Gabriel M. Ahlfeldt and Nicolai Wendland

Fifty years of urban accessibility: the impact of the urban railway network on the land gradient in Berlin 1890-1936

Article (Accepted version) (Refereed)

Fifty Years of Urban Accessibility: The Impact of the Urban Railway Network on the Land Gradient in Berlin 1890-1936*

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

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

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

– FORTHCOMING IN REGIONAL SCIENCE AND URBAN ECONOMICS –

Abstract: As the first to use an archival data set on historical land values in Berlin, Germany, from 1890 to 1936, we investigate the impact of the rapid transport system on urban decentralization, using comparative statics of classical rent theory as a benchmark. We find that the monocentric model performs well over the entire period studied, revealing gradients that – although diminishing over time – turn out to be relatively steep in international comparison. Travel time to CBD measures incorporating the rapid transport network, however, clearly outperform traditional distance to CBD measures in terms of explanatory power. The evolution of the rapid transit network, and the subsequent changes in travel times to the CBD, explain almost three quarter of the overall trend in decentralization. Endogeneity concerns are addressed in an IV framework using a counter-factual transport network as an instrument.

Keywords: *Transport Innovations, Land Values, Location Productivity, Economic History, Berlin*
JEL classification: *N7, N9 R33, O12*
Version: *September 2010*

* We thank Stephen Redding, Daniel Sturm and Nikolaus Wolf for excellent research environments in Berlin and London. We acknowledge the hospitality of the CEP at the London School of Economics, where a considerable part of this research was conducted. We thank Edward Glaeser, Daniel McMillen, Volker Nitsch, Stuart Rosenthal, Daniel Sturm, and two anonymous referees for very helpful comments. We furthermore thank the participants of the KOF research seminar (ETH Zurich), the conference of the German Economic Association (Magdeburg), the EGIT (Darmstadt), and the Mega-Projects conference (Berlin) for fruitful discussions. Ahlfeldt also thanks the KOF of the ETH Zurich for its generous hospitality. We are deeply indebted to Andreas Matschenz from the Landesarchiv Berlin, who provided us with invaluable material and support.

1. Introduction

Accessibility is one of the most striking determinants of urban structure. Both early rent theory (Alonso, 1964; Mills, 1969; Muth, 1969), as well as more recent polycentric models, acknowledge the trade-off between transport cost, and access to firms, employment opportunities, employees, and customers, from which land values emerge. Some of the largest shocks to urban accessibility patterns and, hence, potentially to land values occurred during the second half of the 19th century in many cities in the industrialized world. Emerging railway networks defined completely new patterns of accessibility and travel behavior. In this realm we use a new archival data set on commercial land values to investigate the case of Berlin (1890-1936), one of the most important and fastest growing cities in continental Europe, during the period of industrialization. We exploit a period where the rapid transit network, consisting of numerous metro-rail and suburban railway lines, was largely established as the backbone of urban transport and considerably reduced travel time and cost. As shown in our analyses, Berlin represented a typical monocentric city that can be investigated within the framework of traditional rent theory. Based on standard comparative statics of the monocentric model we hypothesize that a) there was significant decentralization over the time studied in terms of *distance* to the CBD, b) there was less decentralization in terms of *travel time* to the CBD and c) decentralization in terms of distance can partially be explained by travel time reductions.

We highlight that we contribute to a still relatively limited body of evidence. There is a long tradition of empirically testing the theoretical predictions of the monocentric economy. However, due to severe data limitations, the majority of studies have been conducted on the basis of population density measures (e.g. Clark, 1951; McDonald, 1989; McMillen, 1994) - although, arguably, the estimation of a bid-rent curve on the basis of land values represents the most direct way of testing the monocentric city model. Effectively, there is still very little evidence available using historical land values outside the U.S. or, more precisely, outside Chicago.[1] The rich body of excellent studies using the historical land value data for Chicago is owed to two unique data sources; “100 Years of

---

1 Further studies exist for Sydney, New York, and Cleveland.

Land Values", by Hoyt (1933), who provides land values on square mile tracks from 1836 to 1928, and "Olcott's Land Values Blue Book of Chicago", presenting annual estimates for land values at block level since the early 1900s. Aside from these, hardly any comparable data sources could be found in the literature.[2] The new archival data for Berlin, Germany, used in this study, is comparable in quality to that for Chicago and is even somewhat more detailed. It is taken from precise city maps at the level of individual plots (1890-1910) and extensive street indices (1928-1936). After digitizing and geo-processing these sources for use in empirical analyses, we are able to add evidence to the evolution of city structure for one of the most dynamic cities in continental Europe during the period of industrialization. In particular we provide evidence for a city with a much longer history and therefore a more established city structure than the few cities for which evidence is currently available. Our case is also unique in the sense that we investigate a capital city with numerous administrative entities that increase the relative importance of the CBD. Most importantly, our analyses make use of digitally-processed network plans, tracking the evolution of the urban rapid transit system, whose level of detail is unique in an historical context. Additionally, we construct a counterfactual least distance network based on exogenous planning objectives, which we use as an instrument in a 2SLS IV strategy in order to address possible endogeneity. The data set is presented in the next section followed by the empirical analyses. First, we review standard land gradient estimates for our study area in the realm of international evidence (section 3). Second, we provide evidence in support of our three hypotheses described above (section 4). The last section concludes.

2. Historical Background and Data

2.1 Industrializing Berlin 1890 – 1936

At the study's starting point, Prussia in general, and especially Berlin, had entered the second phase of industrialization. As is typical for industrializing regions, the revolutio-

---

[2] Among the studies using the Hoyt data, Kau and Sirmans (1979), McDonald and McMillen (1990), McMillen (1990), McMillen et al. (1992), McMillen (1996), and Mills (1969) feature most prominently. Data from "Olcott's Land Values Blue Book of Chicago" has been used by Bednarz (1975), Berrry (1976), McDonald and Bowman (1979), McDonald (1981), McMillen (1979), McDonald and McMillan (1990), McMillen and McDonald (1991), Mills (1969), and Yates (1965).

nary changes in production technologies generated enormous demand for a larger labor force, drawing peasants and villagers into the fast-growing cities. In addition, Berlin, after 1871, held the status of the capital for both Prussia and the German Reich, which was formed after the victorious French-Prussian war. This required the building of a variety of new administrative entities, which were incorporated into the CBD and contributed to the perceived attractiveness of that area. In particular, firms and service-oriented industries like banks and the media were drawn into its proximity with increased physical contact opportunities.

During the next few decades, a new inner-city public railway network was established within this environment of high urban concentration. In 1877, the circular line, which connected Berlin to its surroundings and to several regional lines, was inaugurated. Then, in 1882, an east-west connection joined several inner city stations with the circular line (Borchert, Starck, Götz, & Müller, 1987). But, this was only a first step in generating inner-city travel systems and it was not for several decades, that gradually added stations created a highly developed, and very dense, network that fundamentally changed the pattern of urban accessibility. The new network provided the opportunity for firms and households to settle in geographically less central boroughs without losing the privilege of excellent accessibility to the core.

Another very influential effect on the urban reorganization process was triggered by the so-called Hobrecht Plan, which aimed at a spatial restructuring of streets and boulevards as well as the provision of large amounts of new residential areas around the very core (the "Wilhelminian Ring").[3] However, the allocation of economic activity within that area was not explicitly influenced by zoning policies. The development of business areas was largely determined by the market (Richter, 1987). The effects of city growth, productivity gains and reduced commuting cost led to constantly increasing levels of land valuation until 1914 (Kalweit, 1928; Leyden, 1933). While World War I hardly affected Berlin's housing stock, since the epicenter of combat operations was far away, the troubled economic environment and the hyper-inflation until 1923 complicated the assessment of land-related, fair market values. By 1928 capital markets had largely sta-

[3] For details see Hegemann (1930)

bilized facilitating a reassessment of land values. However, prices had only reached pre-war levels in a few locations before another notable downward adjustment occurred, as the economy entered a period of decline and rising unemployment. The subsequent price stop was imposed by Hitler at the end of 1936 in order to impede another inflation and therefore did not affect our data.

2.2 Land Values

In a similar way to McMillen (1996) we restrict our sample to commercial land values. Our results can therefore be interpreted strictly with respect to businesses, which are typically assumed to discount distance to the CBD more strongly than households. Commercial areas were manually extracted and digitized from a city map created by Bruno Aust (1986), which displays real land uses at the individual plot level for a large part of Berlin in 1940. We obtained 1718 commercially used plots within a 9 kilometer radius around the city center. Due to huge losses of raw data, caused by the two wars, the identification of reliable information on land values, covering a sufficiently long time period, proved to be challenging. However, two valuable sources could be retrieved from Berlin's historical archives. The first was created by the renowned technician Gustav Müller (1881-1910). In cooperation with official planning authorities he presented a collection of very detailed colored maps. These maps were presented in a similar way to Olcott's land values, which contributed to Chicago becoming a unique laboratory for Urban Economics in an historical context. Müller's maps provide data at an astonishingly disaggregated level of individual plots. The stated objective was to provide official and representative guides for both private and public investors participating in Berlin's real estate market. While Müller himself did not explicitly reveal the exact procedure of land valuation, the imperial valuation law (Reichsbewertungsgesetz) of the German Reich contained a strict order to use capital values for the assessment of commercial plots based on fair market prices. In line with the valuation laws for commercial land, Müller claims that his assessment refers to the pure value of land, which is adjusted for all building and even garden characteristics. He also corrects for specific location characteristics such as single and double corner lots, subsoil and courtyard properties. The maps cover an area of similar scope to Bruno Aust's (1986) map on land uses. After scanning and geo-referencing Müller's maps within a GIS environment, land values were assigned to commercial areas, gathering a total sample of 8,101 observations for the years 1890, 1896, 1900, 1904, and 1910.

The second source was created by Ferdinand Kalweit (1928, 1936). He was the first to provide detailed information on land prices in Berlin after Müller. In his function as a chartered building surveyor ("gerichtlich beeideter Bausachverständiger"), he offered great expertise regarding land valuation procedures, and received a government assignment in order to overcome the lack of documentation created by the troubled environment of WWI and hyperinflation. Kalweit´s work resulted in two books containing land values for all streets in the city in 1928 and 1936. Like Müller, he followed the explicit rules of the imperial valuation law. He additionally considered information on real sales as a basis for local adjustments. After controlling for subsoil property and location characteristics, he assigned representative minimum and maximum values of the pure land value to each street. These street stretches were frequently larger than single commercial areas and often contained non-commercial uses. To the extent possible, we applied consistent rules in order to identify the provided land value information as precisely as possible. First, we assume that within residentially and commercially used streets, Kalweit's upper bound estimate refers to commercial use. Second, if provided values referred to very long road stretches, land values at sub-stretch level were gathered by considering values assigned to crossing roads. In addition, a colored map for 1938, prepared by Runge (1950), which shows many similarities to the Müller maps, served as a guidance. Runge received an official assignment from authorities after WWII in order to provide an overview of land values based on the pre-WWII situation. Due to a lack of comprehensive documentation, this map was not considered a primary source in the analyses but nevertheless provided valuable information and crosschecks on the spatial structure during the interwar-period. The extracted Kalweit data provide an additional 3,420 observations, so the whole sample of historical land values amounts to 11,521 observations. Table 1 provides summary statistics that reflect the historical evidence laid out in the previous section, in particular the positive and negative trends before and after WWI.

TAB 1 ABOUT HERE

A brief description of data used in studies that we consider as benchmarks for our results follows. The most impressive data set so far has been used by McMillen (1996). Within the period until 1928 it is taken from Hoyt (1933) who provides the values of square mile tracts between 1836 and 1928, ranging from 94 to 148 observations each year. From 1960 to 1990, McMillen uses commercial land values, published in Olcott`s book on land values. The detailed block level allows for 696 to 721 observations each year. Smith (2003) uses a random sample of plot sales for his survey on Cleveland. This mostly consists of residential areas totaling 61 to 125 observations a year between 1915 and 1980. New York data (Atack & Margo, 1998) are based on the prices of vacant land published in newspapers and provide 72 to 208 observations for the years 1835 to 1900.[4] For a more recent period, from 1931 to 1989, Abelson (1997) uses a sample of randomly selected residential areas within Sydney's 22 local government regions, ranging from 1800 to 4400 observations.

2.3 Railway Network

The generation of a travel-time based, centrality indicator that accounts for transport infrastructure basically consisted of three steps. First, we traced back the evolution of the city's complete public railway network including up to 222 stations, over the course of our study period in order to form digital maps.[5] The total length of the network, as calculated within a GIS environment, amounted to more than 410 kilometers in 1936, which is close to the same size of the contemporary network (475 km). Second, representative velocities needed to be defined for train and non-train trips as a prerequisite for the calculation of travel times. Historical network plans provided information on bilateral travel times between adjacent stations, separately presented for the suburban railway and metro lines. Summing up the indicated trip times (in minutes), and merging them with our replicated digital network, yields an almost constant average train veloci-

---

[4] Due to direct taxation on property sales, Atack & Margo (1998) state that published prices may be biased. Another interesting work on New York stems from Margo (1998), who exploits rental prices of housing in New York City from 1830 to 1860 and finds that the relative price of housing rose in that period.

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

ty of 33.8 km/h over the complete period for both suburban and metro rail lines. Unfortunately, it is hard to avoid some arbitrariness in the definition of non-train related trip velocities. On the basis of an approximation of the modal split, based on historical sources, we set a speed of 1/3 of the calculated train velocity to reflect a combined average speed of walking, bus- and streetcar-rides, while at the same time keeping our models as simple and comprehensive as possible.[6] Third, following Ahlfeldt(2010), the actual travel times from our predefined commercial areas to the identified CBD were calculated as the fastest combined train and non-train network trip, taking the abovementioned velocities as given. 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 for the whole trip. If they choose rapid rail transit, their journey consists of a combined network path of a non-train trip to the next station, and a combination of a train ride along the network with a final non-train trip to the city center, which minimizes travel time.

3. Land Gradient Evolution in International Comparison

This section provides estimates of historical land gradients in Berlin, which are discussed against the background of international evidence. The point of departure for our empirical analysis is the standard monocentric city model in which firms bid higher prices for land closer to an exogenous CBD due to lower transport costs and/or travel time savings (Alonso, 1964; Mills, 1969; Muth, 1969). Evidence suggesting that land values (*LV*) 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 & Margo, 1998; Kau & Sirmans, 1979; McDonald & McMillen, 1990; McMillen, 1990, 1996; McMillen et al., 1992; Mills, 1969; Smith, 2003). The exponential functional relationship is usually estimated using the well-established log-linear specification.

[6] Historical sources report a relative high velocity due to a dense network of streetcars and buses – even in peripheral areas. In 1934, 72 streetcar lines covered 638 km and bus lines summed up to 343 km (Beier, 1990; Bley, 2003; Borchert et al., 1987; Dittfurth, 1993; Hoffmann-Axthelm, 1982).

$$\log(LV_{it}) = \alpha + \beta\ distCBD_{it} + \varepsilon_{it} \quad (1)$$

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 kilometer away from the CBD and ε_{it} is an error term satisfying the usual conditions. As the gradient node – the CBD – we choose a point on the prestigious Friedrichstrasse, halfway to the famous boulevards Unter den Linden and Leipziger Strasse. The continuing centrality of this location is reflected by the nearby metro station "Stadtmitte" (downtown).[7]

Table 2 shows parameter estimates corresponding to equation (1). In line with the predictions of the monocentric model, our estimates yield significant and negative coefficients on distance to the CBD (*distCBD*) and suggest a steeply descending land gradient during the period of observation, flattening from a 75.5% decrease per kilometer in 1890 to 35.9% in 1936. LM-tests for spatial dependency indicate the presence of a limited degree of spatial autocorrelation. Since test scores reject the spatial lag-model in favor of an error-correction model, spatial dependencies are most likely to be caused by omitted variables correlated across space or spatial measurement errors (Anselin & Bera, 1996). Application of spatial error correction models, however, yield qualitatively similar results.[8]

TAB 2 ABOUT HERE

---

[7] We also employed a more flexible specification estimating the gradient node as a function of geographic coordinates. However, we did not find a systematic variation in the location of these estimated centers, with nodes located within 0.6 km (0.375 miles) of our CBD proxy in all years. The following specification has been estimated using a non-linear, least squares estimator, 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*. $\log(LV_{ti}) = \alpha - \beta\ ((X^{CBD} - X_{it})^2 + (Y^{CBD} - Y_{ti})^2)^{0.5} + \varepsilon_{ti}$. Results are available from the authors.

[8] We chose a row-standardized weights matrix (W), where transactions within a distance band of 300 meters are treated as neighbors. This weights matrix provides the best fit compared to alternative specifications and minimizes the Akaike and Schwarz criteria. Exemplarily, LM test scores (p-values) for 1890 are: LM_{lag} = 0.000, LM_{error} = 0.000, robust LM_{lag} = 0.256 robust LM_{error} = 0.000, which indicate the appropriateness of estimating a spatial error model. Formally, the error correction model that we estimate, employing a maximum likelihood estimator, corrects for the spatial structure of the error term in equation (1) as follows: $\varepsilon = \lambda\varepsilon + \mu$, where, μ is an independent and identically distributed vector of error terms. Results, however, remain qualitatively unchanged and are available from the authors.

Besides the evident decentralization reflected in a decrease in the marginal value of being located closer to the CBD, it is notable that the model fit in Table 2 declines considerably after 1910, indicating either that the monocentric structure of the city was breaking up, or that omitted location characteristics account for a larger spatial variation in land values.[9] In addition to the distance to the CBD, the productivity of commercial land, the quality of public services, as well as land taxation are mirrored in land values. Therefore discontinuities in the land gradient may arise at the boundaries between intra-urban jurisdictions. Greater-Berlin, during the study period, comprised of numerous communities (Ortsteile) whose authorities were encouraged to set up services and taxes locally (Richter, 1987). In order to account for potential discontinuities, we re-estimate equation (1) including fixed effects for up to 48 communities within our study area.[10] Results are presented in Table 3. In comparison to Table 2, gradients are slightly flatter, but the degree of decentralization over time remains almost the same. From 1890 to 1936, the marginal value of being located 1 kilometer closer to the CBD accordingly diminishes from 73.8% to 30%. Notably, the coefficients of determination increase for all years, with the by far most substantial changes occurring in 1929 and 1936. These results indicate that, even in the mid 20th century, proximity to the CBD, together with community specific characteristics, account for three quarters of the spatial variation in land values.

TAB 3 ABOUT HERE

As noted, the majority of empirical tests of the monocentric city model have been conducted on the basis of population density measures (e.g. Clark, 1951; McDonald, 1989; McMillen, 1994). Besides being general supportive with respect to the overall implications of the model, these studies yield some specific results. Accordingly, larger cities

---

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

[10] It's noteworthy that during the 1920's a prominent sub-center emerged along the boulevards Kurfüstendamm and Tauentziehnstraße, which later grew to the centre of West-Berlin during the post-war division period. We run unpublished robustness checks where we, following Ahlfeldt & Wendland (2009), extend the baseline specification by a dummy variable denoting the area within 1 km of Breitscheidplatz. While the resulting coefficients are positive and statistically significant, in particular after 1910, the point estimates for the gradient coefficients only change at the third decimal place.

exhibit flatter gradients – possibly due to decentralization of economic activity – while densities in older cities tend to be more concentrated towards the downtown areas. Due to the limited evidence, very few attempts have been made to estimate historical land gradients outside Chicago. The few exceptions include U.S. cities (Cleveland and New York) and Sydney. In this context, the case of Berlin is particularly valuable, because it adds evidence not only for the first European city, but also for a city with a particularly long history and the first capital city with important governmental institutions within the boundaries of the CBD. Table 4 compares the existing international evidence for historical land gradients. In line with the evidence for Chicago (McMillen, 1996), Cleveland (Smith, 2003), New York (Atack & Margo, 1998) and Sydney (Abelson, 1997), we find a flattening gradient and decreasing coefficients of determination over time. Notably, our estimated decay coefficients are larger compared to most previous studies, including 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. Very high transport costs, which could be typical for relatively old cities, in principle, could account for such a dense concentration. However, this explanation is not very persuasive since following the implementation of the Hobrecht plan Berlin possessed a network of spacious boulevards and, at least by the end of the observation period, a well-developed public transport network, which will receive more attention in the next section. The relatively steep gradient estimates are also unlikely to be explained by the size of the city since Berlin does not feature among the particularly small cities considered in Table 4. While for the available years, gradient estimates are comparable to Cleveland, Berlin, in terms of population, exceeded the city of Cleveland by roughly a factor of five.[11] In contrast, although Berlin and Chicago were roughly of the same size during the study period, the magnitude of gradient estimates is much larger for Berlin than for Chicago. However, there are at least two aspects that distinguish Berlin from the other cities in Table 4 – its relatively high age and its role as a capital city. Notably, the CBD by the end of our observation period, hardly exceeded the boundaries of the historic downtown district established hundreds of years ago (Elkins &

[11] Population in 1900: Berlin, 1,888,848; Chicago, 1,698,575; Cleveland, 381,768; New York, 3,437,202; Sydney, about 500,000.

Hofmeister, 1988; Leyden, 1933). The particular importance of being located close to the CBD in Berlin might therefore be related to both its historically established position and the various administrative entities that concentrated within the CBD boundaries, as the city held the status as capital for both Prussia and the German Reich. More studies investigating land gradients in historic cities are desirable to affirm this notion.

TAB 4 ABOUT HERE

4. The Impact of Accessibility

In this section we turn our attention to some simple hypotheses derived from the monocentric city model regarding the adjustment of land values to travel cost reductions: a) A reduction in transport cost relatively increases the bids for parcels of land in the urban periphery at the expense of central locations, which is mirrored in a flattening land gradient in terms of *distance*. b) Assuming that perceived transport cost are largely determined by the opportunity cost of travel time, the decline in the marginal benefit of being located closer to the CBD over time will be lower in terms of *travel time* than in terms of *distance* if transport innovations are a significant driving force of the overall decentralization process. This implies a flattening of the land gradient that is less pronounced in terms of *travel time* than in terms of *distance*. c) Under the assumptions made, the evolution of *travel time* will explain a significant proportion of the overall decentralization process in terms of *distance*, which in turn means that in the absence of transport innovations the city would have experienced a lower degree of decentralization.

Distance vs. travel time

As noted, Berlin during the study period makes a good case for testing these hypotheses, as the peak time of industrialization brought forth the implementation of the rapid transport network, which exhibited a pronounced impact on accessibility along its lines. Figures 1 and 2 illustrate how, in terms of travel time, the CBD became more accessible from remote locations and the concentric form of CBD-accessibility broke up into a more complex pattern. Note that the travel time measure strictly refers to the fastest journey to the CBD whereby agents are allowed to choose whether to use rapid transit lines for a part of the journey or not. As 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 should essentially be affected by these major transport innovations.

[FIG 1 ABOUT HERE]

[FIG 2 ABOUT HERE]

Addressing endogeneity

In order to assess the marginal impact of travel time to the CBD on the value of land and how the marginal impact changes over time, we substitute distance to CBD (equation 1) with the travel times displayed in Figure 2 , which yields equation (2). If focal blocks, areas, and municipalities within the boundaries of Berlin were randomly assigned for connection or connected due to considerations that were entirely exogenous to the economic development, estimation of equation (2) using OLS would yield unbiased coefficients.

$$\log(LV_{it}) = \alpha + \beta \; ttCBD_{it} + \varepsilon_{it} \qquad (2)$$

Exogeneity in this sense is supported by several historical sources, which clearly indicate the unexpected outcomes regarding the routing of many lines due to long-lasting political processes, as well as a speculative environment, in which newly establishment lines were to connect entirely unpopulated areas. The connection of the Kurfürstendamm area, which later became the major secondary center of pre-WWII Berlin, and the major center during the period of the city´s division, by the first metro-lines when the area was hardly developed at all, only represents the most striking and prominent example (Bohm, 1980; Ribbe, 1987). In many other cases the stated objective was to connect remote municipalities in order to stimulate the settlement behavior within the outer rings and the economic interactions with the CBD. However, the argument that some lines may have been built to meet already existing demand structures, which raises the intuitive concern that planners may have targeted areas with higher expected economic returns on the way between two termini, cannot completely be rejected.

To reject these endogeneity concerns, we introduce instruments for travel time to the CBD, which have to satisfy the following conditions: a) being (spatially) correlated with the measures displayed in Figures 1 and 2, b) only using variation provided by "exogenous" requirements that affected the design of the network, c) only impacting on land value via a reducing travel time, which is the identifying assumption. To meet these criteria we constructed a hypothetical minimum cost network. The rationale for the network is derived from the shortest paths (straight-line) planners could have chosen in order to connect the CBD with focal municipalities outside Berlin. Additionally, the straight lines are connected by a circular line, which is consistent with existent networks in many European cities (see Fig.A1).[12] We started with connecting 12 municipalities that lie outside the borders of even the contemporary Berlin, which were chosen to be important destinations along the suburban railway lines (Bley, 2003). Additionally, it is known that the area around the Kurfürstendamm was to be subdued in order to generate a representative boulevard for Kaiser Wilhelm. He used this formerly completely undeveloped pathway to reach one of his residences in the southwest (Schloss Grunewald). We consequently constructed another line to address this fact. The straight-line network presents a credible way to address concerns of non-random routing on the way between the CBD and focal municipalities as it is developed acknowledging the requirement of connecting the city´s centre to the closest centers outside the city. Whether a location along these straight-lines becomes connected is exogenous to its own economic development.

Under the identifying assumption that the straight-line distance to the CBD is only affecting the evolution of land values by directly influencing the effective travel times, we employ a 2SLS IV strategy where we use the following first-stage estimation equation to ensure that the error term is uncorrelated with travel times in the second stage equation (2).

$$ttCBD_{it} = \gamma_0 + \gamma_1 popd_{i,t-1} + \gamma_2 nwdist_{i,t} + \gamma_3 distCBD_i + \gamma_4 CBD \text{ x } nwdist_{i,t} + \varpi_{it} \quad (3)$$

[12] The radius of the hypothetical circular line (5.3 km) corresponds to the average radius around the CBD needed in order to connect the outer parts of the Wilhelminian Ring (see 2.1). The original circular line (1877) had been built around the Wilhelminian Ring with the intention to allow workers to settle within remote districts without losing the privilege of acceptable accessibility to the employment center.

where $popd_{i,t-1}$ indicates the 10 year-lagged population density within block i, $nwdist_{i,t}$ is the straight-line distance of block *i's* geographical centroid to the closest point of our hypothetical network, $distCBD_i$ is the distance to the CBD, and $CBD\ x\ nwdist_{i,t}$ is an interactive term including the distance to the CBD and to the network. Standard specification test suggest that OLS results would be biased and confirm the strength of the used instruments.[13] The following analyses are carried out using the predicted values for *ttCBD*.

Results based on the log-linear specification presented in the section above indicate a considerable flattening of the land gradient (in terms of *distance*) over our study period. While this functional form is well established in the literature and satisfies the convexity requirement in the negative distance price relationship predicted by urban rent theory, recent literature has made considerable advances in applying new regressions techniques that allow estimating the functional form much more flexibly (see McMillen, 2010 for a review). As noted above, our strategy of estimating the causal effect the development of the transportation network had on decentralization relies on a two-stage strategy where the availability of instruments restricts the degree to which we can allow for flexibility in our benchmark specifications. For the purpose of a descriptive analysis of the relationship between land values and distance and travel time respectively we employ a non-parametric, locally-weighted regression approach to identify how the unknown gradient functions change over time.[14]

Figure 3a visualizes the non-parametric estimates for the relationship between the log of land value, normalized to the median, and the *distance* to the CBD in kilometers for selected years. Results confirm that over the study period, peripheral areas gained in value relative to more central areas. They also show that the log-linear approximation fits best for the period from 1900 to 1910, while in 1890 there is a relatively sharp discontinuity at a distance of about 6 kilometers and gradients for 1929 and 1936 exhibit a considerable degree of convexity. A clearly negative relationship between land valua-

---

[13] The appendix provides first stage results for IV estimates (Tab.A1) as well as the test statistics Tab A3).

[14] See Ahlfeldt (2010), Cleveland & Devlin (1988) McMillen (1996, 2004) for applications of the same technique.

tion and access to the city center is also evident in terms of *travel time* (Figure 3b). Moreover, the log-linear approximation seems to fit best for 1900 and, again, there is some convexity apparent in the 1929 and 1936 gradients. In terms of decentralization, however, the picture is much less clear than in Figure 3a. While there is some relative increase in peripheral areas from 1890 to 1900, the gradients for the following years are, if at all, indicative for a modest re-centralization. Rather than to promote the appropriateness of the log-linear specification over any alternative, we view these results as descriptive evidence that the process of decentralization was less pronounced when expressed in terms of travel time than distance and that the log-linear specification provides a feasible approximation of the true functional form in the realm of our two-stage strategy, in particular when travel times are considered.

[FIG3 ABOUT HERE]

Figures 3a and 3b, thus, support our hypotheses of significant decentralization in terms of *distance* to the CBD (a) and a lower degree of decentralization in terms of *travel times* (b).[15] In order to provide a formal test of these hypotheses, we estimate the following specification using a pooled data set.[16]

$$\log(LV_{it}) = \beta \ distCBD_{it} + \sum_u \beta_u distCBD_{it} \times year_u + \varphi_{jt} + \varepsilon_{it} \tag{4}$$

Where u stands for all years included in Table 2 with the exception of 1936; $year_u$ is a dummy variable denoting year u and φ_{jt} is a full set of fixed effects denoting areas i within an "Ortsteil" (community) j in a given year t. Equation (4) is estimated both for distance to the CBD (*distCBD*) as well as using the predicted travel time to the CBD (*ttCBD*) obtained from the first-stage IV regressions (equation 3); in each case with and without fixed effects φ_{jt}.[17] Coefficient estimates for β_u that are negative and satisfy con-

---

[15] Note that Figure 3b is constructed using the predicted values taken from the IV estimates. As a robustness check we also plot the original values (*ttcbd)*, which are presented in the appendix and yield a consistent picture.

[16] A more flexible functional form (e.g. a spline) would surely be favourable to formally test for decentralization (see McMillen 2010 for a review). However, only being able to use one instrument for travel time we chose the standard exponential function.

[17] Note that if "Ortsteil" fixed effects are omitted, year effects are included instead.

ventional significance criteria are indicative of significant decentralization between year *u* and 1936.

Estimation results corresponding to specification (4) are presented in Table 5. Based on column (1) and (2) results, we can reject the hypothesis that the estimated *distance* gradients are of the same magnitude as in 1936, for all years but 1929 based on conventional significance criteria. The negative coefficients imply that significant decentralization occurred between year *u* and 1936. These results are consistently found in columns (1) and (2), revealing that our results are robust to local policies that potentially vary across jurisdictions and time. The marginal value of being located 1 kilometer closer to the CBD, according to column (1), decreased by as much as 52.5 % (58.2% for column (2)) over our study period ($\left[\beta \widehat{\times 1890}\right]/\left[\hat{\beta} + \beta \widehat{\times 1890}\right]$).

Taking *travel times* as a basis, however, we cannot reject the hypothesis that gradient estimates are of the same (or a larger) magnitude as in 1936 for all years, but 1890 and 1896. Hence, we cannot affirm any significant decentralization in terms of travel time from 1900 to 1936, which stands in strong contrast to our results obtained for the distance gradients. Again, results are consistently found whether "Ortsteile" fixed effects are considered (3) or not (4). Referring to the whole period from 1890 to 1936, the marginal value of reducing travel time to the CBD by 1 minute declined by 29.2% (column 3) or 37.1% (column 4) respectively. While the significant decentralization that occurred prior to 1900 in terms of travel time clearly points to additional driving forces for decentralization besides the reduction in travel time, we note that the results presented in Figure 3 and Table 5 are nevertheless strongly in support of our hypotheses a) and b). We also emphasize that estimates obtained using the travel time measures outperform the corresponding results obtained for distances both in terms of overall explanatory power (R2) and standard information criteria (AIC).

[TABLE 5 ABOUT HERE]

Counterfactual

In the last step of our analysis we focus on a quantitative assessment of the degree to which the transport network promoted decentralization. As noted, the dynamic environment of industrial revolution, which is reflected in a population that more than quadrupled over the study period, offers a range of alternative explanations for decentralization. Not least, the rapid city-growth caused planning authorities to decide to widen and completely restructure large parts of the city, even including surrounding communities and towns. The so-called Hobrecht-Plan was implemented in 1862 and led to far-reaching building and reorganization processes until 1914 (Hegemann, 1930). Within an area of more than 85 km^2, it created new high-density residential space combined with the concept of mixed-use development.[18] This was especially true along the representative boulevards, which in many cases led radially away from, or in circles around the old CBD and where large proportions were dedicated to commercial areas. The new development plan clearly favored the decentralization of employment, population and market opportunities.

Using again a pooled dataset, we employ the following specifications to identify the yearly change in the land gradient as a measure of decentralization, and how this measure reacts if we control for the evolution of travel times:

$$\log(LV_{it}) = \beta \; distCBD_i + \gamma \; distCBD_i \times trend_z + \delta \; ttCBD_{it} + \eta_t + \varepsilon_{it} \qquad (5)$$

where $trend_z$ is a yearly trend variable that takes a value of 0 in 1890, $ttCBD_{it}$ is the travel time to the CBD in year t at location i (predicted value) and η_t is set of year dummies. Parameter γ gives an estimate of the average yearly change in the marginal value of distance to the CBD over our study period. A positive and statistically significant coefficient, hence, indicates decentralization. Equation (5) is estimated both with and without travel times ($ttCBD_{it}$). The difference in the parameter estimates are interpreted as the proportion of decentralization that can be explained by the evolution of travel times. Estimation results are presented in Table 6. Column (1) results indicate that over the study period, the marginal price effect of proximity to the CBD declined by 0.6 percentage points per annum *(distCBD x trend).* This figure diminishes to 0.2 if travel times are introduced into the model (2). These reductions correspond to a percentage

---

[18] Area estimated within a GIS environment on the basis of georeferenced historic maps.

decline of 71.77%.[19] Analogous estimates are provided in columns (3-8) for selected observations periods. Notably, estimated γ coefficients diminish over time, revealing a declining dynamic of the decentralization process. Our estimates further suggest that the proportion explained by travel times varied considerably over time. For the period from 1890 to 1900 only a relatively small proportion of decentralization of 19.42% can be explained by the evolution of travel time to the CBD (3-4). This indicates that during this first period other factors besides the transport network might have had a more dominant effect on the spatial reorganization process. Chief among a range of potential explanations might be the realization of the Hobrecht-Plan, a major urban development plan, which amplified increasing densities at intermediate distances from the CBD (Strohmeyer, 2000), and could have dominated the effects of the emerging transport network. This relationship reverts after 1900, when the numbers raise to the considerable magnitudes of 74.97% in 1910-1936 and even 99.92% in 1900-1910, suggesting that the evolution of the transport network was one of the, if not, the key driving force of decentralization.

[TABLE 6 ABOUT HERE]

5. Conclusion

In this study we have provided evidence for the positive impact of accessibility on the productivity of commercial land, using the evolution of the rapid transport network in Berlin, from 1890 to 1936, as a case study. We have introduced a new archival land-value data-set, which is unique in terms of detail for European, historically grown, and capital cities. We have shown that a) over the study period the city experienced a considerable degree of decentralization, which was a typical phenomenon during the study period. International comparison reveals relatively steep bivariate gradient estimates, pointing to the marginal value of being located 1 kilometer closer to the CBD that diminishes from 75.5% to 35.9% over time. These gradients are steep in international com-

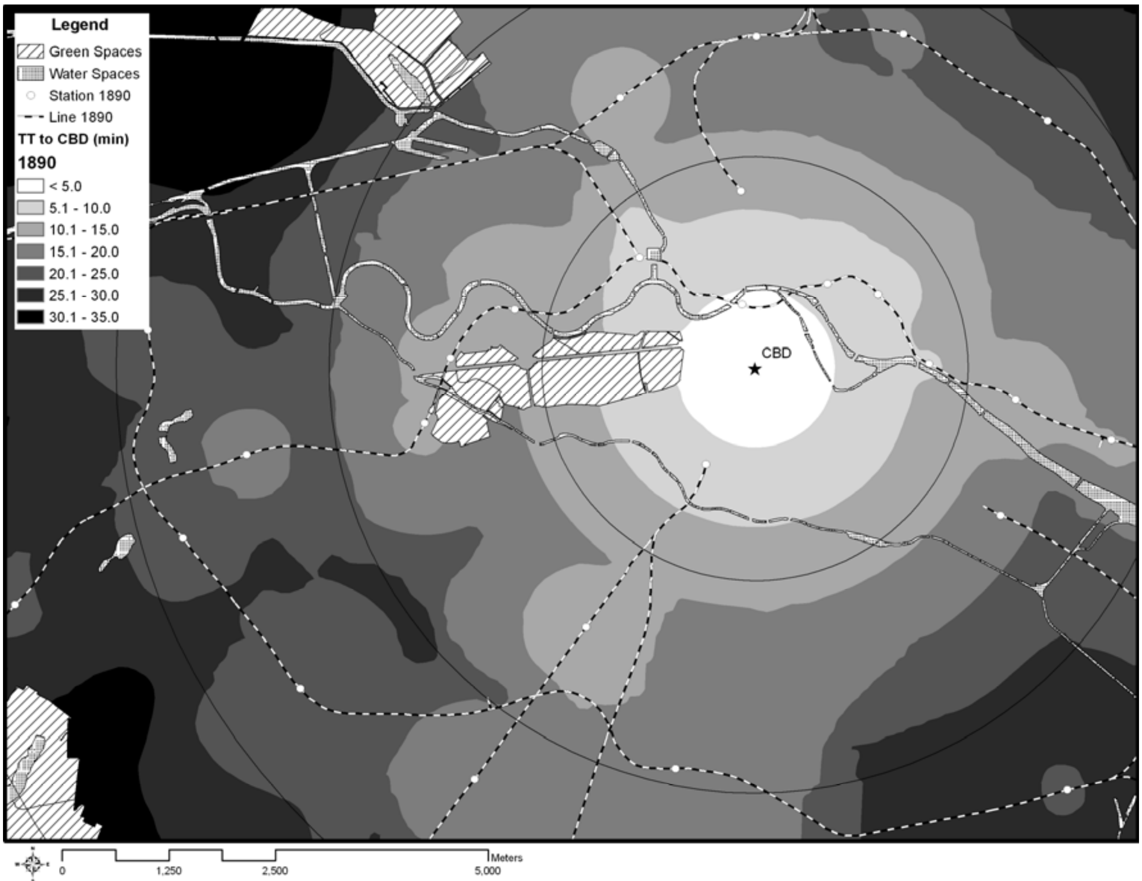
[19] The percentage decline is calculated as $(1-\hat{\gamma}_c/\hat{\gamma})\times 100$, where the $\hat{\gamma}$ $(\hat{\gamma}_c)$ is the coefficient estimate on *distCBD x trend* without (with) control for travel time (*ttCBD*) obtained from the estimation of equations (5).

parison, which is potentially explained by the more established city structure or the capital role. More cases, however, are required to affirm this notion.

Clearly, Berlin even by the mid of the 20^{th} century is well-described as an monocentric economy, as almost 75% of the variation in land value can be explained by the log-linear land gradient, if we allow for discontinuities at boundaries between jurisdictions (Ortsteile/communities) that collect taxes and provide services locally. Tracking the evolution of the rapid transit network on the basis of geo-processed historic network plans, which we instrument using a counterfactual least distance network to reject endogineity concerns, we have further shown that b) the marginal value of being located closer to the CBD diminished considerably less in terms of *travel time* (29.2- 37.1%), than in terms of *distance* (53.0-59.5%). Finally, our results have revealed that c), the evolution of *travel time* explains a significant proportion of about, on average, 71.77% of the overall decentralization process in terms of *distance.* When applying travel time measures the overall explanatory power as well as standard information criteria outperform traditional measures of distance to CBD.

In all, our results are strongly in support of accessibility as an important determinant of the spatial structure of cities in general, and as a central part of classical urban rent theory in particular. Variation in transport costs, due to improvements in infrastructure, is counterbalanced by an adjustment in land value, as predicted by theory. While almost the entire decentralization process after 1900 can be explained by reduced effective transport costs, other factors such as increasing demand for land, city growth, and urban development policies also contributed to the effective flattening of the land gradient, in particular prior to 1900.

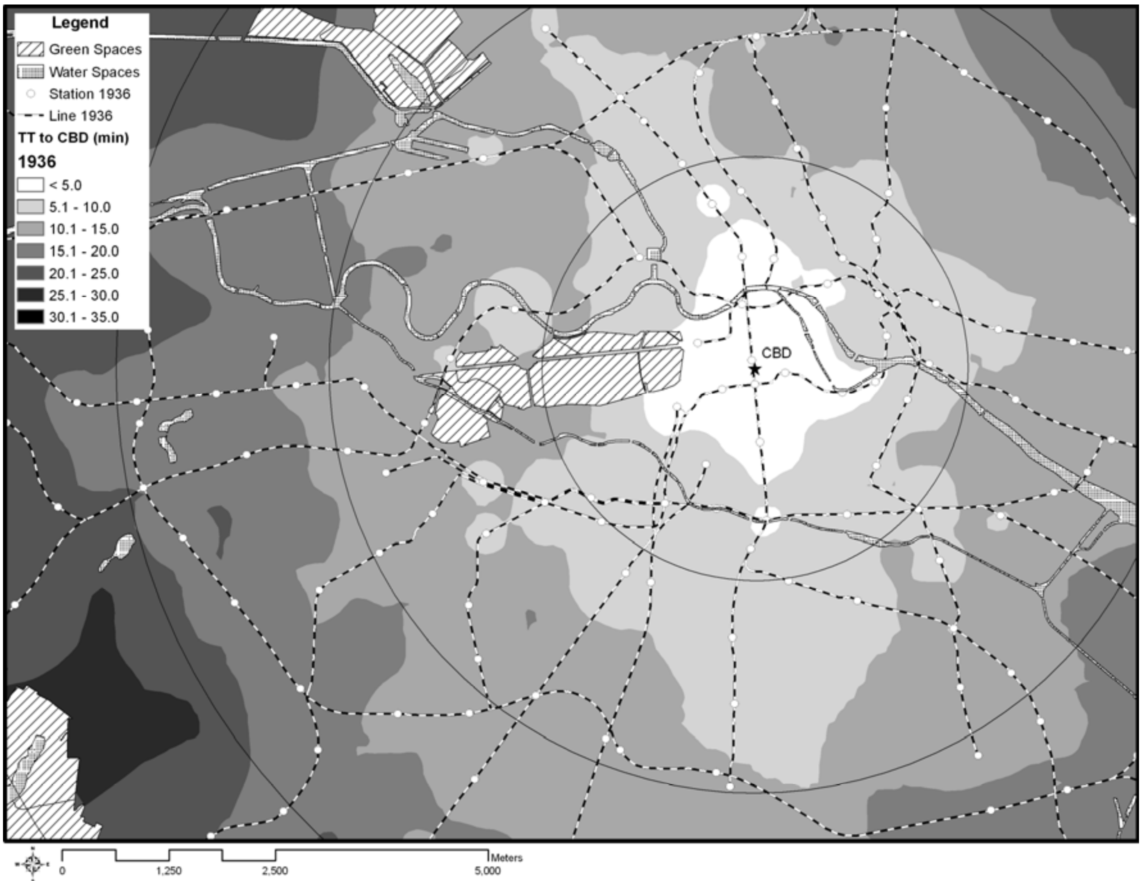
Fig. 1 Travel Time to CBD 1890



Notes: Map shows spatially interpolated travel times using ordinary kriging with a spherical semivariogram model.

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

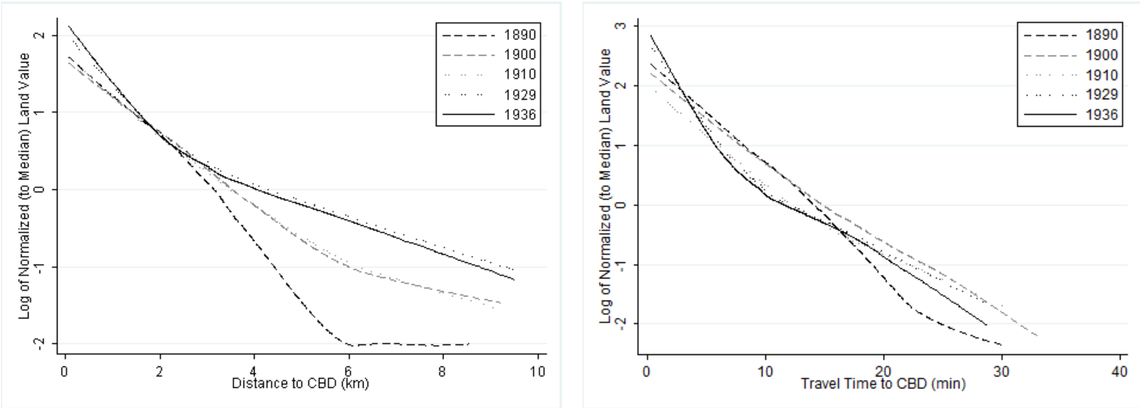
Fig. 2 Travel Time to CBD 1936



Notes: Map shows spatially interpolated travel times using ordinary kriging with a spherical semivariogram model.

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

Fig. 3 Non-parametric gradient estimates



Notes: Own illustration.

Tab. 1 Summary Statistics on Land Valuation

	1890	1896	1900	1904	1910	1929	1936
Mean	176.97	223.95	268.94	309.87	398.41	228.85	204.35
Median	100	150	168	208	278	101.67	96.67
SD	229.46	267.61	301.75	327.19	388.54	321.29	293.32
Obs.	1479	1624	1683	1686	1681	1709	1711

Tab. 2 Land Gradient 1890 – 1936 (OLS)

	1890	1896	1900	1904	1910	1929	1936
Const (α)	6.877**	6.811**	6.874**	7.000**	7.104**	6.173**	6.064**
	(0.042)	(0.027)	(0.027)	(0.026)	(0.026)	(0.042)	(0.041)
Dist. to	-0.755**	-0.566**	-0.493**	-0.479**	-0.418**	-0.364**	-0.359**
CBD (*β*)	(0.016)	(0.009)	(0.008)	(0.008)	(0.008)	(0.011)	(0.011)
Obs.	1479	1624	1683	1686	1681	1708	1711
R2	0.74	0.75	0.75	0.75	0.7	0.44	0.46

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

Tab. 3 Land Gradient 1890 – 1936 (FE)

	1890	1896	1900	1904	1910	1929	1936
Const (α)	6.822**	6.638**	6.724**	6.846**	7.087**	5.937**	5.849**
	(0.099)	(0.091)	(0.074)	(0.076)	(0.071)	(0.066)	(0.066)
Dist. to	-0.738**	-0.516**	-0.451**	-0.436**	-0.413**	-0.298**	-0.299**
CBD (β)	(0.031)	(0.027)	(0.022)	(0.022)	(0.02)	(0.018)	(0.019)
"Ortsteile Effects"	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	1479	1572	1683	1686	1681	1709	1711
R2	0.86	0.85	0.86	0.85	0.83	0.77	0.75

Notes: Endogenous variable is log of land value (*LV*) in RM/sqm in all models. All models include "Ortsteile" (community) fixed effects. Robust standard errors are in parenthesis. + denotes significance at the 10% level, * denotes significance at the 5% level, and ** denotes significance at the 1% level.

Tab. 4 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	-0.76 (0.74)	-0.31 (0.58)		-0.11 (0.28)	
1900	-0.50 (0.75)			-0.06 (0.01)	
1910-15	-0.42 (0.70)	-0.30 (0.61)	-0.40 (0.49)		
1928-31	-0.36 (0.43)	-0.12 (0.24)	-0.27 (0.32)		-0.094 (0.55)
1936-48	-0.36 (0.45)		-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 (1). Chicago results are from McMillen (1996) 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 1. Coefficients of determination are presented in parenthesis. * Coefficients are re-scaled from miles to km.

Tab. 5 Test for decentralization

	(1)	(2)	(3)	(4)
	Distance	Distance	Travel time	Travel time
β x 1890	-0.397**	-0.440**	-0.064**	-0.078**
	(0.019)	(0.036)	(0.005)	(0.009)
β x 1896	-0.207**	-0.217**	-0.017**	-0.027**
	(0.014)	(0.032)	(0.005)	(0.01)
β x 1900	-0.135**	-0.152**	0.00	-0.009
	(0.013)	(0.028)	(0.005)	(0.008)
β x 1904	-0.120**	-0.137**	0.003	-0.004
	(0.013)	(0.029)	(0.005)	(0.01)
β x 1910	-0.059**	-0.114**	-0.004	-0.005
	(0.013)	(0.028)	(0.005)	(0.01)
β x 1929	-0.005	0.001	-0.002	-0.001
	(0.015)	(0.026)	(0.006)	(0.011)
β	-0.359**	-0.299**	-0.155**	-0.132**
(Base year 1936)	(0.011)	(0.019)	(0.004)	(0.011)
“Ortsteil” x Year Effects	-	Yes	-	Yes
Year effects	Yes	Yes	Yes	Yes
Obs.	11,572	11,572	11,572	11,572
R2	0.7	0.85	0.72	0.85
AIC	21255.54	13890.03	20663.551	13798.41

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

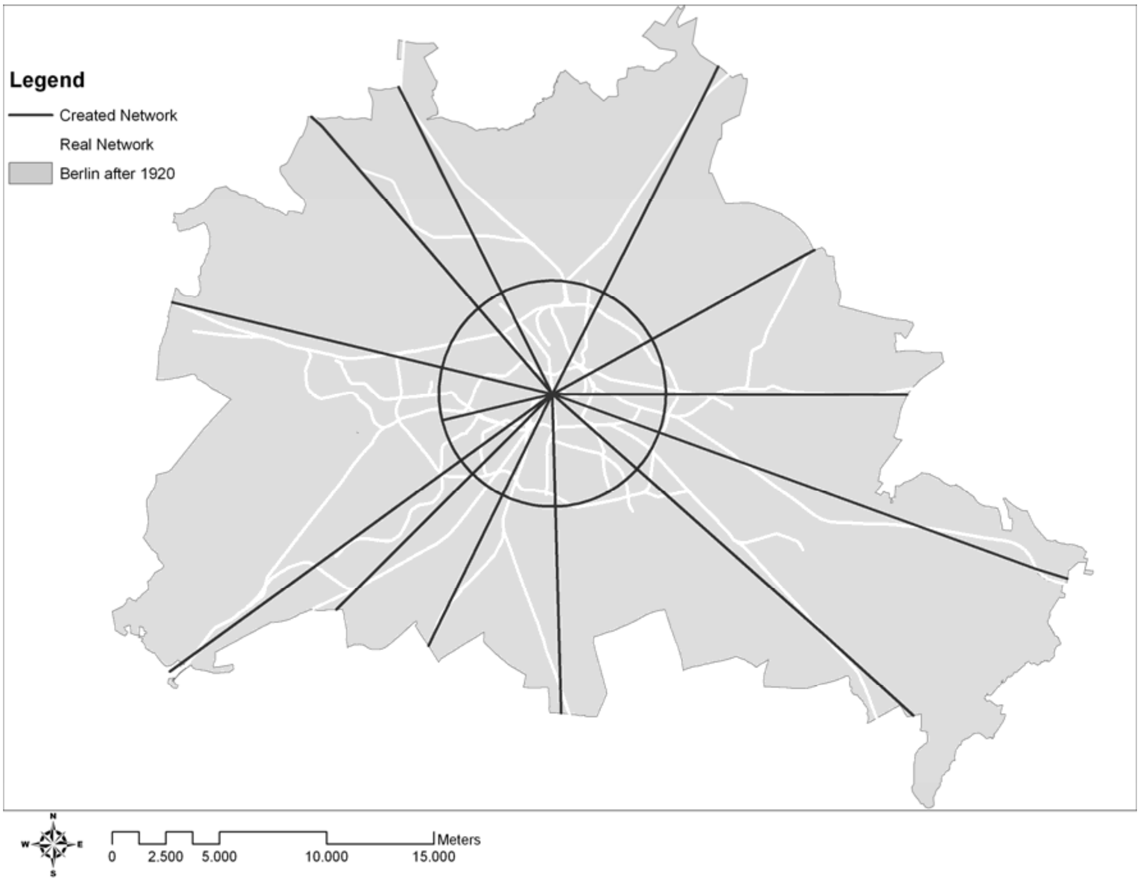
Tab. 6 Explaining decentralization

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
distcbd	-0.606**	0.00	-0.744**	-0.119**	-0.578**	-0.095**	-0.463**	-0.057+
	(0.006)	(0.022)	(0.014)	(0.04)	(0.017)	(0.032)	(0.016)	(0.034)
distcbd x trend	0.0063**	0.0018**	0.0262**	0.0211**	0.0078**	0.00001	0.0024**	0.0064**
	(0.00)	(0.00)	(0.002)	(0.002)	(0.001)	(0.001)	(0.00)	(0.00)
ttcbd		-0.178**		-0.180**		-0.124**		-0.188**
		(0.006)		(0.011)		(0.007)		(0.01)
Constant	6.395**	7.039**	6.840**	7.454**	6.896**	7.353**	7.097**	6.506**
	(0.023)	(0.028)	(0.037)	(0.043)	(0.024)	(0.032)	(0.026)	(0.043)
Period	1890-1936	1890-1936	1890-1900	1890-1900	1900-1910	1900-1910	1910-1936	1910-1936
Observations	11572	11572	4786	4786	5050	5050	5100	5100
R2	0.69	0.71	0.76	0.77	0.75	0.77	0.58	0.60
AIC	21597.77	20962.84	8541.042	8210.77	7109.039	6822.766	10143.33	9948.749
Explained de-cent. (%)		71.77		19.42		99.92		74.97

Notes: Endogenous variable is log of land value (*LV*) in RM/sqm in all models. The explained decentralization is calculated based on the estimated coefficients in full precision. Robust standard errors are in parenthesis. + denotes significance at the 10% level, * denotes significance at the 5% level, and ** denotes significance at the 1% level.

Appendix

Figure A1 – Counterfactual Network



Tab. A1 First Stage Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Popd_1925	-2.046						
	(1.996)						
Nwdist_1936	1.627**	1.960**	6.363**	4.195**	4.899**		
	(0.282)	(0.280)	(0.444)	(0.374)	(0.409)		
distCBD	2.383**	2.400**	3.044**	3.518**	3.546**	3.693**	3.731**
	(0.031)	(0.031)	(0.045)	(0.048)	(0.052)	(0.055)	(0.056)
Cbd x nwdist_1936	-0.211**	-0.251**	-1.037**	-0.774**	-0.923**		
	(0.043)	(0.043)	(0.067)	(0.057)	(0.062)		
Popd_1919		-2.803					
		(2.056)					
Popd_1900			18.917**				
			(3.048)				
Popd_1895				8.510**			
				(2.702)			
Popd_1890					-0.157		
					(2.132)		
Popd_1885						-7.708**	
						(2.690)	
Nwdist_1895						3.682**	
						(0.368)	
Cbd x nwdist_1895						-0.859**	
						(0.058)	
Popd_1880						-10.474**	
						(3.062)	
Nwdist_1890						3.545**	
						(0.346)	
Cbd x nwdist_1890						-0.844**	
						(0.057)	
Constant	2.050**	1.992**	0.756**	1.669**	2.357**	2.625**	2.615**
	(0.134)	(0.134)	(0.253)	(0.223)	(0.225)	(0.238)	(0.243)
Observations	1718	1718	1718	1718	1718	1718	1718
R2	0.86	0.86	0.75	0.86	0.84	0.85	0.85

Notes: Endogenous variable is the travel time to the CBD for the years 1936, 1929, 1910, 1904, 1900, 1896, and 1890. The hypothetical network did not change after 1895. Robust standard errors are in parenthesis. + denotes significance at the 10% level, * denotes significance at the 5% level, and ** denotes significance at the 1% level.

Tab. A2 Travel Time Gradients

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ttCBD1890	-0.204**						
	(0.004)						
ttCBD1896		-0.174**					
		(0.003)					
ttCBD1900			-0.155**				
			(0.003)				
ttCBD1904				-0.152**			
				(0.003)			
ttCBD1910					-0.159**		
					(0.003)		
ttCBD1929						-0.157**	
						(0.005)	
ttCBD1936							-0.157**
							(0.005)
Constant	7.448**	7.486**	7.489**	7.539**	7.665**	6.568**	6.568**
	(0.045)	(0.038)	(0.035)	(0.032)	(0.034)	(0.051)	(0.051)
Observations	1479	1624	1683	1686	1681	1708	1708

Notes: Estimates refer to equation (2) and use the predicted values from IV estimates. . Robust standard errors are in parenthesis. + denotes significance at the 10% level, * denotes significance at the 5% level, and ** denotes significance at the 1% level.

Tab. A3 IV (2SLS) Estimation Tests

	Endogeneity Test	Kleibergen-Paap rk LM Statistic	Kleibergen-Paap rk Wald F Statistic
ttCBD1890	195.870	642.230	3002.437
	(0.0000)	(0.0000)	(0.0000)
ttCBD1896	127.517	735.957	1777.263
	(0.0000)	(0.0000)	(0.0000)
ttCBD1900	267.794	746.402	1927.590
	(0.0000)	(0.0000)	(0.0000)
ttCBD1904	190.443	699.282	2310.579
	(0.0000)	(0.0000)	(0.0000)
ttCBD1910	223.354	619.335	1653.220
	(0.0000)	(0.0000)	(0.0000)
ttCBD1929	75.399	584.661	2514.745
	(0.0000)	(0.0000)	(0.0000)
ttCBD1936	73.999	585.924	2369.346
	(0.0000)	(0.0000)	(0.0000)

Notes: P-values in parentheses

Literature

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

Ahlfeldt, G. M. (2010). If Alonso was right: Modeling Accessibility and Explaining the Residential Land Gradient. *Journal of Regional Science, DOI: 10.1111/j.1467-9787.2010.00694.x*.

Ahlfeldt, G. M., & Wendland, N. (2009). Looming Stations: Valuing Transport Innovations in Historical Context. *Economics Letters 105*(1), 97-99.

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

Anselin, L., & Bera, A. K. (1996). Simple diagnostic tests for spatial dependence. *Regional Science & Urban Economics, 26*(1), 77.

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

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

Bednarz, R. S. (1975). *The Effect of Air Pollution on Property Value in Chicago*. Chicago: University of Chicago Press.

Beier, K. (1990). *S-Bahn Berlin der neue Triebzug ET 480*. Darmstadt: Hestra-Verlag.

Berry, B. J. L. (1976). Ghetto Expansion and Single-Family Housing Prices. *Journal of Urban Economics, 3*(4), 397.

Bley, P. (2003). *Berliner S-Bahn*. Düsseldorf: Alba-Verlag.

Bohm, E. (1980). *Kurfürstendamm. Entstehung und erste Entwicklung*. Berlin: Colloquium Verlag.

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

Clark, C. (1951). Urban Population Densities. *Journal of the Royal Statistical Society. Series A, 114*(4), 490-496.

Cleveland, W. S., & Devlin, S. J. (1988). Locally Weighted Regression: An Approach to Regression Analysis by Local Fitting. *Journal of the American Statistical Association, 83*(No. 403), 596-610.

Dittfurth, U. (1993). *Strecke ohne Ende.Die Berliner Ringbahn.* Berlin: GVE.

Elkins, T. H., & Hofmeister, B. (1988). *Berlin: The Spatial Structure of a Divided City*. London: Methuen.

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

Hoffmann-Axthelm, D. (1982). *Einige historische Voraussetzungen der Eisenbahnstadt*. Berlin: Ästhetik und Kommunikation.

Hoyt, H. (1933). *One hundred years of land values in Chicago*. Chicago: Univ. of Chicago Press.

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

Kalweit, F. (1936). *Die Baustellenwerte in Berlin*. Berlin: Carl Heymanns Verlag.

Kau, J. B., & Sirmans, C. F. (1979). Urban Land Value Functions and the Price Elasticity of Demand for Housing. *Journal of Urban Economics, 6*(1), 112.

Leyden, F. (1933). *Groß-Berlin. Geographie der Weltstadt*. Breslau: Ferdinand Hirt.

McDonald, J. F. (1981). Spatial patterns of business land values in chicago. *Urban Geographie, 3*, 201-215.

McDonald, J. F. (1989). Econometric studies of urban population density: A survey. *Journal of Urban Economics, 26*(3), 361-385.

McDonald, J. F., & Bowman, H. W. (1979). Land value functions: A reevaluation. *Journal of Urban Economics, 6*(1), 25-41.

McDonald, J. F., & McMillen, D. P. (1990). Employment subcenters and land values in a polycentric urban area: the case of Chicago. *Environment and Planning A, 22*(5), 1561-1574.

McMillen, D. P. (1979). *Economic analysis of an urban housing market*. New York: Academic Press.

McMillen, D. P. (1990). Consistent estimation of the urban land value function. *Journal of Urban Economics, 27*(3), 285-293.

McMillen, D. P. (1994). Vintage Growth and Population Density: A Empirical Investigation. *Journal of Urban Economics, 36*, 333-352.

McMillen, D. P. (1996). One Hundred Fifty Years of Land Values in Chicago: A Nonparametric Approach. *Journal of Urban Economics, 40*(1), 100-124.

McMillen, D. P. (2004). Locally Weighted Regression and Time-Varying Distance Gradients. In A. Getis, J. Mur & H. G. Zoller (Eds.), *Spatial Econometrics and Spatial Statistics*. New York: Palgrave MacMillan.

McMillen, D. P. (2010). Issues in spatial data analysis. *Journal of Regional Science, 50*(1), 119-141.

McMillen, D. P., Jarmin, R., & Thorsnes, P. (1992). Selection bias and land development in the monocentric city model. *Journal of Urban Economics, 31*(3), 273-284.

McMillen, D. P., & McDonald, J. F. (1991). Urban land value functions with endogenous zoning. *Journal of Urban Economics, 29*(1), 14-27.

Mills, E. S. (1969). The value of urban land. In H. Perloff (Ed.), *The quality of urban environment*. Baltimore, MA: Resources for the Future, Inc.

Müller, G. (Cartographer). (1881-1910). *Karte zur Berechnung des Grund- und Bodenwerthes in Berlin*

Muth, R. F. (1969). *Cities and Housing: The Spatial Pattern of Urban Residential Land Use*. Chicago: University of Chicago Press.

Ribbe, W. (1987). *Geschichte Berlins*. München: Verlag C.H.Beck.

Richter, G. (1987). Zwischen Revolution und Reichsgründung. In W. Ribbe (Ed.), *Geschichte Berlins*. München: Verlag C.H.Beck.

Runge, E. (Cartographer). (1950). *Bodenwertkarte Gross-Berlin (1938)*

Smith, F. H. (2003). Decaying at the core: Urban decline in Cleveland, 1915-1980. In *Research in Economic History* (Vol. Volume 21, pp. 135-184): JAI.

Strohmeyer, K. (2000). *James Hobrecht. (1825–1902) und die Modernisierung der Stadt.* Potsdam: Verlag für Berlin-Brandenburg.

Yeates, M. H. (1965). Some Factors Affecting the Spatial Distribution of Chicago Land Values, 1910-1960. *Economic Geography, 41*(1), 57-70.