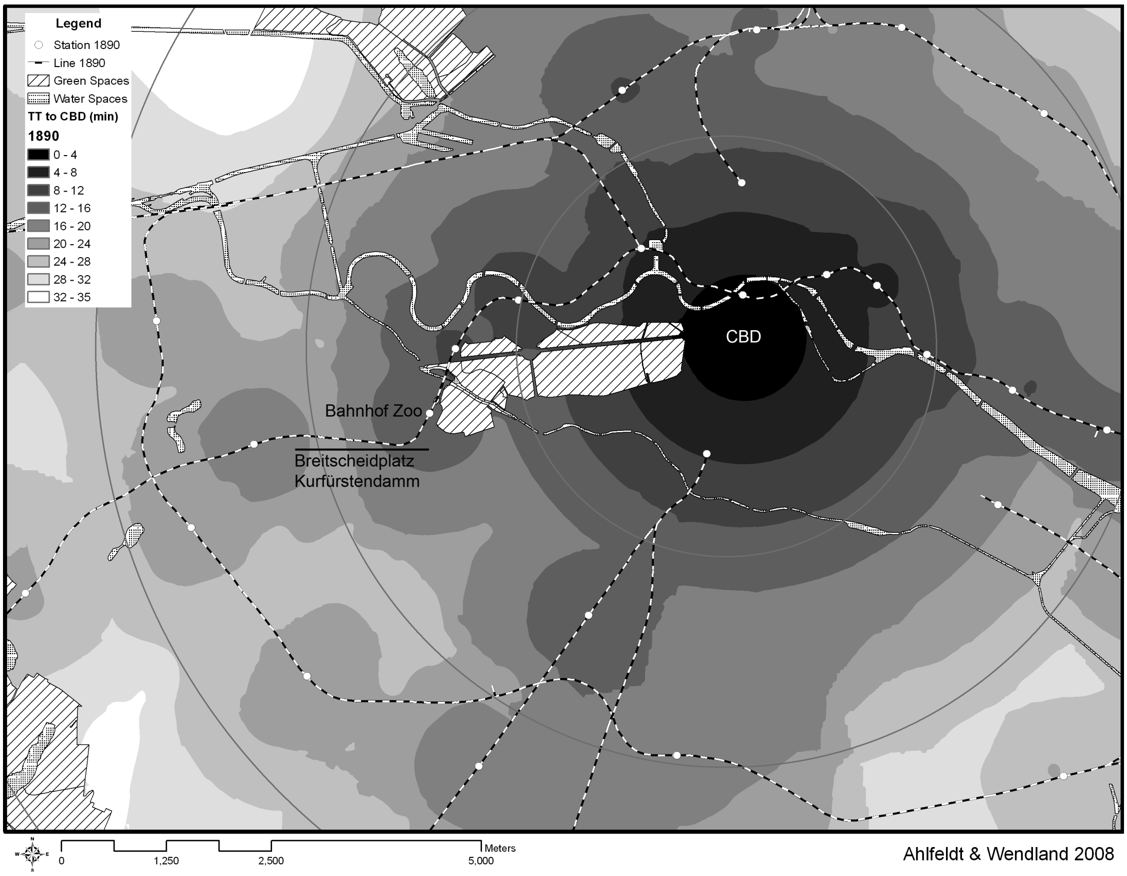
The estimated impact for a 100 m decrease in distance to a railway station of 2.0% to 2.5% is relatively large compared to the findings of Gibbons and Machin (2005), whose estimates range from 0.15% to 0.55% per 100 m reduction. Several explanations may account for this difference. First, their analysis is restricted to residential property prices. The impact on commercial land is probably greater compared to residential properties, since marginal transport costs of firms exceed the marginal commuting costs of residents by far. At the same time, commercial land value may be less sensitive to the depreciating impact of environmental factors such as noise. A lower impact of station proximity on residential relative to commercial land value has recently been shown for present-day Berlin (Ahlfeldt and Maennig, 2008).

Several other explanations of relatively high impacts refer to the historical context of this analysis. The marginal value of having a station close by critically depends on the transport mode employed for moving to and from stations. Thus, a decrease in marginal cost over time is expected from an increasing availability of cars, buses and bikes. This should theoretically increase the values of a dense public railway network in general, even if certain plots do not experience an explicit decrease in distance to a station. Another point refers to the exact period investigated, which may have been biased by much uncertainty in the market. While the time-differences span enough time to account for anticipation effects (McMillen and McDonald, 2004), uncertainty might have led to a considerable overestimation of the expected impact of new stations' real estate price effects during the first period from 1890 to 1910. Historians provide strong evidence for much speculation in the market (Bohm, 1980; Erbe, 1987), accompanied by large investments and protracted struggles regarding the routing of planned lines (see also 2.2.). Amplified by the troubled environment of World War I and the Great Depression, the following disillusionment may have led to an exaggerated downward adjustment of expectations, which is reflected in the time-difference estimates from 1910 to 1936.

5.3.3. The Marginal Value of Travel Time Reduction

A second feature regarding increasing values of business plots owing to transport innovations is the effect of saved travel time. One would expect plots better connected to the CBD to benefit due to increased network density. Following the strategy of 5.3.1, the calculated travel times are visualized for the years 1890, 1910, and 1936 in Figures (15-17). The improvements to the network clearly had a huge impact regarding the symmetry of travel time patterns. The simplicity of the monocentric model assumes a symmetric accessibility from the CBD towards all locations. Asymmetric patterns explicitly influence the transport costs in different directions, leaving certain locations peripheral in terms of accessibility. By reviewing the results of previous chapters and combining them with Figures (15-17), it becomes quite clear how western and southwestern districts benefited relatively more from the implementation and expansion of the rapid railway system. By 1936, a complex pattern of accessibility across all commercially used plots seriously challenges the acceptance of a mere monocentric structure. This topic will be addressed in more detail in 5.4.

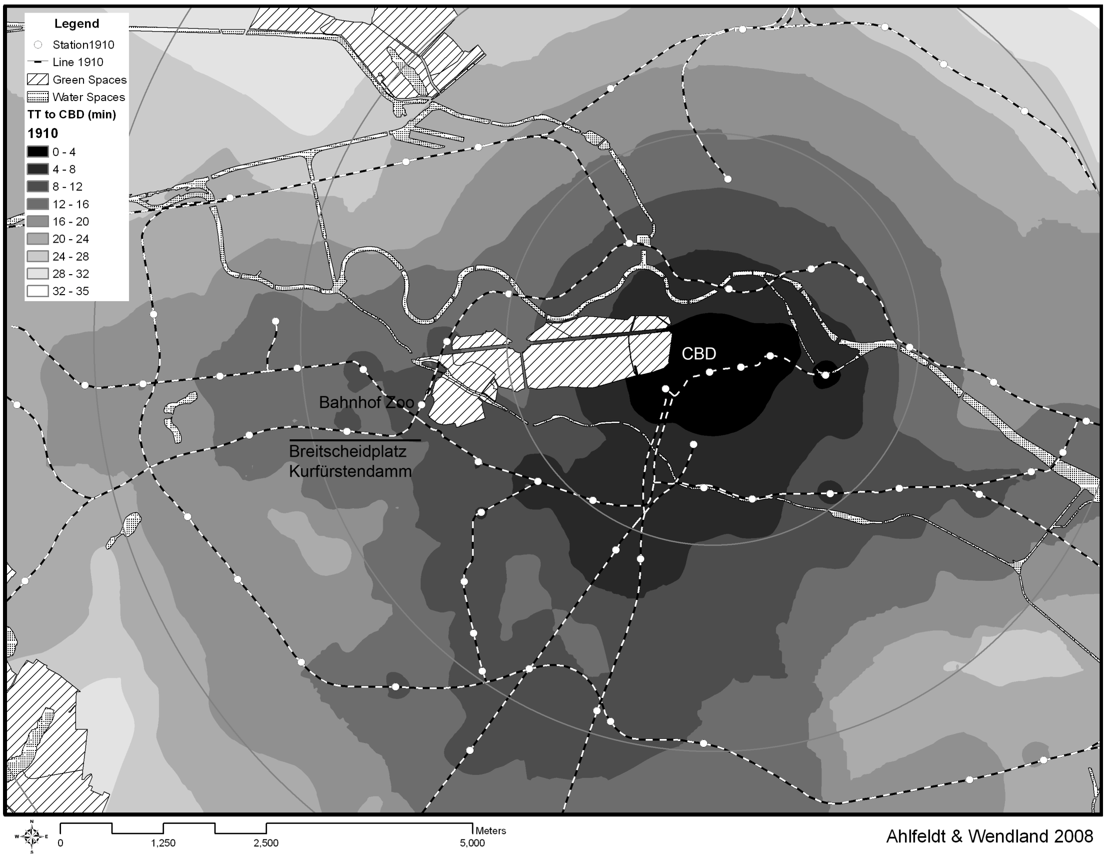
Fig. 15 Travel Time to CBD 1890



Notes: Map shows spatially interpolated travel times using kriging techniques.

Source: Own calculations. Urban and Evironmental Infromation System of the Senate Department Berlin (2006), Network Plans. Taken from Ahlfeldt and Wendland (2008a).

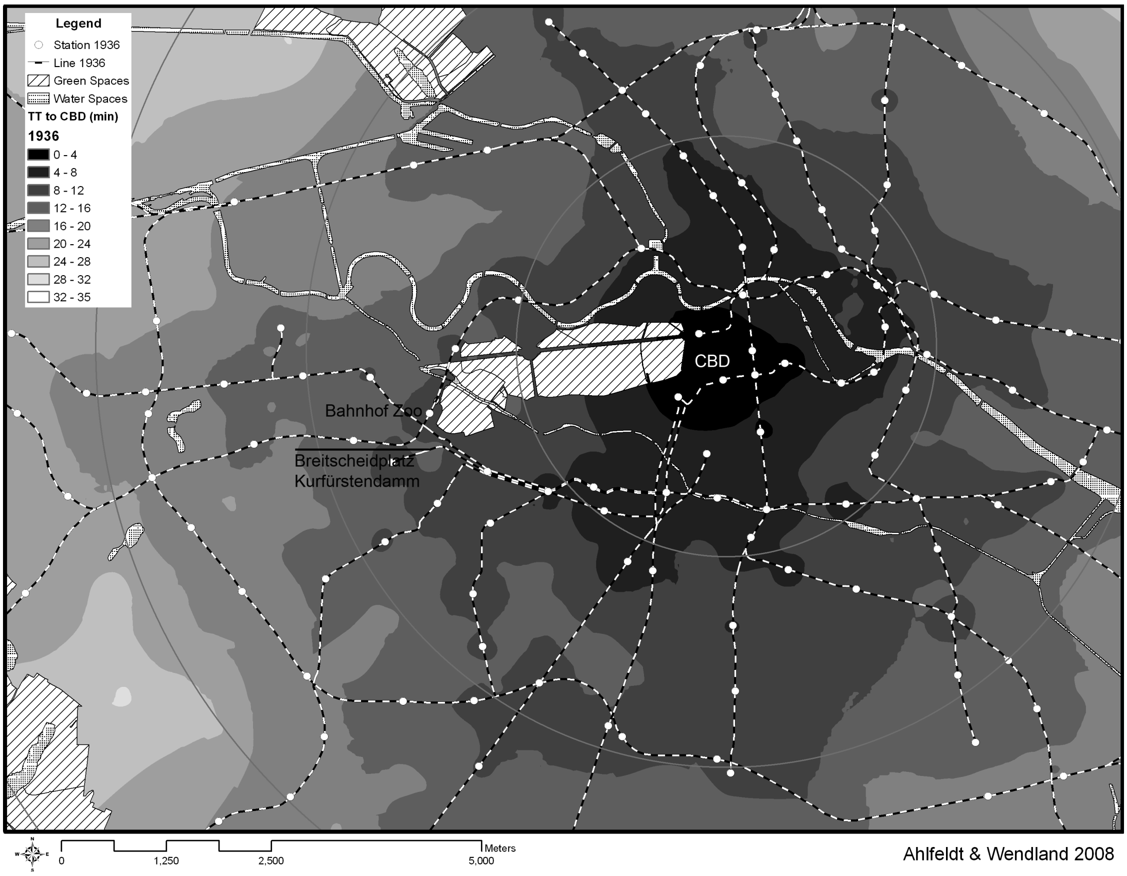
Fig. 16 Travel Time to CBD 1910



Notes: Map shows spatially interpolated travel times using kriging techniques.

Source: Own calculations. Urban and Evironmental Infromation System of the Senate Department Berlin (2006), Network Plans. Taken from Ahlfeldt and Wendland (2008a).

Fig. 17 Travel Time to CBD 1936



Notes: Map shows spatially interpolated travel times using kriging techniques.

Source: Own calculations. Urban and Evironmental Information System of the Senate Department Berlin (2006), Network Plans. Taken from Ahlfeldt and Wendland (2008a)

Now, applying the calculated travel times allows for assessing the marginal benefits which plots may receive over time. The specification of equation (16) controls for unobserved time-invariant location characteristics, assuming that marginal price effects remain constant. Column (1) of Table 6 shows a time-difference estimate corresponding to equation (16). The marginal increase in land value of 13.5% for a one-minute reduction of travel time to the CBD fits exactly into the range of cross-sectional OLS results presented in Table 11 of section 5.4.3.

Tab. 6 Marginal Value of Travel Time

	(1)	(2)	(3)
α_t–α_{t-1}	-0.126***	5.866***	5.870***
	(0.0394)	(0.3000)	(0.311)
β	0.135***	0.104***	0.105***
	(0.0071)	(0.0065)	(0.0066)
X-Coordinate (km)		-0.157***	-0.156***
		(0.0087)	(0.0091)
Y-Coordinate (km)		-0.114***	-0.115***
		(0.0111)	(0.0112)
KUarea			0.950***
			(0.1600)
KUarea x *distKU*			-1.520***
			(0.225)
Obs.	1478	1478	1478
R^2	0.197	0.429	0.440

Notes: Endogenous variable is log-difference between land values 1936 and 1890. Standard errors (in parenthesis) are heteroscedasticity-robust. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

However, at least two major changes in the spatial structure of the city deserve closer attention. In line with anecdotal evidence, previous results suggested a significant increase in land values in the west and southwest of Berlin during the observation period. Since this shift in location desirability may be attributable to other factors besides the improved accessibility by rapid transit lines, I introduce X- and Y- coordinates as location controls in model (2) of Table

6. While the coefficients on coordinates show the expected signs, the marginal value of reduced travel time to the CBD is somewhat reduced, although still exceeding 10% per saved minute for the journey to the CBD.

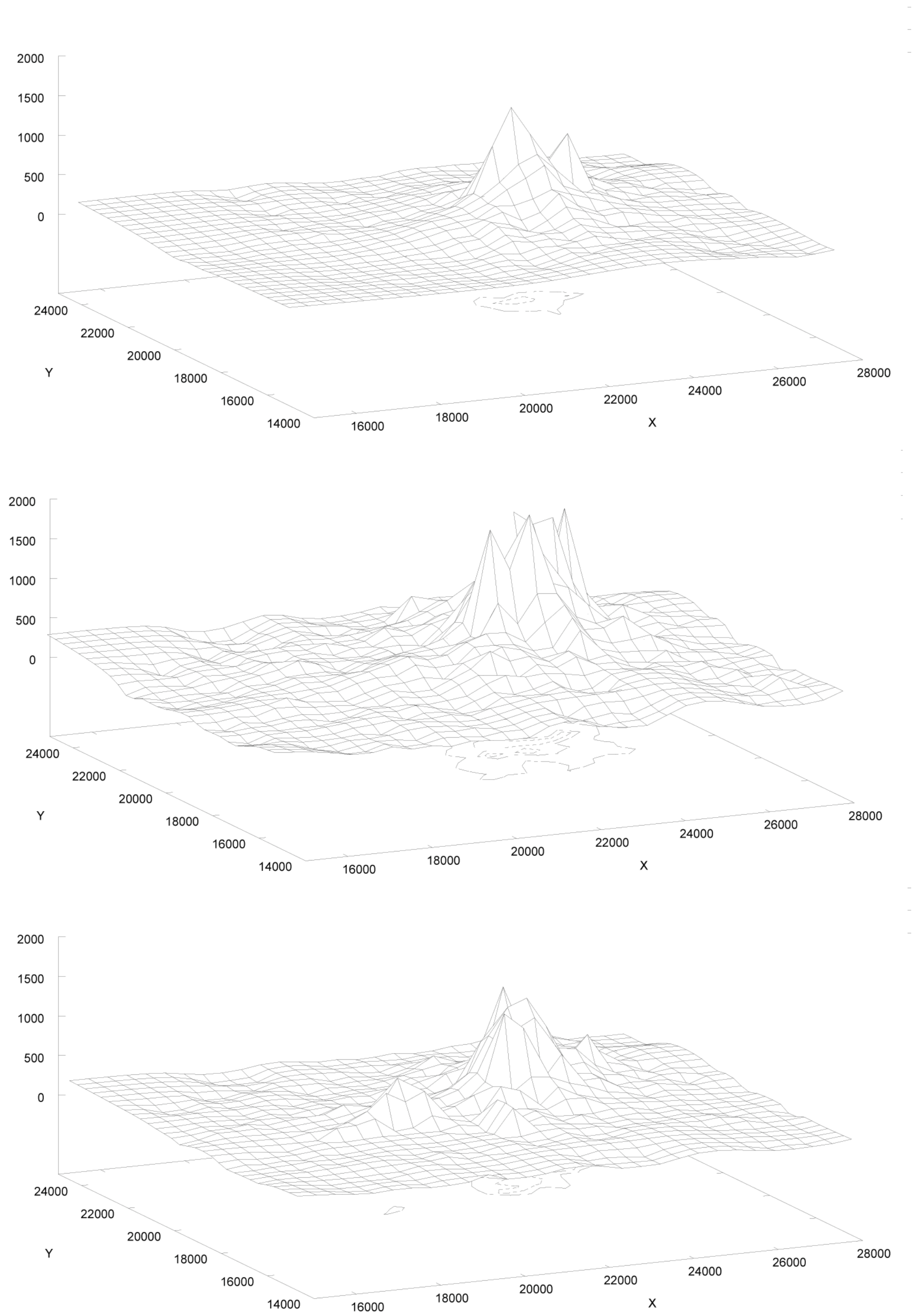
Figure (18) illustrates the emergence of the area around Breitscheidplatz and Kurfürstendamm as a dense cluster of economic activity during the study period. Interestingly, comparing the three pictures lets us observe the dynamic environment to some extent. While 1890 presents a fairly homogenous pattern with one clear peak of land values within the historical CBD, in 1910 the city seems more heterogeneous, showing a lot of noise across the valuation. In 1936, however, a clear new trend has emerged with an obviously weakened CBD and a second center within the abovementioned Kurfürstendamm area.

Since the new business agglomeration itself probably became an autonomous source of production externalities, I further extend the model in order to allow for a local increase in the marginal value of proximity within the respective area (column 3). The coefficient on *KUarea*, a dummy denoting plots within a 1000 m radius from Breitscheidplatz, indicates a relative increase in land values of up to approximately 159%. As suggested by the coefficient on the interactive term between *KUarea* and distance to Breitscheidplatz (*distKU*), the effect diminishes with distance and disappears after 1 km or so.[39] These results confirm the conventional wisdom on the emergence of the strong sub-center at a location, which is today known under the label “City-West”. At the same time, the

[39] Both Akaike and Schwarz criteria as well as adjusted R^2 reject alternative specifications for (500 m, 1.5 km, 2 km) in favor of the 1 km model.

estimate on marginal value of travel time-saving remains almost unaffected, even slightly increasing to 10.5%. This value notably falls within the range of cross-sectional SAR estimates presented in section 5.4.

Fig. 18 Change in Land Values 1890, 1910, and 1936



Notes: Coordinates refer to the Soldner System defined by the Senate Department Berlin. The west peak of 1936 data represents the emerged center of Kurfürstendamm.

5.4. Decentralization and Urban Structure: Does Monocentricity still Hold?

Building on the work presented in previous chapters, this section will conduct a comprehensive analysis regarding the question of sustainable urban structures. As has been shown, the enormous city growth combined with all the abovementioned dynamics worked as a huge shock to the preexisting patterns and the historically grown monocentric structure. Following the theoretical implications presented in chapter 4, one expects a structural break-up at an *a priori* unknown endogenous level of spatial extension and population. Reviewing both the population growth and the spatial development, which took place within the focal research period (see 2.1 and 2.4) and led to a state of more than 4 million residents by 1936, might imply that the monocentric urban structure dissolved even before the start of World War II. Contemporary Berlin is commonly accepted as a duo-centric city, further characterized by a large proportion of mixed-use areas and widely dispersed employment. This fact raises the question, whether this state can be traced back to the years of separation, which led to the development of two self-sufficient centers or if it may stem from the 1920s, when the upcoming Kurfürstendamm area gradually developed and experienced its golden years. Its establishment might already have had an impact strong enough to disrupt the former equilibrium.

So far, only little empirical work has focused on the land gradient to test the monocentric city model, mostly because the relevant data are scarce and imperfect. The very rare exceptions are presented in 4. While before 1900 a simple exponential function manages to explain the distance land price relationship well, starting from the first decades of the 20th century, the model fit deteriorates considerably (e.g. Kau and Sirmans, 1979; McDonald and McMillen, 1990; McMillen, Jarmin, and Thorsnes, 1992). In order to explain urban structures (in terms of land gradients) in subsequent decades, higher order exponential functions have to be used to account for decentralizing and polycentric patterns. For example, McDonald (1979) and McDonald and Bowman (1979) find that a fourth-order polynomial is required to adequately describe land values in Chicago. The model fit could be further improved by dividing the city into different sectors. Their main finding regarding this work is that land values may even increase with distance to the CBD, which seriously challenges traditional expectations. However, there is not yet much evidence for upward-sloping land value functions in a historical context. However, simple extensions to the basic monocentric model that maintain its character can already account for more complex forms. The addition of the transport infrastructure, for example, can show how transport costs may not be equal in all directions and allow for more realistic explanations of complex land gradient forms.

Hence, this section will apply both extended cross-sectional and time-difference estimates in order to test the validity of the monocentric model up to the year 1936. In addition to creating the land gradient and controlling for spatial dependency, rail-based travel times from all commercial plots to the CBD are calculated in order to capture heterogeneities more precisely. Trying to disentangle the effects of transport systems from other influences, a counterfactual scenario will show how much of the variation in land values towards the city fringe can be explained by innovations in transport infrastructure.

From an economic perspective, three hypotheses arise. If land value emerges from a trade-off between transport cost and CBD accessibility (as predicted by theory), transport innovations causing declining transport cost should lead to:

- A flattening distance gradient.
- A constant transport cost (travel time) gradient.
- A substantially steeper counterfactual distance gradient if transport cost is controlled for.

5.4.1. Data and Methodology

The land use map of 1940, as described in 3.3, defines the geographical framework. It provides 1718 commercially used plots. Again, the data set used in previous sections is extended considerably by now introducing all collected land values, increasing the observations to 11,512. They correspond to the identified plots for all available years (see 3.4). Combined with the completely modeled urban railway system, data on land valuation sets the base for the following analysis.

Land Values

The land values have been gathered for 1890, 1896, 1900, 1904, 1910, 1929, and 1936. Since not all plots had been properly developed in all years, some values were eventually been ignored.

To place this section in line with important findings regarding the exploration of changing urban structures over time, I will shortly summarize the samples used by other authors. Their estimations on land gradients in a historical context are presented in Table (10). For the period from 1836 until 1928 McMillen(1996) used data of square mile tracts provided by Hoyt(1933). His sample offers a range of 94 to 148 observations. From 1960 to 1990 he concentrated on commercial land values published in Olcott`s book on land values. The detailed block level allowed for 696 to 721 observations in each year. For his survey on Cleveland, Smith(2003) uses a random sample of plot sales. It mostly consists of residential areas counting from 61 to 125 observations between 1915 and 1980. The presentation of New York data (Atack and Margo, 1998) is based on the prices of vacant land published in newspapers and provides 72 to 208 observations for the years 1835 to 1900.[40] The more recent period from 1931 to 1989 covered by Abelson (1997) is strictly restricted to randomly selected residential areas within Sydney's 22 local government areas. However, he provides a total sample ranging from 1800 to 4400 observations.

[40] Due to direct taxation on property sales, Atack & Margo (1998) state that published prices may be biased.

Railway Network and Travel Times

The same strategy has been applied as presented in 5.3.1.

Land Gradients

The point of departure for this section's analysis is again the standard monocentric city model in which firms and residents bid higher prices for land closer to the CBD due to lower transport costs and travel time savings (Alonso, 1964; Mills, 1972; Muth, 1969). Only the need for land keeps the city from collapsing into a single point. Evidence suggesting that land values (*LV*), and therefore the city structure, may be well described by an exponential function of distance to the CBD (*distCBD*) is available for the cities of Chicago, Cleveland, New York and Sydney (Atack and Margo, 1998; Kau and Sirmans, 1979; McDonald and McMillen, 1990; McMillen, 1990; McMillen, 1996; McMillen, Jarmin, and Thorsnes, 1992; Mills, 1969; Smith, 2003). The gradient will be calculated using the well-established log-linear specification.

$$\log(LV_{it}) = \alpha - \beta \ distCBD_{it} + \varepsilon_{it}, \tag{17}$$

Parameter α corresponds to the log of land value in the city center while β presents the land gradient, which is the percentage change in land value as one moves 1 km away from the CBD, and ε is an error term satisfying the usual conditions.

To allow for the CBD to move over time, it has been estimated endogenously by applying the same strategy as presented in 5.2. This way it is possible to more precisely account for changes in the structure within the research period.

5.4.2. Evidence from Land Gradients

A first step in explaining the changes within Berlin's structure until 1936 is by applying the log-linear specification to calculate the land gradient over time. This allows for comparing the results with previously conducted analyses by other authors. The model will be gradually extended and altered as I proceed in this section.

Table (7) shows parameter estimates corresponding to equation (17) estimated by the use of non-linear least squares.

Tab. 7 Land Gradient 1890 – 1936 (NLS)

	1890	1896	1900	1904	1910	1929	1936
α	6.947***	6.846***	6.918***	7.052***	7.166***	6.255***	6.1363***
	(0.0431)	(0.0281)	(0.028)	(0.027)	(0.027)	(0.044)	(0.043)
β	0.775***	0.583***	0.520***	0.509***	0.453***	0.4051***	0.3971***
	(0.0160)	(0.010)	(0.009)	(0.008)	(0.008)	(0.012)	(0.011)
X^{CBD}	23.860***	23.824***	23.748***	23.697***	23.656***	23.452***	23.420***
	(0.0035)	(0.0038)	(0.0033)	(0.0033)	(0.0041)	(0.0071)	(0.0059)
Y^{CBD}	21.022***	20.781***	20.604***	20.614***	20.492***	20.534***	20.653***
	(0.0037)	(0.0039)	(0.0037)	(0.0037)	(0.0036)	(0.006)	(0.0069)
Obs.	1479	1572	1683	1686	1681	1709	1711
R^2	0.7451	0.7548	0.7650	0.7663	0.7237	0.458	0.4743

Notes: Endogenous variable is log of land value (*LV*) in RM/sqm in all models. Coordinates refer to the Soldner system by the Senate Department Berlin, whose origin lies south-westward from the boundaries of present day Berlin. Standard errors (in parenthesis) are heteroscedasticity-robust estimates from separate OLS regression for parameters α and β, where distance was calculated from estimated CBD coordinates. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

The obtained results suggest a steeply descending land gradient during the period of observation. While the α represents the logs of the land value peaks for each year in the city center, the β represents the gradient coefficient. Starting with an extraordinarily high value of 77.5% in 1890, the results point to highly localized externalities, with short ranges of spill-overs. Until 1910, we observe an overall growing level of land valuation followed by an era of declining maximum values until 1936. Note that the α values do not correspond to the highest land values in general but to the highest values within the endogenously defined center of gravity. Especially in 1929 and 1936 single plots reveal higher prices than the most expensive land in 1890.

Over time, the gradient flattens out to reach a value of only 39.7% in 1936. Within the same period, the model fit declines considerably, especially after 1910. This may indicate that either the monocentric structure of the city was breaking up or that omitted location amenities account for a larger spatial variation in land values.[41] In case of the latter, there would be a spatial structure within the error term. Since other location factors, despite centrality to the CBD, potentially exhibited an influence on land prices during the whole study period, a spatial structure in the error term is very likely to arise. To account for this problem I estimate a spatial error correction model to control for error terms and omitted variables that are correlated across space (Anselin, 2003; Anselin and Bera, 1996; Anselin and Florax, 1996).[42]

To appropriately approach this topic, defining an adequate weights matrix is crucial. The choice of a spatial weights matrix is still a very difficult methodological issue within the field of spatial econometrics (for an overview

[41] Since the data source changes from 1910 to 1929, there is also the possibility that a higher volatility is attributable to the method of land value assessment.

[42] Another form of spatial dependency emerges from the fact that sales prices are endogenous to neighboring transactions. This dependency can be dealt with by the application of a spatial lag model. Methodological aspects of spatial error and spatial lag models are covered by ANSELIN (1988) and ANSELIN & BERA (1998).

see Guillain and Le Gallo, 2006). Regarding this setting, several distance-based matrices have been tried. After careful evaluation, all observations within a distance band of 300 meters were treated as neighbors[43] and arrow-standardized weights matrix (W) was chosen. Formally, the spatial autoregressive (SAR) model that I estimate employing a maximum likelihood estimator corrects for the spatial structure of the error term in equation (17) as follows:

$$\varepsilon = \lambda W + \mu , \tag{18}$$

where, μ is an independent and identically distributed vector of error terms.

[43] This weights matrix provides the best fit compared to alternative specifications and minimizes the Akaike and Schwarz criteria.

Tab. 8Land Gradient 1890 – 1936 (SAR)

	1890	1896	1900	1904	1910	1929	1936
α	6.156***	6.339***	6.747***	6.860***	7.122***	5.932***	5.893***
	(0.1369)	(0.1019)	(0.0838)	(0.0824)	(0.0824)	(0.1153)	(0.043)
β	0.565***	0.540***	0.546***	0.532***	0.519***	0.386***	0.383***
	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
λ	0.883***	0.891***	0.853***	0.848***	0.833***	0.839***	0.816***
Obs.	1479	1572	1683	1686	1681	1709	1711
R^2	0.9308	0.9361	0.9216	0.9153	0.8815	0.8214	0.8053

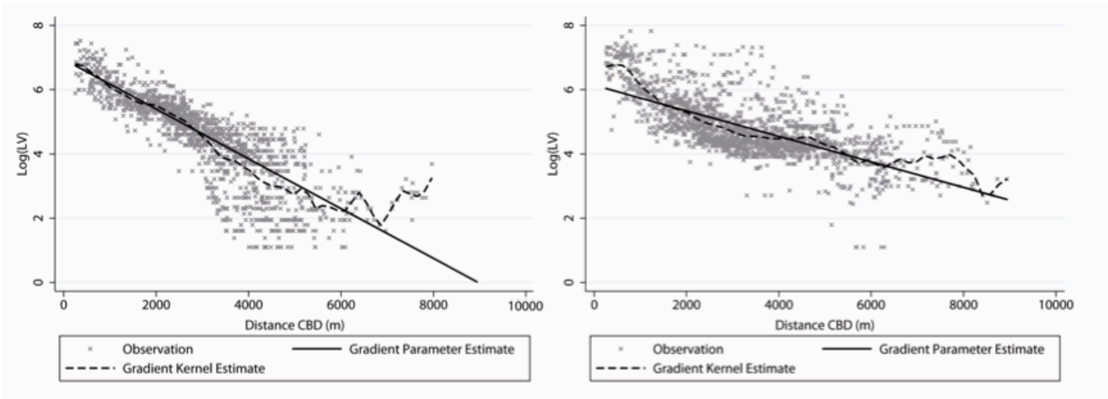
Notes: Endogenous variable is the log of land value (*LV*) in RM/sqm in all models. Standard errors (in parenthesis) are robust for spatial dependency. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

The estimated pattern of results remains unchanged when compared to that presented in Table (7). Notable differences are a considerably reduced gradient coefficient for 1890 and a slight increase in the coefficient for 1910. By correcting for spatial correlation, the lag-coefficient λ also accounts for omitted control variables, which shows in a considerable increase in the coefficient of determination, in particular for the years after 1910. For the year 1929, the estimated R^2 increases from below 0.5 (in Table 7) to above 0.8, but leaving gradient estimates almost unchanged. Until 1910, the land gradient changed only slightly but still decreases significantly for the years 1929 and 1936. The high significance of the introduced λ supports the feasibility and the necessity of correcting for spatial correlation across the error term.

These results indicate that despite an increase in importance of additional location factors, Berlin maintained a basic (but weakened) monocentric structure until at least the mid 20th century. The findings resemble the results provided by McMillen (1996), who found a major decrease in the explanatory power of a simple negative exponential power function after 1910. However, after employing spatial extension models and locally weighted regressions,[44] the results for Berlin turn out to look more favorable for the monocentric city model until 1929. Figure (19) highlights that the negative relationship between land value and distance from the center of Berlin remained stable until 1936, although the gradient became flatter and the variance of land values increased. The increasing variance can be attributed to the emergence of decentralized local pockets of increased economic activity. This is accounted for not only by the identified sub-centers account (5.2) but also by a general tendency towards mixed-use areas created according to the Hobrecht Plan.

[44] Locally weighted regressions were also applied to the model but did not change the scope or character of the results. Hence, they are not presented here.

Fig. 19 Log(*LV*) and Distance from the CBD 1890 and 1936



Notes: The left illustration refers to 1890, the right one to 1936. Parameter estimates refer to Table 1. Kernel regressions of log(*LV*) on *distCBD* use the Epanechnikov function. Figure taken from Ahlfeldt and Wendland (2008a).

To explore the possibility of asymmetric structures, which were mentioned previously, it is important to allow for more heterogeneity in the land gradient. In order to do so, I interact the distance to the CBD with dummies denoting locations that lie west or south from the estimated gravity center. This approach is a marked alternative to the conducted SAR estimations. Both models address spatial variation in land values that is not explained by the simple exponential function. The interactive terms enter equation (17) with a negative sign, revealing whether the land gradient descends more or less steeply to the west and south compared to the east and north. The results are presented in Table 9. Especially for the years 1929 and 1936, which experienced the strongest decline in the overall land gradient, the results indicate a significantly smaller gradient decay towards west and south. Accordingly, after 1904 the remarkable decrease in gradient coefficient of below 50%, as suggested by Table (7), is almost entirely attributable to an increase in the valuation of southern and western areas of Berlin. These results are in line with the south-west movement of the city's centre of gravity found in Table (7) as well as with anecdotal historical evidence, which notes a considerable increase in economic wealth in these areas at the beginning of the 20th century (Elkins and Hofmeister, 1988; Hofmeister, 1990; Leyden, 1933; Louis, 1936). Improvements in transport infrastructure as well as the previously mentioned emergence of the Boulevards Kurfürstendamm and Tauentzienstraße may also account for these spatial asymmetries and will be addressed in the remainder of this section.

Tab. 9 Heterogeneity in Land Gradients 1890 – 1936 (OLS)

	1890	1896	1900	1904	1910	1929	1936
α	6.947***	6.883***	6.956***	7.085***	7.198***	6.326***	6.217***
	(0.0439)	(0.0336)	(0.0274)	(0.0268)	(0.0262)	(0.0403	(0.0385
β	0.778***	0.540***	0.572***	0.556***	0.500***	0.504***	0.503***
	(0.0195)	(0.0002)	(0.0112)	(0.0108)	(0.0104)	(0.0157)	(0.0153)
distCBD	-0.014	-0.008	-0.010	-0.007	-0.005	-0.034***	-0.038***
x*West*	(0.0122)	(0.0110)	(0.0072)	(0.0070)	(0.0068)	(0.0102)	(0.0096)
distCBD	-0.019	-0.038***	-0.048***	-0.046***	-0.051***	-0.080***	-0.080***
x*South*	(0.0125)	(0.0089)	(0.0071)	(0.0069)	(0.0066)	(0.0104)	(0.0102)
Obs.	1479	1572	1683	1686	1681	1709	1711
R^2	0.746	0.759	0.772	0.773	0.734	0.483	0.500

Notes: Endogenous variable is the log of land value (*LV*) in RM/sqm in all models. Standard errors (in parenthesis) are heteroscedasticity-robust. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

Comparing the results from Tables (7) and (9) as well the implications of Figure (19) shows a clear picture. In line with the existing evidence for Chicago (McMillen, 1996), Cleveland (Smith, 2003), New York (Atack and Margo, 1998) and Sydney (Abelson, 1997) a flattening gradient and decreasing coefficients of determination over time can be observed. Notably, the estimated decay coefficients are larger compared to previous studies, including the analysis conducted by McMillen (1996), who also restricted the sample to commercial land values. These large coefficients reflect a very high concentration of economic activity within a relatively small core area. Such a strong agglomeration may result either from a production technology that generates highly localized externalities resulting in an incentive for firms to locate closer to each other or from very high transport costs.[45] The latter seems somewhat unlikely since at least by the end of the observation period Berlin possessed a well-developed transport network, which will receive more attention in the following section. These results, which are the first available for Europe, are more likely to reflect some kind of historical persistency, which could be typical for relatively old cities. Berlin's central business district, even by the end of the observation period, hardly exceeded the boundaries of the historic downtown district established hundreds of years ago, covering an area of not more than 1.5 km radius (Elkins and Hofmeister, 1988; Leyden, 1933).

However, the assessment of the land gradient over time together with a still relatively high explanatory power of the log-linear specification strongly indicates that the monocentric model is capable of adequately describing the urban structure of Berlin until 1936.

Table 10 compares the existing international evidence on historical land gradients.

[45] As the strict functional segregation and a very high density within the very core markedly influenced advantages in physical proximity (see 2.3 and 2.4), I assume that highly localized externalities account for steeper gradients.

Tab. 10 International Land Gradient Estimates

	Berlin	Chicago*	Cleveland*	New York*	Sydney
1835-36		0.38 (0.83)		0.40 (0.72)	
1857-60		0.40 (0.84)		0.19 (0.63)	
1873-75		0.30 (0.71)		0.09 (0.17)	
1890-92	0.78 (0.75)	0.31 (0.58)		0.11 (0.28)	
1900	0.52 (0.77)			0.06 (0.01)	
1910-15	0.45 (0.72)	0.30 (0.61)	0.40 (0.49)		
1928-31	0.41 (0.46)	0.12 (0.24)	0.27 (0.32)		0.094 (0.55)
1936-48	0.40 (0.47)		0.30 (0.49)		0.078 (0.53)
1968-70		0.03 (0.02)	0.11 (0.21)		0.032 (0.28)

Notes: Coefficients refer to simple negative exponential models estimated in log-linear specification as represented in equation (17). Chicago results are from MCMILLAN (1997) referring to 1836, 1857, 1873, 1892, 1910, 1928, and 1970. Cleveland results are from SMITH (2003) referring to 1915, 1930, 1940 and 1970. New York results are from ATACK&MARGO (1998) referring to 1835, 1860, 1875, 1890 and 1900. The model also includes a control for corner lot. Sydney results are from ABELSON (1997) referring to 1931, 1948, and 1968. Berlin results are taken from Table 7. Coefficients of determination are presented in parenthesis. * Coefficients are rescaled from miles to km.

5.4.3. Evidence from Travel Time Gradients

As discussed earlier, the observation period in this work covers the peak time of industrialization in Berlin, characterized by ongoing city growth, technological progress and major improvements in transport infrastructure. The implementation of rapid transit lines as a means of mass transportation potentially exhibited a major impact on the value of urban land as effective accessibility was reshaped along these lines. The analyses conducted in previous chapters strongly support these assumptions. As a second feature of this section, the effective travel time from all commercial plots to the CBD (as calculated in 5.3) is used in order to approach the question of possible asymmetric urban developments from another side. The visualized travel times have been presented in Figures (15-17). They illustrate how the monocentric form of CBD-accessibility broke up into a more complex pattern.[46] The travel time measure strictly refers to the fastest journey to the CBD, whereby residents are allowed to choose whether to use rapid transit lines for a part of the journey or not. Assuming that the use of rapid transit lines in general was affordable (Bley, 2003) and, hence, opportunity cost of travel time dominated physical distance in terms of perceived accessibility, land values for a given location should essentially depend on the time the journey to the CBD takes.

In order to account for infrastructural improvements, particularly the expansion of the rapid transit network, the straight-line distances, which had been applied to assess the land gradients, are replaced by travel times and used in equation (17). By comparing how both distance and travel time gradients change over

[46] The corresponding CBD for each year is defined on the basis of Table (7) results.

time, one may infer the question if and how the inauguration of rapid transit lines changed the pattern of land valuation.

Tables (11) and (12) show travel time gradient estimates referring to the location of the CBD as estimated in Table (7). To follow the previously applied strategy, both OLS and SAR estimators are employed.

Tab. 11 Travel Time Gradient 1890 – 1936 (OLS)

	1890	1896	1900	1904	1910	1929	1936
α	7.047***	7.096***	7.056***	7.234***	7.231***	6.624***	6.489***
	(0.0458)	(0.0398)	(0.0373)	(0.0361)	(0.0371)	(0.0506)	(0.0497)
β	0.175***	0.150***	0.128***	0.140***	0.124***	0.156***	0.153***
	(0.0034)	(0.0030)	(0.0025)	(0.0027)	(0.0030)	(0.0042)	(0.0041)
Obs.	1479	1572	1683	1686	1681	1709	1711
R^2	0.641	0.630	0.616	0.657	0.588	0.489	0.497

Notes: Endogenous variable is the log of land value (*LV*) in RM/sqm in all models. Standard errors (in parenthesis) are heteroscedasticity-robust. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

Compared to the distance-based estimates presented in Table (7), variation in the gradient coefficient is generally much smaller. There is also no clear tendency apparent in the evolution of the gradient over time. If any, there is a flattening of the gradient until 1900, which is largely reversed by 1929. These changes in travel time gradients may be attributable to changes in production technology, as during the respective period both heavy industry and services experienced a boom. As productivity of heavy industry did not essentially depend on proximity to the CBD, the increasing need for land led to an outward movement to the city fringe and potentially supported the flattening gradient around the turn of the centuries.[47] The central land, which became available was occupied by services industries, whose interactions with other economic and government agents were largely based on face-to-face contacts. Corresponding agglomeration economies were therefore highly localized and increased the value of the CBD proximity. The slightly varying travel time gradient coefficients probably reflect the tension between both driving forces.

Table (12) repeats the SAR estimation for travel time gradients in order to account for possibly omitted location variables by capturing a spatial structure in the error term. The highly significant λ together with the high explanatory power of the model indicate the appropriateness of SAR estimates in this case and deliver strong evidence for the existence of omitted location determining structures and/or amenities.

[47] Local legislation supported the displacement of heavy industry from the urban core due to environmental concerns and to prevent ongoing congestion.

Tab. 12 Travel Time Gradient 1890 – 1936 (SAR)

	1890	1896	1900	1904	1910	1929	1936
α	5.986^{***}	5.088^{***}	5.424^{***}	5.799^{***}	6.091^{***}	5.880^{***}	5.960^{***}
	(0.1647)	(0.1492)	(0.1413)	(0.1278)	(0.1263)	(0.1162)	(0.1056)
β	0.116^{***}	0.084^{***}	0.083^{**}	0.096^{***}	0.100^{***}	0.116^{***}	0.124^{***}
	(0.0077)	(0.0068)	(0.0065)	(0.0062)	(0.0066)	(0.0076)	(0.0071)
λ	0.908^{***}	0.949^{***}	0.941^{***}	0.931^{***}	0.922^{***}	0.842^{***}	0.814^{***}
Obs.	1479	1572	1683	1686	1681	1709	1711
Ad. R^2	0.931	0.934	0.919	0.914	0.880	0.821	0.805

Notes: Endogenous variable is the log of land value (*LV*) in RM/sqm in all models. Standard errors (in parenthesis) are robust for spatial dependency. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

The absence of a clear trend in the travel time gradients together with a continuously decreasing straight-line distance gradient suggest that transport innovations essentially promoted the relative increase in the attractiveness of peripheral locations. As the travel time gradient indicates the percentage change in land value as we move 1 minute away from the CBD, a rather constant gradient over time could, by itself, lead the conclusion of no substantial structural change at all. Given the knowledge gathered in the network development, combined with the evidence presented from the straight-line distance gradient, which clearly indicates an overall process of decentralization, the travel time gradient provides evidence of a generally more decentralized environment by 1936.

Table (13) investigates spatial heterogeneity in the travel time gradient employing the same methodology as in Table (9) by introducing dummy variables denoting the development towards southern and western locations. Results again suggest a significantly flatter gradient decay towards the western and southern parts after 1910. In previous years, the relationship was the other way round, showing an even higher decay towards the southern and western parts of the city. This may be due to a general abundance of vacant land in the corresponding districts of Charlottenburg and Wilmersdorf resulting in lower plot prices in early years. For the south, there is a significantly lower valuation in 1890, 1904, and 1910 with respect to effective accessibility, where the simple distance measure had suggested the opposite effect (Table 9). A similar, even stronger, switch from a positive to negative sign is found for the western interactive, probably reflecting the emergence of the Kudamm area as a strong sub-center. As can be seen in Figure (15), the respective areas, in particular the area around Kurfürstendamm and Bahnhof Zoo, were already well-connected by 1890. After all, development of transport infrastructure apparently preceded the evolution of land values, again, indicating a causal importance of transport infrastructure for the value of urban land (see 5.2).

Tab. 13 Heterogeneity in Travel Time Gradients 1890 – 1936 (OLS)

	1890	1896	1900	1904	1910	1929	1936
α	7.018***	7.011***	7.079***	7.283***	7.316***	6.652***	6.527***
	(0.0450)	(0.0406)	(0.0368)	(0.0318)	(0.0327)	(0.0495)	(0.0493)
β	0.137***	0.116***	0.114***	0.116***	0.105***	0.171***	0.167***
	(0.0041)	(0.0044)	(0.0036)	(0.0031)	(0.0031)	(0.0047)	(0.0047)
distCBD	0.040***	0.036***	0.027***	0.034***	0.034***	-0.010***	-0.013***
x*West*	(0.0027)	(0.0024)	(0.0019)	(0.0019)	(0.0021)	(0.0027)	(0.0026)
distCBD	0.015***	0.004	-0.0018	0.009***	0.007***	-0.008***	-0.002
x*South*	(0.0028)	(0.0028)	(0.0024)	(0.0021)	(0.0022)	(0.0031)	(0.0029)
Obs.	1479	1572	1683	1686	1681	1709	1711
Ad. R^2	0.705	0.683	0.661	0.727	0.662	0.495	0.503

Notes: Endogenous variable is the log of land value (*LV*) in RM/sqm in all models. Standard errors (in parenthesis) are heteroscedasticity-robust. * denotes significance at the 10% level, ** denotes significance at the 5% level and *** denotes significance at the 1% level.

5.4.4. What if: A Counterfactual Scenario

As was discussed above, several factors such as city growth, increasing demand for industrial land, or changes in production technology potentially influence the evolution of the land gradient over time. These effects are difficult to separate, in particular since some of the driving forces point in opposite directions. The results so far suggest a significant effect of reduction in implicit transport cost to the CBD on the value of urban land as it is also predicted by the monocentric city model. Therefore, the connection of peripheral urban areas to a system of rapid mass transportation obviously exhibits a price-appreciating effect. But to what extent did the fundamental change in accessibility observed during the study period promote decentralization of economic activity? I address this question by asking what would have happened in a counterfactual scenario without the construction of the new transport network.

Therefore, I subtract the estimated price effect for every plot corresponding to the effective reduction in travel time between 1890 and 1936 from the 1936 log land values, using estimated $\hat{\beta}$ from Table (6) in section 5.3, columns (1) and (3).

$$\log(LV_{it}^{c}) = \log(LV_{it}) - \hat{\beta}\ (ttCBD_{it} - ttCBD_{it-1}) \qquad (19)$$

The counterfactual land values (LV^c) are used for standard gradient estimates corresponding to equation (17). The resulting counterfactual gradient estimates range from a 52% to a 56% decrease per km, depending on whether location control variables were considered in the baseline estimation or not. Hence, the counterfactual scenarios suggest that without the major improvements in transport infrastructure, the flattening of the land gradient would hardly have exceeded the effective 1896/1900 level. This finding is in line with cross-sectional travel time gradient estimates from Table (11), which do not show a systematic decrease after 1896.

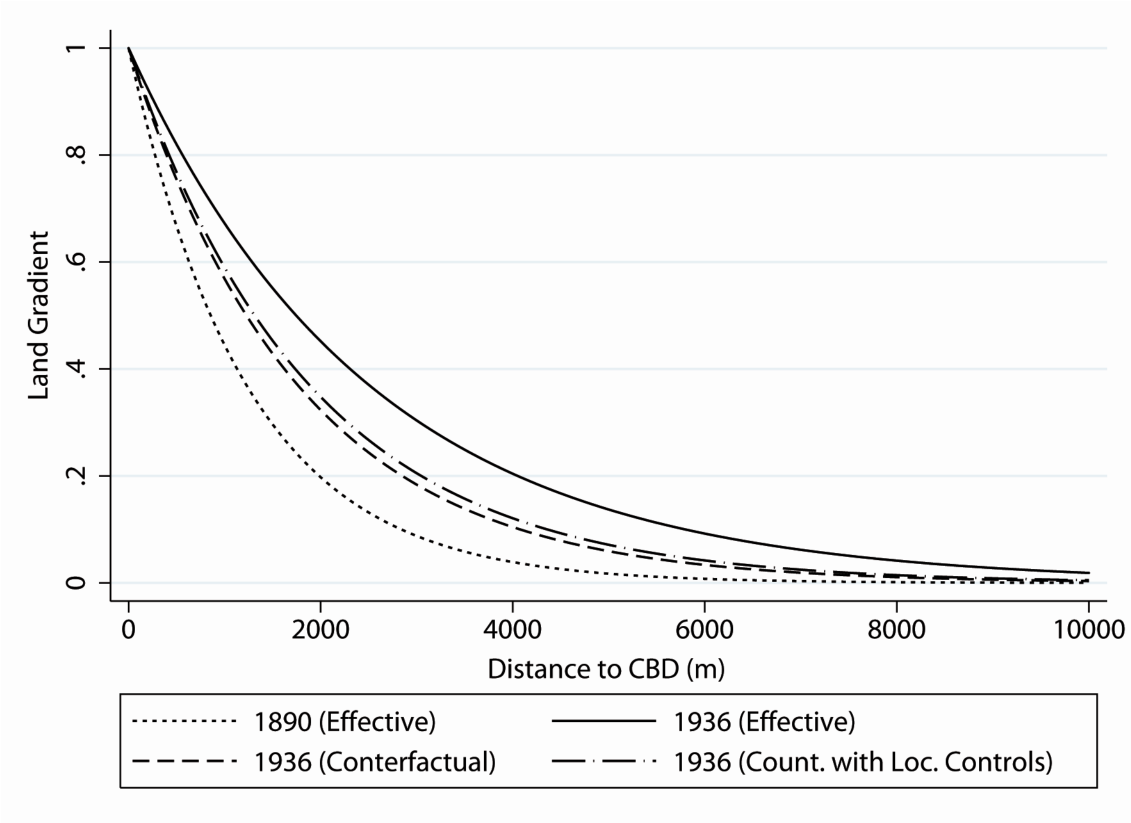
Tab. 14 Counterfactual Land Gradient Estimates

	(1)	(2)
α	6.087***	6.097***
	(0.0488)	(0.0469)
β	0.564***	0.528***
	(0.0138)	(0.130)
Obs.	1711	1711
R^2	0.5926	0.5812

Notes: Endogenous variable is counterfactual land value 1936 as defined in equation (19) in both models. Model (1) is based on $\hat{\beta}$ estimate from Table (6), column (1), model (2) the respective estimate from column (3). Standard errors (in parenthesis) are heteroscedasticity-robust. *denotes significance at the 10% level, **denotes significance at the 5% level and *** denotes significance at the 1% level.

As illustrated in Figure (20), effective reductions in travel times seem to account for at least about one half of the decentralization observed from 1890 to 1936. On the other hand, transport innovations cannot entirely explain the flattening of the land gradient during the observation period. Additional improvements besides the rapid transit lines may also have exhibited an important effect. After all, the common phenomenon of a flattening land gradient seems, in the case of Berlin, to be attributable to a combination of decreasing transport costs and increasing city size and demand for land by industries, which dominated the potentially agglomerating effect of the CBD transformation into a pure government and office district.

Fig. 20 Effective and Counterfactual Land Gradient 1936



Notes: Figure illustrates gradient estimates from Table (6) and Table (7). Figure is taken from Ahlfeldt and Wendland (2008a).

5.4.5. Discussion

The results are clearly in line with theoretical implications on the relationship between proximity and transport costs, hence validating abovementioned hypotheses. Cross-sectional estimates point to a flattening land gradient by 1936, suggesting rising attractiveness for peripheral business locations. Simultaneously, a quite constant travel time gradient indicates existing transport innovations, which led to constantly decreasing transport costs and the possibility of locating further from the center without losing the privilege of good accessibility. The counterfactual scenario attributes about 50% of the dynamic development of land valuation to infrastructural improvements. Accordingly, the counterfactual gradient estimates indicate a hypothetical, steeper decline as one moves away 1 km from the CBD.

This section provides strong evidence for the validity of the monocentric city model in the case of Berlin from 1890 to 1936 using an archival land value data set, which so far is unique for Europe. In line with existing evidence, the univariate gradient models point to a land gradient that with respect to distance to CBD flattens over time, accompanied by a considerable decline in model fit. However, by addressing spatial dependency in the data, it can be shown that during the observation period the monocentric model did not become fundamentally unsuited to describing the basic structure of the city. Instead, more localized location amenities are likely to have become more important. The gradient estimates ranging from 77.5% to 39.7% per km indicate a relatively steep gradient decay compared to U.S. cities during the same period, which has been shown by presenting available land gradient estimates from other works. This finding reveals a highly concentrated business agglomeration that hardly exceeded the boundaries of a relatively small historic city district; a phenomenon, which might be typical for European cities with a long development history. Persistency of historic city structures is also indicated by the relatively stable location of the city's center of gravity, which moved only slightly within the whole period, despite a quite dynamic environment. Similar research on historically evolved city structures would definitely lead to a more profound understanding and is desirable.

This section adds to the literature by modeling effective travel times, taking into account development of the rapid transit network, which substantially reshaped the pattern of accessibility over the course of the observation period. Compared to the evolution of the land gradient with respect to distance, trends in travel time gradients are much less precise, suggesting that peripheral locations experienced a rise in attractiveness as the connection to the center was improved. Particularly for the southwest, there is evidence that a considerable increase in land values was preceded by fundamental improvements in accessibility. The importance of the rapid transit network for the spatial structure of the city is also highlighted by the counterfactual estimates, which indicate that the land gradient would have declined considerably less if a new transport infrastructure had not been developed.

In total, the results support the monocentric model not only on the basis of the static comparison of land value and distance to the center, but also from a more dynamic perspective. Variation in transport costs due to improvements in infrastructure is counterbalanced by an adjustment in land value, as would be predicted by theory. However, while reduced transport costs essentially promoted decentralization during the observation period, other factors such as increasing demand for industrial land, city growth, and urban development policies also certainly contributed to the effective flattening of the land gradient.

6. Conclusion and Summary

In the past years and decades, many historians rendered extraordinary services to the fields of *Urban History* and *Urban Economics*, by gathering an invaluable amount of sources and information on the historical development of European metropolises. These sources allow for a deep understanding of the processes, which have been active in shaping urban areas since the early years of the Industrial Revolution. In order to sustainably benefit from their efforts and findings, one has to integrate them into contemporaneous urban planning and urban development concepts. The reoccurring and seemingly random effects of exogenous shocks represented by wars, crises or even simple development strategies have to be disentangled and assessed more carefully. Consequently, it will be possible not only to understand the respective ongoing processes but also the economic forces behind them. Modern methods should allow for more reliable models, which help to uncover and to quantify working forces and causalities.

Following this idea, the first sections (2 and 3) of this work aimed at presenting the knowledge acquired by historians in order to convey descriptive evidence on the historical development of the city within the aforementioned time period. Section 4 provided a state-of-the-art overview of seminal works and relevant *Urban Economics* literature regarding the theories of spatial urban transformation and the driving forces responsible for the dynamics, which may lead to new spatial equilibria. Starting from section 5, detailed analyses were conducted in order to measure, quantify, and analytically explore the actual effects of the most important events on the city. By exploring the economic and spatial development of Berlin, Germany, over a period which covers the foundation of the German Reich in 1871 as well as the years shortly before World War II, it is possible to assess a whole battery of exogenous shocks on an urban structure and spatial equilibrium which had grown and manifested itself over many centuries. Observing the effects step by step and within an environment of enormous city growth delivers a unique degree of detail, which could hardly ever be obtained by applying the conducted studies to the quite static urban structures of contemporaneous cities.[48]

5.1 sets the staring point by implementing a measure of urban centrality in terms of market access generated by a city's inhabitants. Standard approaches dating back to Harris (1954) were extended by introducing the effective accessibility of each of Berlin's 15,937 statistical blocks, which was generated by the public transit system. By visualizing the results in Figures (6) and (7) it could be shown which parts of Berlin benefited most from infrastructural developments in terms of market access. The ongoing decentralization of residents and employment was obviously facilitated and strengthened by a constantly expanding network of rapid transit lines. Building on these findings, 5.2 introduced a data set of commercial land values of the most important sub-

[48] Exceptions to this statement might be found in recent studies regarding the rapid urbanization processes in Asian regions, especially China (e.g. Deng *et al.*, 2008; Lichtenberg and Ding, 2009; Zhao, 1999).

centers for the time period between 1890 until 1936. It could be shown how, in a gradually decentralizing environment, those areas that present advanced accessibility in terms of market access are most likely to undergo an excellent development. While the area around the Kurfürstendamm was identified as the strongest sub-center in terms of land valuation over time, powerful evidence could be found that large initial advantages regarding private investment and created connectivity most probably could account for this development. In a micro setting it became clear that those blocks which exhibited the most attraction in terms of advanced market access were to form the very core of the new center. They represented the one point where relevant spill-over effects started and where cumulative causation led to strong agglomeration forces. These results strongly underlined theoretical implications which point towards the major importance of market access in shaping economic environments.

To address the more detailed question of which marginal benefits for individual plots of land can be directly derived from advanced accessibility, section 5.3 offered two approaches. First, it was assessed how, in a decentralizing urban economy, premiums are paid for additional stations within the immediate proximity of properties. It was found that for the period between 1890 and 1936 commercially used plots experienced an average increase of 2.23% per 100 meter reduction in distance to the closest station. Probably owing to the historical setting, the estimates were much higher compared to contemporaneous studies. This finding underlines the additional insights that can be gained by choosing historical settings for urban research settings. The second approach estimated the marginal value of travel time reductions experienced by plots over time. It was found that a one minute reduction of travel time to the CBD yielded an average increase in prices of 13.5%. The findings of 5.3 strongly support public infrastructure's role in promoting economic decentralization and are consistent with cross-sectional estimations of 5.4.

While the previous sections offered analytical and quantified evidence for processes of decentralization, section 5.4 aimed at assessing to which extent they contributed to a possible break-up of the historically evolved monocentric structure. To this end, it was tested whether the traditional monocentric model is suitable for describing the urban structure over time. In the last decades, several measures and approaches have been developed to identify a city's spatial structure to answer the question at exactly which point monocentric structures break and at which point they can be referred to as polycentric urban areas. The results revealed an initially extraordinarily steep land gradient of 77.5% that flattened out over time to reach 39.7% by the end of the research period. A higher variation in land values, especially in those further away from the CBD, and a possibly stronger influence of decentralized location amenities significantly weakened the gradient and the coefficient of determination until 1936. However, after controlling for omitted location-specific variables by applying a spatial autoregressive regression, it could be concluded that the monocentric model was well suited to explaining the city structure until the beginning of World War II. By combining this analysis with the results of the calculated travel time gradient it became clear that the observed overall processes of economic dispersion were largely promoted by the expanding rapid transit network. In a subsequent counterfactual scenario, the quantified contribution of the network in fostering the dispersion was estimated to be about 50%.

The collection of historical data is time-consuming and complicated. Trying to process and fit them into modern models and technical environments of *Urban Economics* is often complicated by a lack of accessible data or a lack of spatially disaggregated detail. However, the huge additional benefits for modern urban planning stemming from these efforts are not to be underestimated. Over the past few centuries, the city has become increasingly important as a living space. Today, cities account for more than three billion inhabitants, roughly half of the world's population. This figure is expected to grow rapidly to 60% in 2030 and 70% in 2050, according to UN forecasts. Given the increasing importance of cities as clusters of economic activity, the internal structure of cities has attracted scholarly interest. Urban planning authorities are in a constant search for means to control and direct city growth in order to account for social equity and a sustainable consumption of resources. Public transport infrastructure has a central role in this thought process. It has to simultaneously guarantee the basic provision of public services and promote economic growth and wealth for expanding urban areas. In order to relieve main roads across urban agglomerations and to counteract increasing congestion costs and energy consumption, strategies counterbalancing the ratio of well-planned mixed-use areas and areas benefiting from major agglomeration forces have to be developed and implemented. While directed land use regulations are capable of shaping the internal geography of residentially used plots and quarters, simultaneously applied public infrastructural strategies must serve to increase the economic attractiveness of focal areas. By this means, an evolved plan outweighing the advantages and disadvantages of the concepts of directed urban centralization and directed urban decentralization might sustainably promote a higher quality of living within urban areas.

However, in order to be able to better anticipate the consequences of future planning models and strategies, it will be indispensable to have recourse to a great variety of natural experiments helping to minimize possible, devastating effects of major miscalculations. Reference to the past of European metropolises, especially to the period of the Industrial Revolution, offers a great opportunity to empirically assess the effects of conducted major urban planning projects and to use the valuable experiences for contemporaneous models and concepts. Consequently, the quite sophisticated modern methods used in the exploration of urban areas have to be applied to a historical context in order to identify and empirically assess the forces at work. This work tried to give a first detailed preview of future possibilities and future knowledge to be gained by exploring the spatial transformation of cities in a historical context.

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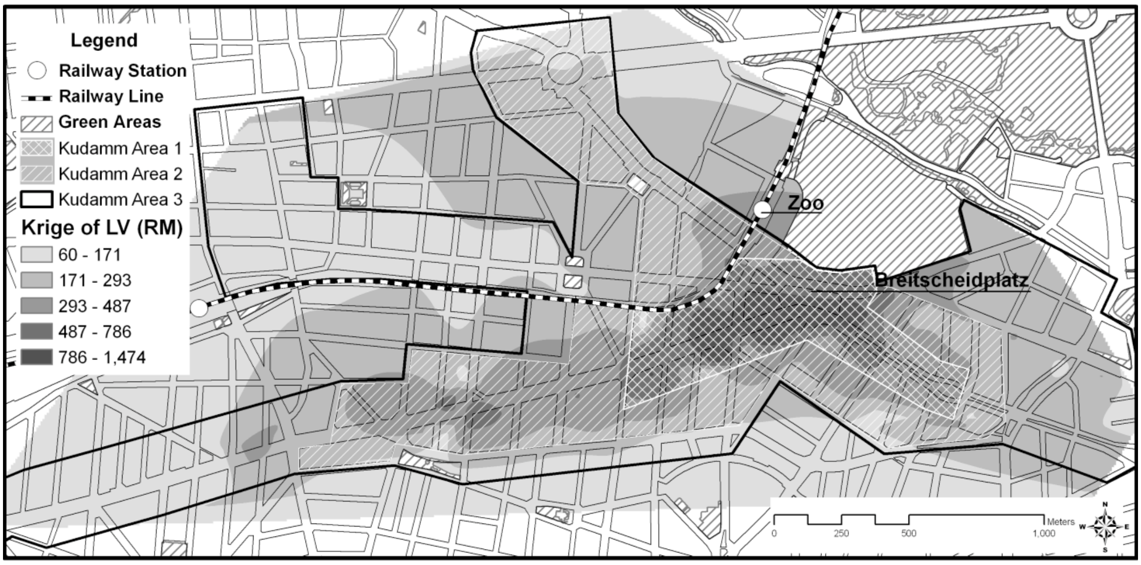
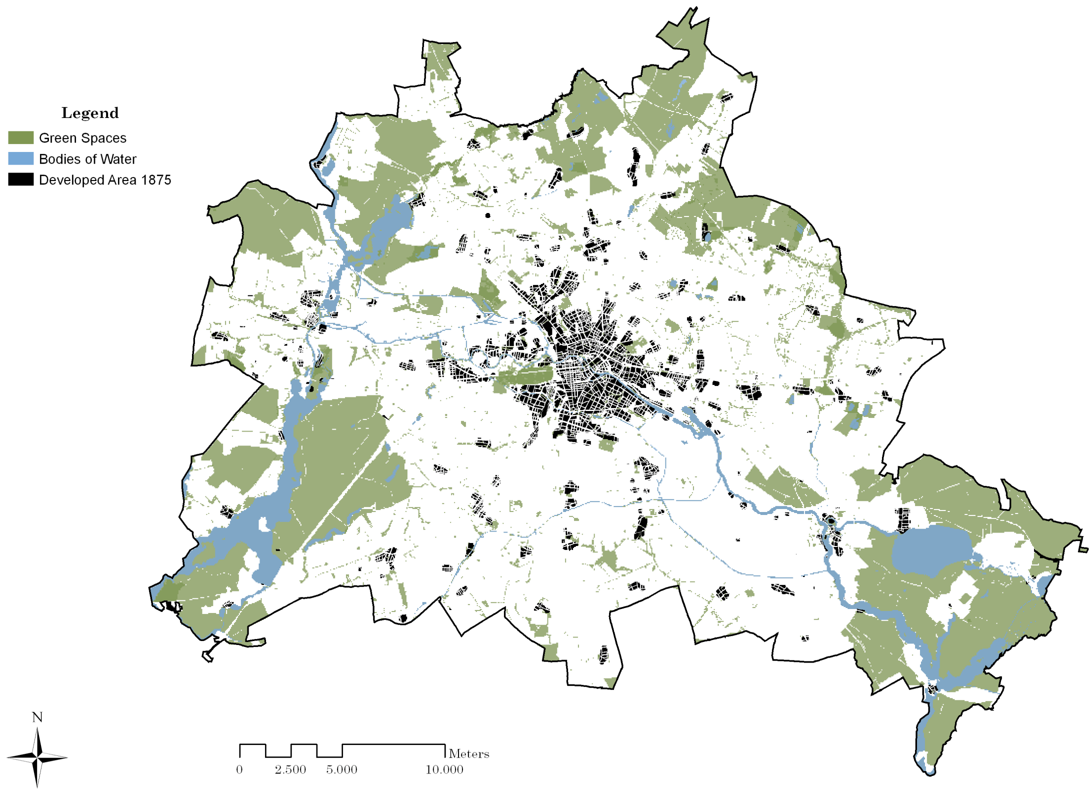
8. Appendix

Fig. A 1Definition of Kudamm Areas and Kriged *SLV* 1929



Source: Urban and Environmental Information System of the Senate Department of Berlin (2006).

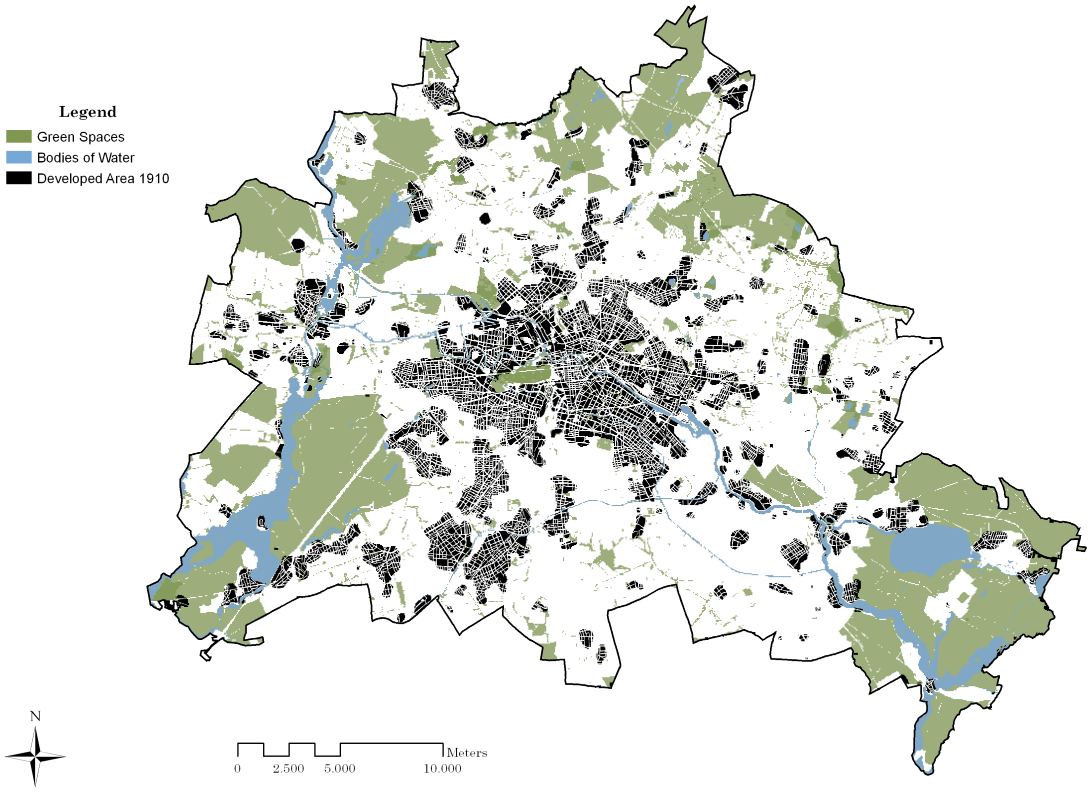
Fig. A 2Built-up Area in 1890



Notes: The area has been assigned to the official block structure.

Source: Own illustrations. Urban and Environmental Information System of the Senate Department Berlin (2006).

Fig. A 3 Built-up Area 1910



Notes: The area has been assigned to the official block structure.

Source: Own illustrations. Urban and Environmental Information System of the Senate Department Berlin (2006).

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Dissertation selbständig verfasst und keine anderen als die angegebenen Hilfsmittel verwendet habe. Alle wörtlich oder inhaltlich übernommenen Stellen habe ich als solche gekennzeichnet.

Die Dissertation ist bisher keiner anderen Fakultät vorgelegt worden.

Ich erkläre, dass ich bisher kein Promotionsvorhaben erfolglos beendet habe und dass eine Aberkennung eines bereits erworbenen Doktorgrades nicht vorliegt.

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Research / Revise and Resubmit

“Fifty Years of Urban Accessibility: The Impact of Urban Railway Network on the Land Gradient in Industrializing Berlin (JOURNAL OF URBAN ECONOMICS, with G. Ahlfeldt)

“Spatial Determinants of CBD Emergence: A Micro-level Case Study on Berlin” (EUROPEAN PLANNING STUDIES, with G. Ahlfeldt)

Research / Presentations

“Fifty Years of Urban Accessibility:
The Impact of Urban Railway Network on the Land Gradient in Industrializing Berlin“
(ETH Zurich, Swiss Economic Institute, Research Seminar, October 06, 2008)

“Fifty Years of Urban Accessibility:
The Impact of Urban Railway Network on the Land Gradient in Industrializing Berlin“
(Verein für Socialpolitik, September 10, 2009)

“Fifty Years of Urban Accessibility:
The Impact of Urban Railway Network on the Land Gradient in Industrializing Berlin“
(Darmstadt University of Technology, EGIT, January 2010)

Research / Expert Reports

“Where Do They Rule? Location and Relocation of Headquarters across Switzerland”
(Report on location decisions of firm headquarters. Initiated by the Swiss Economic Institute, Zurich 2008)

Referee
Spatial Economic Analysis (SEA)

LANGUAGES

- German: Native
- English: Spoken: fluent; Written: fluent
- Spanish: Spoken: fluent; Written: fluent
- French: Spoken: advanced; Written: advanced
- Turkish: Spoken: basic; Written: basic
- Latin: 9 Years Experience