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Cities and Innovation

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ABSTRACT: Cities are more than centers of production. This paper introduces new spatial variables in order to gain new insights into the role cities play as centers of leisure, consumption and beauty. First, a revealed preference indicator of urbanity is constructed based on geo-tagged photos shared in web-communities. Second, spatial variables are generated to capture features that have received little attention in quantitative urban research. Among them, the quality of the built environment, both with respect to contemporary as well as historic architecture, and the cultural endowment constituted by mainstream and avant-garde establishments. From a comparative spatial analysis of the European metropolises Berlin and London, I find that urbanity defined along these lines is of similar importance for the spatial structure cities as labor market accessibility and spillover effects. Urbanity attracts consumption affine households, especially the high-skilled.

JEL Codes: R20, R30

Keywords: Amenities, consumer city, hedonic analysis, photography geography, property prices.

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1 Introduction

Cities are more than centers of production. They are also more than just the living place for the majority of people around the globe. Cities are centers of leisure, consumption and aesthetic beauty. This view stands in some contrast to the classic perspective economists have long taken on cities. Accordingly, economic concentrations are the outcome of either natural advantages or the mutual attraction of firms that benefit from agglomeration economies. Workers are then pulled towards these economic concentrations due to the interplay of higher wages and reduced commuting costs. Access to attractive employment opportunities, accordingly, overcompensates for costs associated with living in congested downtowns, which ultimately reflects in higher rents for living space. The phenomenon that wealthier households tend to live in suburban areas rather than downtowns in many metropolitan areas has supported the view that central cities are, mostly, undesirable places to live.[1]

More recently, however, some economists have started to challenge this view. Firms have been argued to become increasingly "footloose" due to improvements in transportation and communication technology and to ultimately follow people. It has also been acknowledged that there are not only scale economies in the production of goods and services, but also in the provision of consumption amenities. Specific amenities that address diverse tastes, e.g., specialized ethnic restaurants, theaters or other entertainment establishments require a large consumer base to operate efficiently. As workers become richer, more educated, leisure oriented and, not least, more diverse in their lifestyle orientations, a highly skilled workforce, sometimes referred to as a creative class (Florida, 2002), becomes increasingly attracted by places with ethnical, cultural and consumption diversity that, often, only central cities can offer. As put down by Glaeser et al. (2001), "[t]he future of cities depends on the demand for density". Certainly it will depend on the ability of cities to attract the most qualified workforce, which will in turn attract human capital intensive industries.

Glaeser et al. (2001) classify four basic categories of urban amenities: [1] the quality and variety of consumption goods; [2] the physical setting, including aesthetic and in particu-

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[1] See Brückner et al. (1999) for theoretical discussion of income segregation, accompanied by stylized facts.

lar architectural beauty; [3] public services; and [4] efficient transport.[2] Understanding how these features define "attractive" urban spaces means understanding how cities can enhance their abilities to adapt to the (changing) requirements of human capital workers and eventually be economically successful. Recent urban economics research has made considerable advances in empirically assessing the value of [3] and [4], e.g., the quality of schools, public transport or crime levels, which are often observable based on official records. Typically, a positive and sizable willingness to pay for these features is revealed by micro-level hedonic analyses of property prices and rich surveys are available that provide a condensed image of the findings (Gibbons & Machin, 2008). It has been more difficult, however, to quantify what constitutes an attractive urban space in terms of local consumption varieties [1] and architectural quality [2], which, arguably, are among the most typical dimensions of urbanity. Some evidence is available for selected large-scale consumption amenities such as sports facilities and franchises (Ahlfeldt & Maennig, 2010a; Carlino & Coulson, 2004), architectural beauty, usually in the context of preserved historic buildings (Ahlfeldt & Maennig, 2010b; Coulson & Lahr, 2005) or cultural facilities (Ahlfeldt, 2011a; Bille & Schulze, 2006). While generally revealing positive amenity effects, such studies are typically very selective with respect to the range of considered amenities and imperfect at best in capturing the whole entity of features that together constitute what is perceived as an attractive urban place.

Carlino & Saiz (2008) offer a compelling alternative. Instead of capturing amenities directly, they make use of the number of leisure trips to metropolitan statistical areas as a measure of consumers' revealed preferences for local leisure-oriented amenities. They show that, based on that definition, more attractive cities substantially exceed their less attractive counterparts in terms of employment and population growth and are particularly attractive to the highly educated. The downside of this composite amenity index is that spatial detail is lost and we learn less about what type of amenities specifically increases the attractiveness of urban places. Carlino & Saiz (2008) partially remedy these limitations by looking into cities, albeit at a relatively aggregated level. As their measure of revealed

[2] Closely related, Brückner et al. (1999) define three categories of amenities, [a] natural amenities, [b] historic amenities and [c] modern amenities. In their model, [a] and [b] are considered exogenous and eventually determine the location of high income, amenity affine households. They correspond to category [2] defined by Glaeser et al. (2001), whose category [1] roughly corresponds to [c].

preferences is not available at a sub city level, they rely on a comparison of central recreational districts (CRD) to the rest of cites and proximity to a limited number of recreational amenities. Within these limitations, they find that more attractive places within cities, in terms of amenities, performed superior in terms of economic growth.

In this paper I pursue a hybrid of both strategies, that is, I look into the city and use a revealed preference amenity index which I merge to a broad range of observable amenities and property data at the maximum spatial detail. As a revealed preference indicator of the attractiveness of urban places I make use of millions of individual photographs taken and shared at web-communities with a detailed spatial reference. While I presume that higher photo densities per spatial unit reflect more attractive spaces throughout the paper, this definition is, of course, not without limitations. For one thing, the propensity of photos being taken at a certain location is not necessarily linearly related to the average perception of, for example, aesthetic beauty. For another thing, those sharing their pictures in web communities such as Flickr or Picasa are very likely a sample selected group. However, I argue that, first, users of this type of new media form precisely the young, creative and high-skilled class that cities aim to attract to be economically successful, and, second, an attractive urban space does not need to appeal to the average, but the marginal buyer (or renter). Places that are perceived to be interesting enough to be photographed by a large number of people, therefore, qualify as attractive places in the sense that is relevant for this study.

To the degree possible, I merge these data with observable location characteristics. In addition to standard urban economics variables, e.g., distance to transport infrastructure, employment access, natural amenities or public services, I also compile a data set of less common features. Among them are cultural consumption amenities, i.e., important museums, theaters and cinemas. Moreover, I borrow from Bass van Heur's fieldwork and geocode hundreds of avant-garde music venues, such as clubs, record labels, etc., to define an index of alternative cultural activity based on the address list provided in the appendix of his PhD (van Heur, 2008). For architectural quality, besides making use of official preservation records, I geocode hundreds of contemporary and historic landmark buildings based on architecture guides (Allinson, 2009; Haubrich, Hoffmann, Meuser, & Uffelen, 2010). To arrive at a limited degree of generalizabilty at the cost of doubling the data collection and processing, I conduct the analysis for two European metropolises: Berlin, Germany, and London, UK. These cities fall into the first category of resurgent dense cities defined by Glaeser et al. (2001) and qualify as natural study areas for an investigation of urbanity and the associated perceived attractiveness. These cities correspond to US amenity city counterparts such as New York, San Francisco, Boston or Chicago.

The structure of the paper follows the main argument. The next section introduces the new revealed preference measure by providing stylized facts and descriptive evidence on the spatial photo pattern. I show that the spatial distribution of photo densities follows the observable determinants as expected and argue that this is reason to believe that the same should hold for unobservables, i.e., a high photo density is a good proxy for attractive urban places or "urbanity". In section three, I move on to analyze whether and how urbanity impacts on household and firm location decisions. At this stage, I use a simple urban bid-rent model to guide the analysis and help interpret the results of a battery of empirical tests based on various response variables. Previewing my results, I conclude in the last section that there is a significant willingness to pay for urbanity by firms and residents, especially by the high-skilled.

2 The Geography of Photography

In this section I introduce a new data set of individual photographs shared by users of web communities, which I use to construct revealed preference indicators of interesting and attractive urban places. Figure 1 shows the raw data. They stem from Eric Fisher's fascinating Geotaggers' World Atlas, whose observations are taken from Flickr and Picasa search APIs.[3] The bounds of the square observation areas with 15 miles on each side are chosen to include as many geotagged locations as possible near the respective central cluster. In total, the data set after deletion of pictures with incomprehensive dates comprises 633,764 individual observations in the case of Berlin and 1,849,403 for London respectively. With these data at hand, what exactly motivates people to take pictures of places is an obvious question. Intuitively, locations that are frequently photographed must be fascinating enough to be of human interest, which in an urban context I define to correspond to a sense of "urbanity". Certainly, these places are attractive to a relatively large number of

[3] See for details http://www.flickr.com/photos/walkingsf/sets/72157623971287575/.

people. What exactly makes these places attractive is a question I attempt to investigate empirically within the constraints of observable location characteristics.

Another natural question to ask regarding the revealed expressions of interest that becomes evident from the photography geography is to which degree tourists and residents differ in their photo behavior. While from the data set it is not possible to observe the place of residence and to sharply distinguish between the two groups, the individual pattern of photos taken by a user at various cities over time facilitates the construction of categories of users that are likely tourists or residents. I follow Fisher's decision rule and define users that took pictures in one of the study cities over less than one month and over a longer period in another city as tourists, and those taking pictures in one of the study cities over more than a month as residents. Inevitably, this definition leaves a residual category of users and pictures that cannot be assigned to either category. Table 2 tabulates the photos in the data set by city, year and category. Clearly, it shows the increasing popularity of both web-platforms since their start in 2002 (Picasa) and 2004 (Fickr) among residents and tourists.

FIGURE 1 ABOUT HERE

TABLE 2 ABOUT HERE

To analyze the spatial distribution of photos, I aggregate the individual photo observations to a density index that can be merged with other data. Specifically, I calculate the number of photos per square kilometer, weighted by the total number of photos taken in a given year, for each of the 11,549 statistical blocks in Berlin that fall into the observation zone. These spatial blocks are officially defined based on homogeneity considerations and small enough to yield a high spatial detail while at the same time large enough to result in meaningful densities (median surface *AREA* 0.18 km^2). For similar reasons, I calculate photo densities (*PD*) for 13,765 official output areas within the respective zone in London (median surface *AREA* 0.27 km^2).

$$PD_i = \frac{1}{AREA_i}\left[\frac{1}{T}\sum_t \frac{n_{ijt}}{N_t}\right] \quad (1)$$

where $2002 \leq t \leq 2009$ denotes the year when a photo j was taken in block i, T=8 is the number of years included in the analysis, n_{ijt} are the total number of photos taken in year t in block i, and N_t is the total number of photos in a given year. The resulting photo densities are mapped in Figure 2. It is evident that in both cases the photo geography forms a map from which the city is recognizable with some knowledge of the local urban geography. In the case of Berlin, both the traditional CBD as well as the City-West spreading along the boulevards Kurfürstendamm and Tauentzienstrasse can be identified. Similarly, high photo densities are evident around major recreation spaces and tourist spots like the central park Tiergarten, the Spree River, Charlottenburg Palace, including the respective gardens, or the East-Side Gallery, a strip of the former Berlin Wall, painted by street artists. Similarly, the central areas in London around the City and the City of Westminster are visible, but also green spaces and tourist destinations like Hyde Park, Kensington Gardens, Thames River, Green Park, Buckingham Palace, Greenwich or Richmond. A first inspection indicates that interesting urban places can be of a very distinct nature, including both places of high economic density or low density recreation spaces but, in general, central places tend to attract more attention. The pattern of pictures taken, moreover, is very similar for residents and tourists, though it seems slightly more concentrated for the latter.

FIGURE 2 ABOUT HERE

Table 2 shows how blocks of respectively output areas that have been photographed differ from those that did not in terms of observable characteristics; in each case for the total population, tourists and residents. Evidently, photo activity is more concentrated in Berlin. About 45.5% of the blocks in the study areas of Berlin feature no recorded photos compared to only 21.6% of London output areas. Within these blocks, however, the mean photo density is about six times as high as for the respective output areas in London. Nevertheless, differences between photo and non-photo areas in both cities are fairly consistent and in line with expectations. Photo destinations are generally more central, both in terms of distance to the central business district (CBD) and the nearest rapid transport stations as well as in terms of the proportion of blocks and output areas along primary roads. They also exhibit about four times higher employment densities. Locations within the photo group also have a higher probability of featuring natural amenity areas, e. g., parks and waterways, and signature buildings (contemporary in the case of Berlin, contemporary and historic in the case of London). Similarly, the average number of major cultural facilities, i.e., museums, theaters, cinemas, etc., is also by several orders of magnitude higher in the photo group for both cities. Alternative music nodes similarly concentrate in photo areas, although the discrepancy is considerably more pronounced for London. As expected, the top tourist destinations compiled as a list of the 20 mostly cited top-sights in various tourist guides, fall exclusively into the photo group. As suspected from the visual inspection of the maps in Figure 2, there are hardly any systematic differences between densities in the tourist and resident blocks and output areas, though densities in the latter are generally somewhat higher. In brief, locations with photo activity are by all definitions more attractive, i.e., economically more central, more beautiful and culturally more interesting.

TABLE 2 ABOUT HERE

Another approach to exploring the nature of photography geography is to look at how photo densities change in selected location attributes, given there is photo activity. Figure 3 illustrates pairwise correlations of the log of photo density as defined above and selected variables, with graphs in the left (right) column referring to Berlin (London).

Evidently, there is a clear negative relationship between the photo density and the distance to the CBD, somewhat resembling the predictions of monocentric models for unit prices of housing space and land and various economic densities (Alonso, 1964; Mills, 1972; Muth, 1969). This is an interesting finding in the context of this analysis as classic (bid-rent) models derive such a negative relationship from reductions in transport costs that pull residents and firms into the center where all employment opportunities and agglomeration economies concentrate. It is, however, not clear a priori why photographers' choices of their subjects should be constrained in the same way. This pattern could be indicative of central areas being attractive places for reasons that are not directly related to the classic urban contraction forces. Similarly strongly, there is a positive correlation between photo densities and employment densities, indicating that centers of economic activity besides the frequently discussed economic spillovers may create a visually appealing environment.

A natural question to pursue is how correlated photo densities are with other revealed preference indices of location quality. The, arguably, most popular measure in urban economics are land values or, if not directly available, the location component embedded in property prices, which can be interpreted as a willingness to pay for location quality. Of course, that indicator is less specific with respect to the amenity endowment of a location as it also – or according to standard theories – primarily comprises the classic economic determinant of urban land value: accessibility. Still, or especially for that reason, a comparison between both indicators yields interesting insights. Notably, there is a positive and approximately (log) linear correlation between the value of land, as reflected in standard land values assessed by the Committee of Valuation Experts in Berlin and photo densities, that is, there is a positive willingness to pay for places that are attractive according to the photo index scores. Similar land values were not readily available for London. To isolate the implicit price paid for location from observable property prices, I run a simple regression of log of transaction prices on observable property characteristics as well as year and output area fixed effects. By recovering the latter, I obtain a land value proxy that I plot against (log) of photo densities in Figure 3.[4] Again, there is a strong and positive correlation between the willingness to pay for location and the attractiveness of urban space as defined by the amenity indicator. The distribution of land values (Berlin) and the estimated location component in observable property prices (London) is depicted in Figure A1 in the appendix.

The last stylized fact that I present is related to the abovementioned idea that certain population groups, e.g. the so called creative class or simply the highly qualified, productive avant-garde that are argued to be so important for the future of cities, are specifically attracted by a sense of urbanity, i.e. high amenity urban space, because of particular consumption preferences. This would be reflected by a higher proportion of these population groups among the resident population living in areas with higher photo densities. To give an indication of such a spatial correlation, I develop a qualification index for each output area in London based on the 2000 census records, which is basically the average of the qualification score at a given location, weighted by the share of the local population in the respective categories.[5] And indeed, as evident from the lower right panel of Figure 3, there is a clear concentration of this population group in urbanity locations.

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4 The regression equation takes the following form: $\log(P_{it}) = \sum_n \beta_n X_{in} + \phi_t + \varphi_j + \varepsilon_i$, where $\hat{\varphi}_j$ are the recovered output area fixed effects, P is the transaction price per square meter floor space and X is a vector of observable location characteristics. I use the well established Nationwide Building Society data set, which has been used, among others, by Gibbons & Machin (2005). They provide a detailed discussion of the data, including the property characteristics.

5 The qualification index (QI) is constructed as follows for each output area where s_n is the qualification score and p_n the population within a qualification category: $QI = \sum_n s_n \frac{p_n}{\sum_n p_n}$

It is more difficult to find a comprehensive human capital indicator for Berlin as no official qualification records are available at a reasonably fine geographic level. One arguably crude way to capture some social phenomena is to make use of a recent phenomenon in the German political landscape: the raise of the Green Party (*Die Grünen*). Emerging from radical ecological movements in the 1980s, the party over the recent decades has evolved into a liberal, eco-orientated mainstream party, which participated as a junior partner in the SPD led governing coalition at the federal level from 1998 to 2005. Socio-economic analyses reveal that voters of the Green Party are typically characterized by an above-average education and modernistic lifestyle attitude (Klein & Arzheimer, 1997). They form a milieu that shares similarities with Richard Florida's definition of a creative class. Proportions of Green Voters from the 2006 Berlin state elections are available at a reasonably fine spatial level of 1,201 voting precincts. Aggregating photo densities to the same level, a clearly positive correlation emerges, likely an effect of a particularly strong preference for urbanity of the captured political and social milieu.

FIGURE 3 ABOUT HERE

These stylized facts support the idea that central cities may have something to offer that goes beyond the mere concentration of employment opportunities and agglomeration economies in the production of goods: a sense of urbanity that makes them interesting enough to be recorded in the (digitial) memories of photographers sharing millions of geo-referenced pictures with the rest of the world. Even though residents seem to have a sizable willingness to pay for these areas, it would be premature to dismiss alternative and more traditional urban contraction forces as determinants of the spatial structure of cities. Figure 2 indicates that the amenity index is strongly correlated with economic density, which could ultimately be the driving force that attracts both residents and photographers.

I devote more attention to disentangling the effects of access to economic mass and urbanity on residents' and firms' location decisions in the next section. Before, I validate the purely descriptive evidence presented so far by estimating partial correlations among the photo index and locational variables using multivariate regressions. I first run bivariete logit regressions to shed light on the features that determine whether or not photo activity takes place at a given location, which corresponds to an extension of the descriptive evidence presented in Table 2.[6] Second, I run OLS regressions to establish partial correlations among (log) photo densities and location characteristics for areas where photo activity takes place, which extends evidence from Figure 3. Third, I run photo level logit regressions to determine which factors make it more likely that a picture has been taken by a (presumed) tourist or resident.

Table 3 (Berlin) and 4 (London) present the results. All effects from logit models are expressed as marginal effects at the mean. The evidence is fairly in line with intuition and the stylized facts discussed above. Central areas, even conditional on observable economic and amenity characteristics receive particularly high attention by photographers. The likelihood of being in the photo sample is reduced by about 25% for an additional km distance to the CBD (1). Within the blocks in the photo group, an additional km reduces the photo density by about 32% in Berlin and 20% in London (2). At the same time, all natural, built and cultural amenities impact significantly positively on photo densities as expected. As expected, locations with major tourist hotspots enjoy particular popularity. A notable exception among the considered location features is population density, which consistently reduces the likelihood of a location being photographed when holding other observable factors constant. This is an interesting and important finding as it suggests that photos are not simply taken where people live. Distinguishing between samples of tourist and resident pictures the pattern in columns (3) to (6) suggests that, with the exception of population density, all considered location features exhibit a stronger impact on tourists' than residents' photo decisions. Still, the direction of effects in column (3) and (4) is consistent and, mostly, within the same order of magnitude. Throughout the rest of the paper, I therefore use the pooled sample of all pictures to exploit the total wealth of information.

Overall, the satisfying explanatory power together with the expected and consistent directions of effects should be reassuring that geocoded photos serve the intended purpose. As an indicator of revealed preferences they show which urban locations benefit from a favorable endowment with amenities that make these places more interesting and attractive. In other words, I argue that the plausible (partial) correlations in observables en-

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[6] This well-known model where p stands for the probability that photo activity takes places at a given location takes the following form: $\log(\frac{p}{1-p})_i = \alpha + \sum_n \alpha_n X_{in} + \varepsilon_i$

courage the application of these data to capture otherwise unobservable location quality in urban research, which is what I do in the next section.

3 The Value of Urbanity

3.1 Theoretical Framework

Classic bid-rent theory, arguably, represents the workhorse of urban economics (Alonso, 1964). Accordingly, the location decision of firms and household are driven by a trade-off of access to a dimensionless point called the central business district (CBD) and the price of a scarce and homogenous recourse economic actors are bidding for: land. The CBD is the destination of all commuting and the source of all agglomeration economies. Of course, this useful but simplistic view on cities needs to be extended to fully understand the role cities are playing as centers of beauty, leisure and consumption.

To guide my empirical analyses, I borrow from a consolidated body of theoretical urban economics literatures. I use a simple framework that incorporates various bits and pieces of classic trade-off, supply and demand as well as more recent agglomeration models. The bid-rent world is developed with the primary objective of motivating empirical tests using different response variables and making the resulting estimates comparable. The key elements of this world are residents who derive a utility from the consumption of accessibility and urbanity and whose utility, through costless mobility, is equalized across locations by correspondingly adjusting (per unit) prices of housing space and substitution of housing and non-housing consumption. Via a housing production function, varying prices across locations translate into different land prices and, due to factor substitution, varying building densities. Following a similar logic, I assume that accessibility and urbanity as two distinct forms of urban agglomeration economies affect total factor productivity and, under the equilibrating assumption of zero economic profit, impact on prices of office space and commercial land as well as economic densities.

Housing demand

I assume a very simplistic world where identical and mobile individuals at location x in a linear city derive a Cobb-Douglas utility from the consumption of a composite non-housing consumption good C, living space $S(x)$, accessibility $A(\mathrm{x})$ and urbanity $Z(\mathrm{x})$.

$$U(x) = C^{\alpha} S(x)^{\beta} A(x)^{\gamma} Z(x)^{1-\alpha-\beta-\gamma} \tag{1}$$

$A(x)$ is an index of accessibility to the overall economic mass, proxied by the distribution of workplace employment.

$$A(x) = \int a_1(y)\, \mathrm{e}^{-b_1 d(x,y)} \mathrm{d}y \tag{2}$$

Note that this world follows the spirit of Alonso (1964) in that individuals have direct preference on labor market accessibility. Such direct preferences on accessibility can result from inconvenience of traveling and the desire to locate centrally within a pool of employment opportunities and correlated services. To simplify matters I assume that, in monetary terms, within a city transport costs do not vary depending on the place or residence (x). This assumption does not imply that monetary transport costs are irrelevant: they may still represent a substantial share of the budget. Instead the idea is that the location varying component is relatively small compared to the fixed cost, e.g., of owning a car, or using public transport, where an increase in distance traveled in practice, if at all, only leads to a marginal increase in monetary transport cost. Minimally, the implication is that the marginal increase in monetary cost in distance traveled is small relative to the inconvenience of longer journeys, which seems like a reasonable approximation for many large metropolitan areas, including Berlin and London.

In the same way, an index of urbanity can be described, where densities refer to the distribution of aesthetic amenities and specialized consumption varieties that come in excess to benefits that can be ascribed to labor market accessibility.

$$Z(x) = \int a_2(y)\, \mathrm{e}^{-b_2 d(x,y)} \mathrm{d}y \tag{3}$$

Households take accessibility and urbanity as given and spend their exogenous budget (net of monetary transport costs) B on living space, with an associated price or bid-rent of $\psi(x)$ for one unit of space $S(x)$ and the composite consumption good whose price is the numeraire. First order conditions imply following indirect demand functions:

$$C = \frac{\alpha}{\alpha+\beta} B \tag{4a}$$

$$S(x) = \frac{\beta}{\alpha+\beta} \frac{B}{\Psi(x)} \tag{4b}$$

Perfect mobility implies that utility is equalized across all locations. Prices bid for living space, which are the equilibrating factor, make individuals indifferent across locations.

$$U(x) = \bar{U} = \left(\frac{\alpha}{\alpha+\beta}B\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\frac{B}{\Psi(x)}\right)^{\beta} A(x)^{\gamma} Z(x)^{1-\alpha-\beta-\gamma} \quad (5)$$

Setting $\bar{U}$ to 1 for simplicity and solving for $\Psi(x)$ yields equilibrium rents as a function of accessibility and urbanity.

$$\Psi(x) = \alpha^{\frac{\alpha}{\beta}}\beta\left(\frac{B}{\alpha+\beta}\right)^{\frac{\alpha+\beta}{\beta}} A(x)^{\frac{\gamma}{\beta}} Z(x)^{\frac{1-\alpha-\beta-\gamma}{\beta}} \quad (6)$$

Taking logs lays the foundations for a reduced form empirical specification. Given the usual parameter restrictions, i.e. α, β, γ > 0 and α+β+γ<1, bid-rents must increase in accessibility and urbanity.

$$\log(\psi(x)) = \log\left[\alpha^{\frac{\alpha}{\beta}}\beta\left(\frac{B}{\alpha+\beta}\right)^{\frac{\alpha+\beta}{\beta}}\right] + \frac{\gamma}{\beta}\log\left(\int a_1(y)\,\mathrm{e}^{-b_1 d(x,y)}\mathrm{d}y\right) + \frac{1-\alpha-\beta-\gamma}{\beta}\log\left(\int a_2(y)\,e^{-b_2 d(x,y)}dy\right) \quad (7)$$

Housing Supply

Equation (7), within the constraints of assumptions made, reflects the demand for housing space in the urban economy. There is, of course, a supply side that needs to be considered to understand the spatial equilibrium of a city as housing supply, even with strong regulatory constraints and limits to densification, is not perfectly inelastic. Very much in the spirit of classic models (Mills, 1972; Muth, 1969), housing is provided by a homogenous construction sector that uses capital (K) and land (L) as inputs in a concave production function, which for simplicity I assume to take the Cobb-Douglas form.

$$H(x) = \frac{1}{R(x)}K^{\delta}L^{1-\delta} \quad (8)$$

where $R = \Upsilon^{\varsigma}$ and Υ is a measure of regulatory restrictiveness that makes the production technology less efficient. This is an important extension as some of the amenities considered in the demand side are, at least partially, an outcome of a regulatory process. Heritage preservation policy that protects buildings with an inherent aesthetic or historic value is a typical example.

Construction firms pay a bid-rent for land Ω(x) while the price of capital, which is a composite of all non-land inputs, is the numeraire. The first order conditions yield the following demand for capital. Land, at a given location *x* is assumed to be fixed and provided inelasticly.

$$\frac{K_l}{(\bar{L})} = \frac{\delta}{1-\delta}\Omega(x) \tag{9}$$

As markets are competitive with full entry and exit, housing is traded at a market price, the housing bid-rent $\psi(x)$, and construction firms make zero profits.

$$\pi = \psi(x)\frac{1}{R(x)}\left(\frac{\delta}{1-\delta}\Omega(\mathrm{x})L\right)^{\delta} L^{1-\delta} - \frac{\delta}{1-\delta}\Omega(\mathrm{x})L - \Omega(\mathrm{x})L = 0 \tag{10}$$

The equilibrium land rent is thus determined by the housing bid-rent and the level of regulatory restrictiveness at location *x*.

$$\Omega(\mathrm{x}) = \psi(x)^{\frac{1}{1-\delta}}(1-\delta)\delta^{\delta}R(x)^{-\frac{1}{1-\delta}} \tag{11}$$

Substituting the equation (6) into (11) yields the residential land market equilibrium condition.

$$\Omega(x) = (1-\delta)\delta^{\delta}\alpha^{\frac{\alpha}{\beta(1-\delta)}}\beta^{\frac{1}{1-\delta}}\left(\frac{B}{\alpha+\beta}\right)^{\frac{\alpha+\beta}{\beta(1-\delta)}} R(x)^{-\frac{1}{1-\delta}}A(x)^{\frac{\gamma}{\beta(1-\delta)}}Z(x)^{\frac{1-\alpha-\beta-\gamma}{\beta(1-\delta)}} \tag{12}$$

Taking logarithms, this equation similar to equation (7) lays the foundation for an empirical test.[7]

$$\log\big(\Omega(\mathrm{x})\big) = \xi - \frac{\varsigma}{(1-\delta)}\log\big(\Upsilon(\mathrm{x})\big) + \frac{\gamma}{(1-\delta)\,\beta}\log\left(\int a_1(y)\,\mathrm{e}^{-b_1 d(x,y)}\mathrm{d}y\right) + \frac{1-\alpha-\beta-\gamma}{(1-\delta)\,\beta}\log\left(\int a_2(y)\,e^{-b_2 d(x,y)}dy\right) \tag{13}$$

Given the usual parameter restrictions, land rents must increase in accessibility and urbanity and decline with tighter regulations. In reality, however, property owners are often compensated for the cost of regulation. A typical example are tax benefits or renovation subsidies in case of restriction of property rights in the realm of preservation policies, which makes price effects less clear a priori in practice.

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[7] Where $\xi = \left[(1-\delta)\delta^{\delta}\alpha^{\frac{\alpha}{\beta(1-\delta)}}\beta^{\frac{1}{1-\delta}}\left(\frac{B}{\alpha+\beta}\right)^{\frac{\alpha+\beta}{\beta(1-\delta)}}\right]$.

Due to the scarcity of land at a given location, the unit value of land net of building structure $\Omega(x)$ is an appealing basis for an empirical test of bid-rent models. Such pure land values, however, can often not be observed directly, except in the case of vacant land that comes with the limitation of normally being vacant for reasons. Where assessed land values are available, as in the case of Berlin, their assessment by experts is often not fully transparent. It can be demonstrated, however, that within the constraints of the assumptions made, the total value of housing space $\left(\psi(x)H(x)\right)$ per land unit L is a linear transformation of the pure land value. In an empirical specification, this ratio can be approximated by the ratio of the selling price of a property to the size of the corresponding plot of land. Compared to the use of pure land values, the coefficient interpretation in a log-linearized empirical specification will not be affected.

$$\frac{\psi(x)H(x)}{L} = \frac{K+\Omega(x)L}{L} = \frac{\delta}{1-\delta}\Omega(x) + \Omega(x) = \frac{1}{1-\delta}\Omega(x) \tag{14}$$

Bid-rents that vary across locations trigger a number of subsequent implications for various density measures that can be tested with the appropriate data at hand. As with the price per land area, the capital to land ratio derived in equation (9) can be shown to be a linear transformation of the land rent. Empirically, it can be approximated by the ratio of the property price net of land value to the area of the respective plot of land.

$$\frac{K_l}{(\bar{L})} = \frac{\psi(x)H(x)-\Omega(x)L}{L} = \frac{\delta}{1-\delta}\Omega(x) \tag{15}$$

Another particularly interesting measure that can be used to test the implications of the model is the so-called floor space index, the ratio of housing space to the corresponding plot of land. It can be shown that housing space *H(x)* per land unit *L* follows the same determinants as the land rent, albeit it is not a linear transformation. Even though the floor space index has the neat feature of being presumably less sensitive to unobserved housing quality, this variable has enjoyed relatively limited popularity as a basis for empirical tests of bid-rent models.

$$\frac{H(x)}{L} = \frac{\Omega(x)+K/L}{\psi(x)} = \frac{\frac{1}{1-\delta}\Omega(x)}{\psi(x)} = \delta^{\delta}R(x)^{-\frac{1}{1-\delta}}\psi(x)^{\frac{\delta}{1-\delta}} \tag{16}$$

Another density measure that can directly be derived from equation (9) is the inverse of the individual space consumption, which corresponds to the ratio of the total number of residents (*POP*) to total housing space at a given location and is a linear transformation of the housing bid-rent.

$$\frac{1}{S(x)} = \frac{POP(x)}{H(x)} = \frac{\alpha+\beta}{\beta B}\Psi(x) \quad (17)$$

Multiplying this measure by building density (H/L) yields an implication for the number of inhabitants per land unit, which in turn is a linear transformation of the land bid-rent function.

$$\frac{1}{S(x)}\frac{H(x)}{L} = \frac{POP(x)}{L} = \frac{1}{1-\delta}\frac{\alpha+\beta}{\alpha B}\Omega(x) \quad (18)$$

Commerce

For the commercial sector, I assume a world where agglomeration economies shift the total factor productivity of homogenous firms that produce a composite good or service (T) with constant returns to scale using labor (N) and (office) space (S) as input factors. I distinguish between two forms of urban agglomeration economies that enter the production function in the usual multiplicative form: First, a human capital externality derived from proximity to neighboring firms and the associated information and communication flows. Second, an urbanity externality related to attractive and interesting places that shifts the productivity of a firm because of the benefits associated with a more prestigious address, the image effects of co-location with well-known buildings or urban spaces as well as direct productivity effects related to the ease of attracting more motivated or qualified workers to more attractive locations. Setting the price of labor as the numeraire, perfect competition and zero economic profits imply that the following condition must hold at all commercial locations x across the city.

$$A(x)^{\theta}Z(x)^{\lambda}N^{\omega}S(x)^{1-\omega} - \psi(x)S(x) - N = 0 \quad (19)$$

where $A(x)$ as described in (2) is an employment potentiality and $Z(x)$ is the urbanity potential defined analogically to (3). $\psi(x)$, as before, is the rent that is bid for one unit of space so to equilibrate (zero) profits. Profit maximizing behavior implies:

$$\frac{1-\omega}{\omega}\frac{N}{S(x)} = \psi(x) \quad (20)$$

Commercial bid-rents must adjust to equilibrate the productivity effects of agglomeration benefits. Combining (19) and (20) and solving for $\psi(x)$ we obtain the equilibrium condition for the (office) space bid-rent.

$$\psi(x) = \omega^{\frac{1}{1-\omega}}A(x)^{\frac{\theta}{1-\omega}}Z(x)^{\frac{\lambda}{1-\omega}} \quad (21)$$

Assuming the same construction technology as in the housing sector, the commercial land rent condition takes the following form.

$$\Omega(\mathrm{x}) = (1-\delta)\delta^{\delta}\omega^{\frac{1}{1-\omega}}R(x)^{-\frac{1}{1-\delta}}A(x)^{\frac{\theta}{(1-\omega)(1-\delta)}}Z(x)^{\frac{\lambda}{(1-\omega)(1-\delta)}} \quad (22)$$

As for the residential sector, we can derive a series of additional implications for the price to land ratio, capital to land ratio, the floor space ratio and the employment per space and land densities.

$$\frac{\psi(x)S(x)}{L} = \frac{K+\Omega(x)L}{L} = \Omega(x) + \frac{\delta}{1-\delta}\Omega(x) = \frac{1}{1-\delta}\Omega(x) \quad (23)$$

$$\frac{K_l}{(\bar{L})} = \frac{\psi(x)S(x)-\Omega(x)L}{L} = \frac{\delta}{1-\delta}\Omega(x) \quad (24)$$

$$\frac{S(x)}{L} = \frac{\Omega(x)+K/L}{\psi(x)} = \frac{\frac{1}{1-\delta}\Omega(x)}{\psi(x)} = \delta^{\delta}R(x)^{-\frac{1}{1-\delta}}\psi(x)^{\frac{\delta}{1-\delta}} \quad (25)$$

$$\frac{N}{S(x)} = \frac{EMP(x)}{S(x)} = \frac{\omega}{1-\omega}\psi(x) \quad (26)$$

$$\frac{S(x)}{L}\frac{N}{S(x)} = \frac{N(x)}{L} = \frac{1}{1-\delta}\frac{\omega}{1-\omega}\Omega(x) \quad (27)$$

This simple, but broad set of theoretical implications can be used to set up a battery of reduced form empirical tests whose design and interpretability I discuss in the next section.

3.2 Empirical Strategy

The empirical strategy builds on separate reduced form tests of the equilibrium conditions derived above to back out the effects of accessibility and urbanity on household utility, firm productivity and the spatial structure of cities. Therefore, it is essential to find empirical correspondences to A(x) and Z(x) defined in equations (2) and (3). The main objective is to establish an empirical link between a rent or density measure at location i and densities of economic activity and urbanity at all other locations j, weighted by distance. I establish this link through a so-called potentiality or gravity equation, which has recently gained popularity in the applied urban economics and house price capitalization literature (e.g. Ahlfeldt, 2011b; Cervero, Rood, & Appleyard, 1999; Osland & Thorsen, 2008).

$$POT_i = \sum_j w_j e^{-T \times D_{ij}} \quad (28)$$

where POT is a potentiality measure at location i, w is a weight measure corresponding to the densities in equations (2) and (3), T is the decay parameter and D_{ij} the bilateral straight line distance between two locations i and j in the city in km units. If not referring to virtually dimensionless addresses or photo coordinates, distances will connect to areas based on the locations of their geographic centroids.

The most important potentialities are created to capture access to economic mass and what I referred to as urbanity in the section above. For the former, I set w_j in (28) to the share of workplace employment at total city employment at location j in a representative year (2003 for Berlin, 2001 for London). The urbanity weight follows the definition in (1), that is, photos are weighted by the total number of pictures taken in a given year $\left(\frac{1}{T}\sum_t \frac{n_{ijt}}{N_t}\right)$. Four more potentiality variables will be defined capturing the endowment with 1) contemporary and 2) historic landmark architecture, 3) mainstream and 4) avant-garde cultural facilities. For 1) and 4), I simply set w_j to the inverse of the total number of landmarks and music nodes. I define w_j for 2) in the same way for the case of London, whereas the share at the total building footprint covered by heritage listed buildings will be used in the case of Berlin. For 3), theaters, museums, movie theaters and event spaces receive weights according to the inverse of the number of facilities in each category.

The virtue of a photo potentiality defined according to equation (28) is that we can proxy the composite good "urbanity" with one single variable. One limitation of this approach is that there is only an indirect connection between the perceived level of urbanity and the density of photos taken. Photo activity in some sense may be viewed as the outcome of a production function where the features u that jointly constitute urbanity are the input factors.

$$PPOT_i = \prod_u UPOT_{iu}^{\theta_u} \tag{29}$$

where $PPOT$ and $UPOT_u$ are potentiality variables as defined in (28) capturing the spatial distribution of photos ($PPOT$) and the urbanity features (1–4) discussed above. It is entirely possible that there are increasing or decreasing returns to urbanity in the photo production function, depending on $\sum_u \theta_u \gtreqless 1$ so that changes in the photo potentiality may overstate or understate effective urbanity levels.

To bring the photo potentiality measure into the scale of observable urbanity features, I first estimate the production function in log-linearized form and then rescale the (log) photo potentiality variable to an index (PI) that matches a constant returns to scale output of the observed amenity features ($\sum_u \theta_u = 1$), assuming these are representative in these terms for all elements of urbanity. Since this is a log-linear transformation it will affect the magnitude of the coefficient estimates, but not the models fit of the log-linear empirical specifications I use.

$$\log(PPOT_i) = C + \sum_u \theta_u UPOT_{iu} + \varepsilon_i \tag{30}$$

$$\log(PI_i) = \frac{\log(\sum_j w_j e^{-T \times D_{ij}})}{\sum_u \hat{\theta}_u} \tag{31}$$

With the employment and adjusted photo potentialities at hand, a simple empirical specification can be set up that serves as a basis for a battery of reduced form tests of equations (7), (12–18) and (21–27).

$$\log(Y_i) = a + b \log\left(\sum_j w_j^E \times e^{T^E \times D_{ij}}\right) + c \log\left(\sum_j w_j^P \times e^{T^P \times D_{ij}}\right) + X_i B + \varepsilon_i \tag{32}$$

where Y is one of the rent and density measures listed in Table (5), X_i is a vector of control variables, a, b, c, T^E, and T^P are parameters to be estimated and B is a parameter vector. Equation (32) is evidently non-linear, which imposes some challenges to the estimation of the parameters, especially the decay parameters. To solve the equation at the maximum spatial detail with hundreds of thousands (up to 1.8 million) of photo weights and distances on the right-hand side, I conduct a grid search over all combinations of parameter values $T^E, T^P = \{0.01, 0.02, \dots 0.1, 0.2, \dots 1, 2, \dots, 10\}$. Therefore, I generate potentiality measures for all considered decay parameters before I run separate linearized OLS regressions and choose the R2 maximizing combination with the only parameter restriction being that b, $c > 0$. Beforehand, I adjust the photo potentiality as discussed above for all values of T^P. Irrespectively of how equation (32) is solved, it is important to note that there is an interdependency of the level and decay parameters in the potentiality variables. Lower decay parameters imply a stronger spatial smoothing, reduce the variance of the potentiality measure and normally produce higher level coefficients. An advantage of the potentiality approach is that even in light of a high spatial correlation of the data (e.g. photo and employment densities), the underlying economic phenomena can be empirically distinguishable if they operate with different spatial scope and if different decay parameters apply.

With two potentiality variables based on spatially correlated data, the identification of the appropriate combination of level and decay parameters becomes particularly challenging and there is a risk that the distinct decay parameters are identified appropriately, but assigned to the wrong variable. If the true decay parameters were known, this problem could be circumvented by fixing the parameters and estimating a linearized version of equation (32). While I don't know the exact spatial scope of accessibility and urbanity a priori and need to indentify the decay parameters empirically, I have some priors regarding their relative size. I define urbanity to be constituted by the endowment with aesthetic and consumption amenities that a neighborhood has to offer, which is presumably a very local phenomenon. Similarly, information spillovers that enhance the productivity of firms critically depend on close co-location that enhances physical contacts among workers. In contrast, access to employment opportunities for households means current or potential reductions in commuting, which occurs over significantly larger distances. This implies a relatively smaller decay parameter in the respective potentiality and any parameter combination will have to pass this "sniff test" to be plausible.

I estimate three versions of equation (32). First, a pure version where the only location attributes are the accessibility and urbanity potentialities and the vector X only contains property attributes. Second, an extended version with other location features that do not fall into the abovementioned urbanity categories. Third, a further extended specification that contains the observable urbanity features to decompose the urbanity effect into a component that can be observed directly and a component that is otherwise unobservable but captured by the revealed preference approach.

A key element of the empirical strategy is to test the implications of the bid-rent world based on a variety of response variables Y. Table 5 gives an overview of the considered measures and how the structural parameters can be identified from the reduced form estimates. Evidently, a number of parameters must be known to infer on the structural elasticity parameters from the coefficient estimates, namely α, ω and δ. Evidence suggests that the income share spent on housing (1-α) is relatively stable and can be set to 32% (Davis & Ortalo-Magné, 2011; Rossi-Hansberg, Sarte, & Owens, 2010). Less research has gone into the output elasticity of labor in an equation (19) type production function. Cheshire, Hilber & Kaplanis (2011), estimating a retail productivity equation, provide compelling evidence that a value of 1- ω=0.85 may be a plausible approximation. Although it is not entirely clear to which degree this value generalizes to other commercial sectors, it is notable that their estimates are close to the respective parameter values used in the quantitative Analyses by Lucas & Rossi-Hansberg (2002). While I have to borrow α and ω from the literature, it is, with the data at hand, possible to estimate δ, at least in the case of Berlin. As demonstrated in the appendix, the output elasticity of land (1-δ) falls into the range of 0.42 for residential properties and 0.45 for commercial properties (Table A2), which is somewhat larger than suggested by the conventional rule of thumb that the value of the building structure should be twice the value of the underlying land.

With these parameters at hand, the structural parameters of the model can be derived from the estimation coefficients. At some stages of the empirical analysis, however, a number of issues arise, three of which I attach particular attention.

FSI Regressions

With few exceptions (e.g. McMillen, 2007), the floor space index has enjoyed relatively little popularity as a basis for empirical tests of bid-rent models despite the very interesting insights it has to offer. For one thing, this variable is less evidently correlated with unobserved housing quality, which can greatly influence selling prices of properties and pose a substantial challenge to any MWTP estimate derived from house price regressions. For another thing, acknowledging that cities are not perfectly malleable, the investigation of floor to land area ratios of buildings constructed at different times at comparable locations offers a way to explore the visible traces of the past with contemporary data. At least in European cities, with large historic building stocks that have remained structurally unchanged and preserved over time, building densities mainly reflect the economic fundamentals, i.e., preferences, construction technologies, and regulatory regimes of the times when they were constructed. While I argue that the careful analysis of building densities potentially opens a universe of opportunities to explore the spatio-temporal structure of cities in further research, I leave it to a simple and straightforward model extension in this contribution for the sake of brevity. To distinguish between contemporary and historic effects reflected by the current *FSI* ratios I include interactive terms of the (potentiality) variables of interest and a yearly trend variable with the zero value referring to 1800. With this simple extension, it is possible to distinguish the structural interpretation of parameters into a historic (1800) and a contemporary (2009) scenario.

Gentrification

Another matter arises when running house price regressions on observable urbanity features. In an urban context, many features are not strictly exogenous, but the relationship is particularly interdependent between property prices and music nodes. A large body of gentrification literature discusses how young, creative professionals settle in cheap run-down downtown areas and open avant-garde establishments alike to the considered music nodes. This qualitatively well-documented, but quantitatively less explored process changes the character of the neighborhood, attracts higher-income households and eventually leads to appreciation (Ahlfeldt, 2011a; Clay, 1979), which is an implication that is easy to test in regression house price capitalization models. Therefore, I consider an interactive term of the music node variable with a trend variable defined similar to the trend variable in the FSI regressions, with the only difference being that the zero value is set to the year 2000. This interactive term should capture any relative increase in prices close to these facilities over time, which would be in line with the abovementioned gentrification phenomenon.

Residential Sorting

In the simple bid-rent world outlined above, I have implicitly assumed residents to be homogenous. In reality, however, residents are evidently heterogeneous and are likely to differ in their tastes and preferences for physical housing space, accessibility and urbanity, i.e. β, γ, and 1-α-β-γ. Such heterogeneous preferences should lead to residential sorting with residents that exhibit stronger preferences for either accessibility or urbanity being more likely to live in neighborhoods with a favorable endowment. Such residential sorting may lead to non-linear, usually convex price gradients, which are the envelope of individual bid-rent curves. In the last step of the empirical analyses, I therefore investigate the slope of the price gradients, which should reflect the utility functions of the local population over various levels of accessibility and urbanity in a non-parametric analysis.

I proceed with the following strategy. First, I estimate a semi-parametric version of equation (32).

$$\log(Y_i) = f(EP_i) + g(PI_i) + X_i B + \varepsilon_i \qquad (33)$$

where *EP* and *PI* are the employment potentiality and the photo potentiality index discussed above, with decay parameters T^E and T^P fixed to the values identified in the grid search. To estimate the true non-linear partial correlations conditional on the vector of control variables *X*, I first run an auxiliary regression the following type:

$$\log(Y_i) = a + X_i B + \sum_q DEP_{iq} + \sum_q DPI_{iq} + \varepsilon_i \quad (34)$$

where DEP_q and DPI_q are sets of dummy variables for one percentile bins (q) of EP and PI. I then create the adjusted log prices ($\log(\hat{Y}_i)$-$X_i B$) and use them in a lowess smoothing regression with multiple predictors to estimate the unknown non-linear functions $f(.)$ and $g(.)$.[8] Based on the first derivatives at all transactions i, I estimate local shares of expenditures on accessibility $\gamma_i/(1-\alpha)$ and urbanity $(1-\alpha-\beta-\gamma)_i/(1-\alpha)$ at housing consumption and regress them on the accessibility and urbanity measures, plus population composition attributes in separate regressions.[9] I consider four household attributes, the average income (INC) and AGE of the resident population as well as a proxy for the local composition by ethnicity (London) or citizenship (Berlin) (FOR) and a proxy for education and qualification (UC). For London I use the qualification index based on 2001 census estimates introduced in section 2. For Berlin, the best proxy I can get is the share of votes for the upscale parties FDP/Liberals and Die Grünen/Greens, whose conditional effect (on age and income) following the argumentation from section 2 should serve as a rude proxy for the local education level.

$$\frac{\gamma_i}{(1-\alpha)} = \frac{(1-\delta)f_i'}{1+(1-\delta)(f_i'+g_i')} = a + \mathrm{d}_1 EP_i + \mathrm{d}_2 INC_i + d_3 AGE_i + d_4 FOR_i + d_5 UC_i + \varepsilon_i \quad (35a)$$

$$\frac{(1-\alpha-\beta-\gamma)_i}{(1-\alpha)} = \frac{(1-\delta)g_i'}{1+(1-\delta)(f_i'+g_i')} = a + d_6 PI_i + d_7 INC_i + d_8 AGE_i + d_9 FOR_i + d_{10} UC_i + \varepsilon_i \quad (35b)$$

I use these final empirical specifications to reveal trends in the estimated elasticity parameters over different levels of accessibility and urbanity, the impact of the local population composition and, ultimately, to which degree the population composition explains observable non-linearities, which I interpret as evidence for the presence of residential sorting.

3.3 Empirical Analysis

Utility Effects

I start the presentation and discussion of empirical results with the Berlin baseline estimates depicted in Table 6. Note that the set of *hedonic* controls does not include location

[8] The methodology of the employed estimator relies on the generalized additive models discussed by Hastie & Tibshirani, 1990 (1990).

[9] The first derivatives of the non-linear functions are approximated by the linear fit to a 1% sample centered around each observation *i*.

variables, but is limited to structural characteristics. *Time Effects* are a set of yearly dummy variables controlling for macro shocks during the observation period (2000–2009) that are common to each of the study areas. The interaction effects (*Time x East)* interact the year dummies with a dummy variable denoting transactions occurring within former East-Berlin to allow for a price differential between the formerly separated parts of the city that varies over time and capture potential convergence processes. It is also notable that throughout the paper, *hedonic* controls exclude variables referring either to floor space or land area as space consumption and housing densities are endogenous in the model world and built into the equilibrium conditions. For the same reasons, I also exclude variables denoting building types that are correlated with building densities except for the price to floor space regressions which focus on the internal usage of buildings only. All locational and non-locational control variables used in the models are tabulated in Table A2 in the appendix. To save space I do not present hedonic estimates in the main tables. Full estimation results are presented for selected models in the appendix (Table A3).

Table 6 starts with models (1–3) where the spatial decay parameters are identified in grid-searches for the employment potentiality (1) and the photo potentiality (2) separately as well as and jointly (3). When estimated jointly, the photo potentiality decay in the R2 maximizing model is steep compared to the employment potentiality, indicating a localized effect of urbanity compared to a more general labor market accessibility effect (3). This spatial decay parameter is close to the one found by Ahlfeldt & Maennig (2010b) who investigate the external effects of heritage listed buildings on the property prices of surrounding buildings.

In model (2), where the photo potentiality is the sole location variable, the relatively small decay parameter in conjunction with a relatively large level parameter indicate that the variable absorbs correlated accessibility effects. Similarly, the results suggest that the pure employment potentiality model confounds the employment accessibility and urbanity effects, leading to an upward bias of about 30% when comparing models (1) and (3). The decay parameters from the preferred specification (3) are presented in Figure 4. The results of the grid search in terms of R2 are illustrated in the left panel of in Figure (5). They suggest that the identified parameter combination is a relatively stable configuration as no multiple peaks are evident on the surface. The results from columns (1) to (3) indicate that there is a significant bias if either of the effects is not controlled for efficiently. Minimally, the results from standard models without urbanity controls should be interpreted carefully, taking into account that in many urban environments any accessibility variable will reflect urbanity effects in addition to labor market effects.

Regarding the implied structural model parameters, Table 6 draws a generally comprehensive picture. The parameters of interest are estimated at high levels of statistical significance in almost all models. Even though based on very distinct dependent variables, the implied structural parameters are generally consistent. The structural parameters listed in the bottom of the table imply that a doubling in accessibility increases household utility by about 3–3.5% (γ). A similar increase in urbanity increases utility by 0.3–0.35% ($1-\alpha-\beta-\gamma$). Interpreting these parameters as expenditure shares and expressing them relative to the share of expenditure on housing consumption including accessibility and urbanity ($1-\alpha$), I conclude that about 10% (1%) of total expenditures into housing are paid to enjoy the benefits of accessibility (urbanity).

These parameters suggest that residents attach a much higher value to a centrality with respect to the economic mass of the city than to less tangible benefits of urbanity when purchasing living space. Partially because of the steeper decay, however, there is a significantly larger variation in the photo potentiality than in the employment potentiality across the city, implying that differences in the consumption of urbanity across the city area are significantly larger. For the spatial structure of the city, therefore, the quantitative relevance of accessibility and urbanity are within a more similar range. Moving from the 1st to the 99th percentile location in terms of accessibility (urbanity) increases the equilibrium land rent by about 85–90% (55–70%) according to the preferred estimates (3, 6, 8, 9). In terms of rents paid for housing space these changes imply adjustments of about 38–40% (25–31%.) Following equation (4b), such a change in the price of living space induces a substitution effect that should lead to a reduction in the per capita consumption of housing space by about 27–29% (20–24%). A particularly reassuring feature of these results is that the implied adjustment in per capita space consumption derived from property prices (3), capital to land ratios (6) and even land values (5) and floor space indices (8) are remarkably close to the estimates based on block level population per housing space (9).

There are two exceptions to the generally consistent pattern in Table 6. First, the property price per floor space regressions (4) produce very small accessibility and urbanity effects. One explanation could be unobserved housing quality that is negatively correlated with centrality (typically older parts of the city) and affects the price per square meter floor space more severely than the price per land unit. This explanation is supported by the fact that the introduction of residential characteristics, especially local income levels that should capture correlated housing quality, remedies the problem to some degree (see Table 7). A phenomenon that is in line with previous evidence (Ahlfeldt, 2011b). Second, the baseline floor space index (FSI) regression yields utility effects that are quite far off from the other variables (7) into the opposite direction, especially regarding accessibility. As discussed in the previous sub-section, the results of such an FSI regression need to be interpreted with some care in light of the durability of the building stock. Once the interaction effects of construction year and urbanity, respectively accessibility effects, are allowed for, the implied 2009 structural parameters come down into the range of the other estimates (8). The implied 1800 accessibility share parameter (γ) instead turns out to be more than three times as high as in 2009 (10.84%). Such a discrepancy between historic and contemporary effects might be partially explainable with a transportation technology that has improved over time and has made the economic centrality of a location less important in the presence of individual and public rapid transport. In that sense, these contemporary FSI regressions confirm the existing evidence of a declining value of accessibility available from studies that have looked at land values over time (e.g. Ahlfeldt & Wendland, 2011; McMillen, 1996). Notably, the population density regression (10) produces almost exactly the same structural parameters as the baseline FSI regressions (7), which is plausible given that the density of the current building stock, no matter what historic circumstances it results from, is a key determinant of the current population density.

The estimated hedonic parameters for the internal structural characteristics offer generally little surprise (see Table A3). Since these do not stand in the focus of this analysis, I will skip a lengthy discussion. One variable, however, is particularly interesting in the context of the model: the heritage designation status of a property. As discussed above, the model predicts regulatory constraints that increase the construction/maintenance costs of housing space to reduce land rents, capital to land ratios and building densities measured in terms of the FSI. At the same time, these policies come with sizable benefits to owners/buyers in the form of tax abatements and renovation subsidies. Designation status is also likely correlated with, if not causally related in either direction, to housing quality. The direction of the effect, thus, becomes mainly an empirical issue into which Table 6 results provide some interesting insights. Accordingly, there is a) no significant impact on the land rent, b) a significantly positive effect on the housing rent and c) a significantly negative effect on the FSI. One interpretation of these findings is that the higher housing bid-rents reflect higher, unobserved housing quality. The significantly negative effects on the FSI likely reflect the effects of restrictions that largely prohibit amendments and extensions of listed buildings. Both effects in conjunction with compensation policies tend to cancel out each other in their effects on the land rent.

The "pure" models in Table 6 feature the employment and the photo potentialities as exclusive locational variables. As I argue, the photo potentiality is a revealed preference indicator for attractive spaces which allows capturing empirically what is otherwise difficult to observe. Of course, other more common variables also capture an endowment with attractive features that are correlated with, if not part of, urbanity. It is therefore an important empirical question to which degree the revealed preference indicator really captures otherwise unobservable variation in locational quality. To disentangle this otherwise unobservable from a directly observable part, I estimate the urbanity effects conditional on observable features in Table 7 based on the two variables that are at the very core of the bid-rent model, i.e., prices per units of land and floor space. While for the sake of completeness I attach the implied model parameters in Table 7 – they should be interpreted with some care. Given that the controls included are strong in the sense that they capture urbanity in parts, lower residual effects of the urbanity variable should be interpreted as evidence for the strength of the controls rather than limited relevance of urbanity per se.

Column (1) suggests that the introduction of what can reasonably be described as strong controls used in house prize capitalization studies brings down the urbanity effect by about 40%.[10] In contrast, the estimated accessibility effect hardly changes. Further expanding the set of controls to include explicit urbanity features, that is, architectural and cultural potentialities (2), reduces the residual urbanity effect by some additional percentage points to about 50% compared to the benchmark (Table 6, column 3). The respective potentiality variables are generated using the urbanity decay parameter. The accessibility effect comes down somewhat, too, indicating that the employment potentiality had to

[10] The vector of control variables controls for spatial trends along the x- and y- coordinates, distance to the nearest park, water body, main street and station, the local noise level measured in db as well as shares of non-Germans and several age groups (<6, 6–18, 18–27,45–55,55–65,>65) at the total population and a GfK estimate of the local purchasing power per capita.

some degree captured amenity effects of these features. To conclude this exercise, at least 50% of the urbanity effect captured by the revealed preference indicator come in addition to what we can capture with a rich set of locational control variables. Hence, the revealed preference variable has something to add empirically, making this approach a promising avenue for further research. As in Table 6, the price per floor space regressions draw a somewhat different picture. The introduction of the location and neighborhood controls substantially increases the estimated accessibility and urbanity effects. One possible explanation, as previously discussed, is that the neighborhood effects pick up unobserved housing quality that had previously confounded the estimates. The introduction of the urbanity features reduces both accessibility and urbanity effects by about 40% compared to the benchmark in Table 6.

It is difficult to interpret the coefficients of the architectural and cultural variables introduced in models (2) and (4) in light of the various spatial measures that compete for the urbanity related variation, especially the spatial trends (X/Y-coordinates) and the photo potentiality. However, as discussed in the section above, it is especially interesting to look at the (relative) price trends in proximity to the music nodes in light of the suspected gentrification processes. Indeed, as reflected by the significantly positive coefficient on the interactive term in model (5), prices appreciated significantly faster over the observation period (2000–2009) in neighborhoods with a high concentration of such avant-garde cultural facilities. Another interesting result is the consistently positive effect of the heritage potentiality variable, reflecting a positive willingness to pay for co-location with heritage listed buildings. Together with the non-negative internal price effects revealed in Tables (5–6), this finding indicates that the current practice of heritage preservation policy in Berlin benefits neighboring property owners without harming those who own a listed building. While this combination points to potentially welfare enhancing effects, these need to be weighed against the significant constraints on housing supply suggested by the FSI regressions in Table 6. If the latter dominates and these policies substantially hinder construction activity to keep up with increasing demand, a supply driven increase in property prices would be the result, which could lead to affordability problems in the long run (Hilber & Vermeulen, 2010).

Within the constraints of data availability, I replicate a number of Table 5 and 6 models for London, using the log price per square meter floor space as a dependent variable. Despite the distinct dependent variables, columns (1) and (2) show similar results to same columns in Table 6. First, the grid searches yield a similar decay parameter for the employment potentiality (0.7 vs. 0.9, column 1) and the same value for the photo potentiality (1, column 2). This is particularly encouraging as it suggests that these variables capture some general and important spatial phenomena. Second, assuming the critical parameter in the housing construction function (δ) generalizes from Berlin to London, the critical accessibility and urbanity parameters as well as the implied effects on the spatial structure are within a similar range in both cities. Once a grid search is run over all parameter combinations of decay parameters in the accessibility and urbanity variable, the results differ substantially from those for Berlin. As illustrated in Figure 6, the grid search suggests an R2 maximizing parameter combination with a relatively strong decay in the employment accessibility variable (4) and a much lower decay in the photo potentiality (1) (column, 3). This would be a world where urbanity clearly dominates accessibility in terms of utility effects and as a determinant of the spatial structure of the city. As discussed above, it is ambitious to empirically identify the decay parameters in light of the relatively strong spatial correlation of employment and photo densities so that the critical assessment of the results seems warranted at all stages. This combination clearly runs counter to plausibility considerations that dictate the effects of urbanity to be more local in scope than those of labor market accessibility. Assuming that these results successfully distinguish the two spatial phenomena with distinct range, but confound the underlying data (employment and photo densities) due the strong spatial correlation (see Figure 3), I flip the decay parameter to match variables (employment and photo potentialities), economic phenomena (accessibility, urbanity) and decay (wide, narrow) in a plausible way (column 4). In this specification, accessibility and urbanity effects are much closer to the Berlin results. Doubling accessibility (urbanity) increases utility by about 2.2% (0.3%). The implied shares at housing expenditures amount to about 6.9% (0.9%). Even in this more careful specification (compared to column 3), urbanity is an important determinant of city structure. The introduction of the urbanity variable (4) reduces the magnitude of the accessibility parameters by more than 50% (compared to column 1). The quantitative effects on prices at different locations (moving from the 1st to the 99th percentile) are even larger for the urbanity than for the accessibility variable (51% vs. 24% in terms of housing rent).

In columns (5–6), additional location control variables are added to the model following the procedure in Table 7. Column (5) adds a range of location and neighborhood controls, which increase accessibility at the expense of urbanity effects. Regarding the effects on the spatial structure, the inclusion of these variables brings the residual urbanity effect captured by the photo potentiality down by about one half. Again, the reduction does not necessarily imply that the urbanity effects are biased in model (4), but that the spatial variables do a relatively good job in capturing amenities that concentrate in some areas more than in others. The introduction of variables that capture urbanity features further brings down the photo potentiality coefficient. Still, about 30% of the urbanity effects captured by the revealed preference variable remain otherwise unobservable. Also, it's notable that the reduction in the (residual) urbanity effect is largely driven by the introduction of neighborhood controls, especially income, which are typically problematic due to endogineity issues. Finally, the interaction effect of the music node potentiality and a time trend again points to a more rapid appreciation in the vicinity of avant-garde cultural faculties, which is in line with the theories and anecdotal evidence known from the gentrification literature.

Productivity Effects

Equation (32) also serves as a starting point for a battery of reduced from estimates based on distinct dependent variables to infer on total factor productivity effects of good access to co-located employment and favorable "urbanity" endowment. Table 9 shows the results from "pure" models with no other location controls than the employment spillover variable and the photo potentiality. The structural interpretation of the agglomeration parameters of interest as well as the implied effects on the spatial structure of land rents, office space prices as well as space per employee are attached at the bottom of the Table. Again, the variables of interest are estimated at high levels of statistical significance. The implied structural parameters are by and large consistent across specifications, and even more stable than in the residential models. In particular, the price per floor space (4) and the FSI (7) regressions yield estimates that are within a reasonable range compared to the other estimates. The most notable exception is the employment per land area regression (10), which produces an employment spillover effect that is several orders of magnitude higher than in any other model. Even though I instrument the employment potential using distance to the CBD in a 2SLS procedure, the large estimate of the spillover parameter should be interpreted with care in light of the mechanical relationship between employment shares that appear on both sides of the equation.

The estimates in the first model, using the employment spillover variable only, suggest a roughly 4% effect on TFP for a doubling in effective access to local workforce (1). As in the residential models, the effect comes down once the photo potentiality is introduced (3), implying that different forms of agglomeration economies are present and the pure information spillover effect may be overstated if urbanity effects are not accounted for. The models featuring both variables suggest significantly larger spillover than urbanity effects. The spillover elasticity parameter ranges between 2–3% in most of the models while the urbanity parameter usually falls into a range of 0.3–0.5%. To some degree, this is related to an even stronger spatial decay identified for the urbanity compared to the spillover component (see Figure 4). Again, the relatively large variation in urbanity across the city translates into an effect on the spatial structure of the city in terms of bid-rents and space per employee that is comparable to the spillover effect. As the results from the price per land area regressions suggest (3), moving from the 1st to the 99th percentile location in terms of employment access (urbanity) yields similar effects in terms of land rent (175%/170%), office space rent, (88%/85%) and space occupied per employee (-47%/-46%). Again, it is particularly reassuring that the effects on occupation of space indirectly derived from the property price regressions are roughly in line with the findings of the office space regression (9): (-58%/-42%).

An interesting and maybe somewhat unexpected finding becomes evident from the decomposition regression in Table 10 where I add locational characteristics to the baseline models from Table 9 (columns 3 and 4). The additional controls tend to reduce the spillover component significantly (up to about 40%), indicating that part of the estimated spillover effect can be explained by correlated location characteristics. Still, the spillover parameter is positive and estimated highly statistically significant. In contrast, the (residual) urbanity effect remains stable or even increases, implying that the variable captures some very local benefits that are not captured by these variables, for example, the prestige attached to "prime" addresses and public exposure.

Another important insight can be gained from comparison of the effects accessibility and urbanity exhibit on bid-rents of residents and firms. Since both are stronger for firms, we expect firms to outbid residents at accessible locations and especially at places with a favorable urbanity endowment, which will drive economic activity into urban clusters. One typical outcome of these forces is the “Mills” map with one dominating business core, surrounded by a residential hinterland, although more polycentric configurations are possible.

Sorting

In the analyses so far, a (log) linear approximation of the relationship between various dependent variables and the accessibility and urbanity proxies has been assumed to be an appropriate functional form. Within the constraints of the model world, which assumes homogenous residents (and firms), this is a plausible assumption. In reality, of course, heterogeneous preferences should affect residents' willingness to pay for accessibility and urbanity so that those with stronger preferences will outbid others at more accessible and urban locations. Given that the individual bid-rent curve is determined by the individual utility function, and the price gradients we observe are the envelope of all individual bid-rent functions, such a residential sorting will affect the slope of the gradients at different levels of accessibility and urbanity. Putting the argument in the reverse order, I compare the slope of the gradients to the composition of the local population to assess the degree to which the heterogeneity in the gradients can be explained by differences in the composition of the local population and to identify which population groups apparently derive a particularly large utility from accessibility and urbanity.

Figure 7 shows non-linear gradient estimates for Berlin based on prices per land area that have been adjusted for internal and locational characteristics as described in the empirical strategy section (equation 34). Figure 7 confirms that prices tend to generally increase in accessibility and urbanity, but also reveals some evident non-linearities. Both gradients vacillate between convexity (at lower levels) and concavity (at higher level), but with a significantly more pronounced degree of convexity (concavity) for the accessibility (urbanity) gradient. The analogical picture for London (Figure 8) similarly shows gradients that follow a convex-concave shape, but the convex shape is generally more dominant. At very low levels of accessibility prices even tend to decrease in accessibility, before the relationship turns to exhibit the expected positive sign. This negative relationship is difficult to explain by residential sorting alone and could reflect some kind of desirable amenity at remote locations that is not appropriately accounted for in the empirical models.

To test whether the differences in the local slopes of the gradients are systematically related to the composition of the resident population, I recover the first derivatives at each observation and compute the shares of housing expenditure on accessibility and urbanity following the procedure described in the empirical strategy and regress them on variables that capture the socio-economic composition of the local residents (equations 35 a/b). The results are presented in Tables 11 (Berlin) and 12 (London). For each city I regress the implied expenditure shares on a potentiality measure (employment or photo) alone and in conjunction with the variables capturing the residential composition. To facilitate a straightforward comparison standardized beta coefficients are shown.

For both cities I find a significant degree of convexity in the accessibility gradient as indicated by positive signs on the employment potentiality coefficients in columns (1). Once the population composition variables are added (2) the coefficients come down by about two thirds (Berlin) to four fifth (London). This pattern is indicative that the convex shape in the accessibility gradients is at least partially attributable to residents who derive a larger utility from labor market access and correspondingly live in more accessible areas. An interesting element in the results is that the presence of highly qualified significantly increases the implied expenditure shares on accessibility in both cities, indicating that this group derives a particularly large utility from this location feature.

Regarding the urbanity gradients, I find a negative sign of the photo potentiality coefficient in Berlin (Table 11, column 3), which is consistent with Figure 7. One explanation could be the presence of a disamenity related to overcrowding by tourists or local visitors at locations that are enjoyable in terms of aesthetic beauty or other consumption amenities. This would create a countervailing externality that could partially cancel out positive utility effects. The same gradient for London is evidently convex (Table 12, column 3), which is in line with Figure 8 and is the typical expected outcome of sorting processes. The introduction of the socio-economic controls reduces the photo potentiality coefficients, but less than the employment potentiality coefficients. The directions of the effects of the population variables are largely consistent across both cities. One interesting finding of the urbanity regressions in Tables 11 and 12 is that the rich seem to derive a below average utility from urbanity. The other side of the coin is that the rich have relatively stronger preferences for housing space, especially in Berlin, where the relative utility from accessibility also seem to be below average for the wealthy. Another particularly interesting common effect is that a larger proportion of highly qualified tends to increase the utility from urbanity. This is in line with the descriptive evidence from section 2 which points to significant concentration of the highly qualified in urbanity areas. Even though the used proxies for the qualification level are imperfect at best, the consistency in the findings across two cities and two fundamental urban location features indicates that a particular preference of the high-skilled for central locations with a favorable endowment could be a general phenomenon, at least in resurgent dense cities discussed by Glaeser et al. (Glaeser et al., 2001).

4 Conclusion

Cities are more than centers of production. And city centers more than job agglomerations. For this analysis, I let people vote with their cameras and find that they clearly choose the city centers to be the most attractive areas in Berlin, Germany, and London, UK. Specifically, I investigate the perceived attractiveness of urban space using a micro level revealed preference indicator, which I construct based on a large data set of geo-tagged photos shared in web-communities and which is then merged with a rich data set on observable location features. As expected, access to jobs, consumption amenities and aesthetic beauty, be it man-made or natural, make places more attractive. And even conditional on observable amenities, central areas are still considerably more attractive than their remote counterparts.

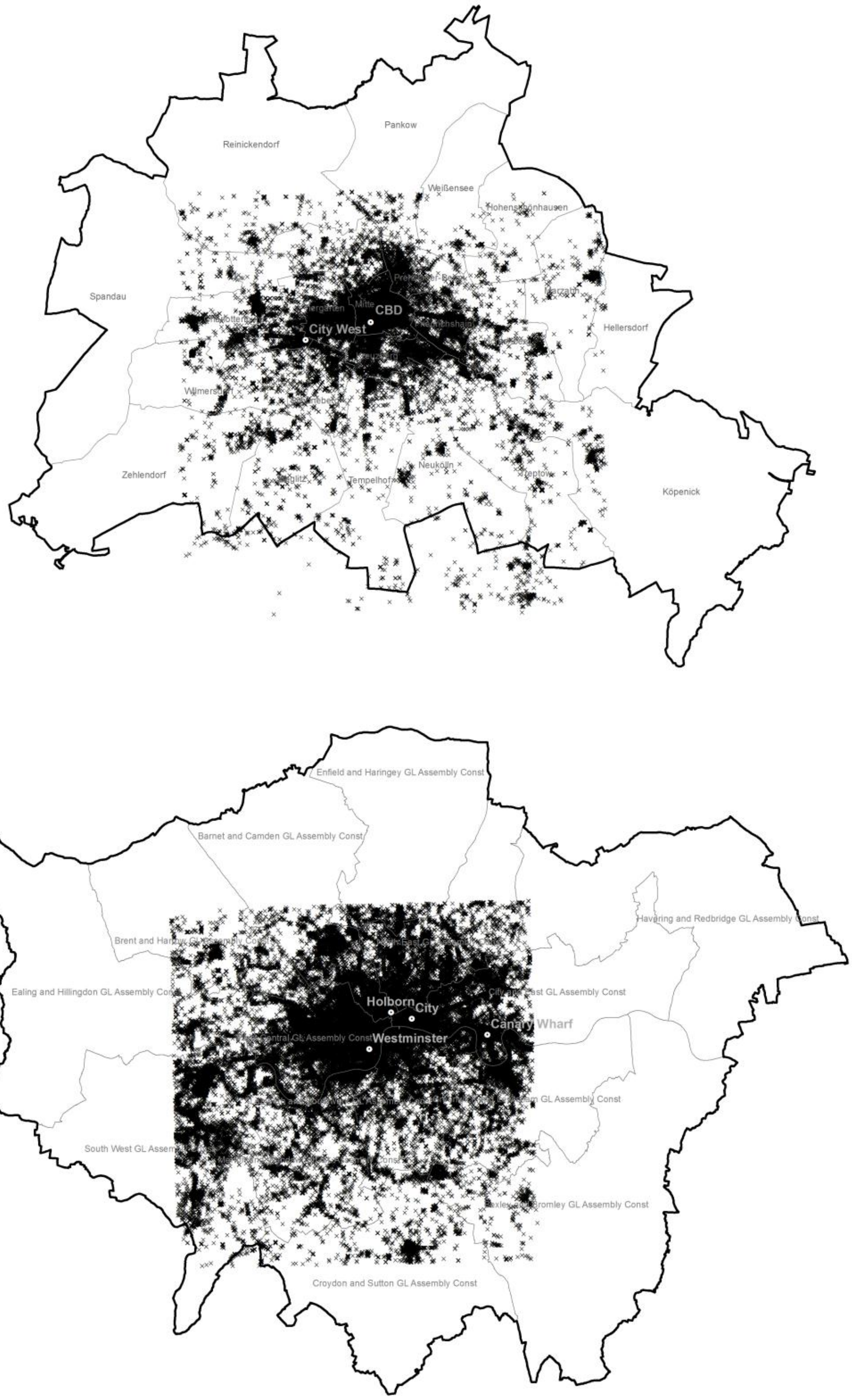
Merging these data with detailed property transaction data and household characteristics, additional insights emerge as individual photo observations can be used to capture otherwise unobservable dimensions of urbanity. I show that there is a positive and significant willingness to pay for urbanity defined along these lines both by residents and firms. In terms of the quantitative effects on the spatial structure of cities urbanity turns out to be similarly important as labor market accessibility and information spillovers. Moreover, urbanity tends to attract the highly qualified – a workforce that is particularly attractive as input factor for human capital intensive industries.

Besides these core results, a number of significant contributions to more or less under researched areas emerge from the analysis of this unusually rich micro-level data set. I show that structural parameters from a simple bid-rent framework can be consistently estimated based on a variety of variables, including prices per land area, land values, capital to land rations, floor area ratios (FSI) or space occupied by households and workers, among others. My results further provide evidence for a significant impact of the built environment on perceived attractiveness of urban space, a factor that despite its intuitively comprehensive relevance has received limited attention in the economics literature. Positive effects are found for contemporary landmark architecture but especially for historic buildings that are often protected by heritage preservation policies. These positive external benefits, however, come at a social cost that adds to the direct monetary compensations paid to landlords for the restrictions of property rights they suffer. Preservation efforts reduce supply of housing and office space and, thus, (artificially) drive prices and potentially induce affordability problems. Another interesting finding relates to the unique data set on avant-garde music establishments. I find that their surrounding neighborhoods have significantly appreciated over the past decade in Berlin and London. These dynamics are in line with gentrification models that view such facilities as catalysts for neighborhood change.

Finally, the results of this paper shed some light on the fundamental mechanisms that drive economic densities and agglomeration. Traditional urban economics models have viewed economic activity as being concentrated in the CBD which then attracted residents facing commuting costs to their workplace. Against this background, the massive decentralization of production during the 20^{th} century, which has transformed many traditional urban economies dominated by a CBD into dispersed metropolitan area clusters, has questioned the role downtowns may play in the future. This analysis based two amenity cities opens a promising avenue: a future as centers of consumption for a highly qualified workforce, which in turn attracts human capital intense industries.

Figures

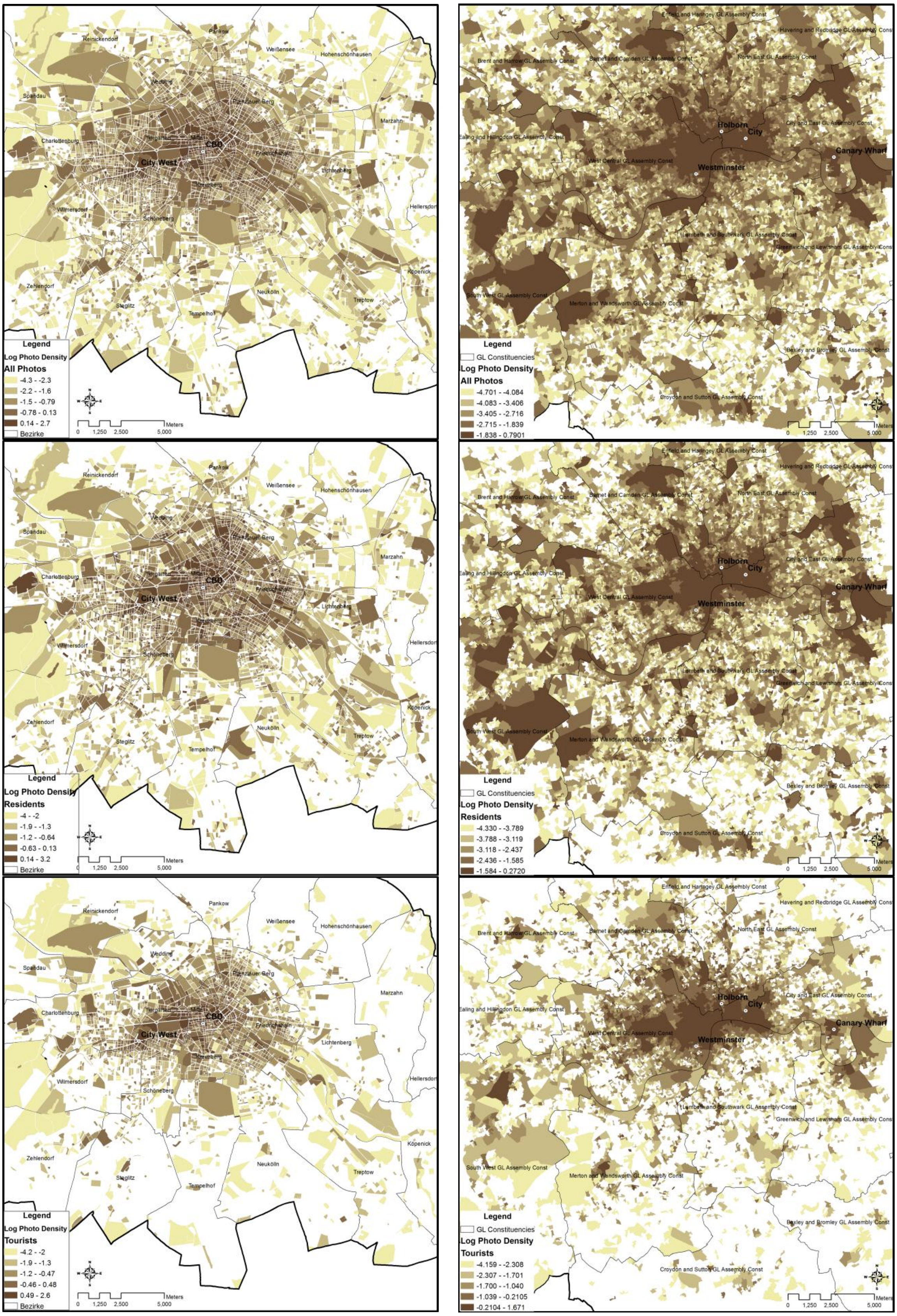
Fig. 1 Distribution of Photo Nodes in Berlin (Top) and London (Bottom)



Notes: Own illustration based on Eric Fisher Geotagger's World Atlas. To improve visibility, a roughly 20% (random) sample of all photos is used in these illustrations.

Fig. 2 Photo Densities

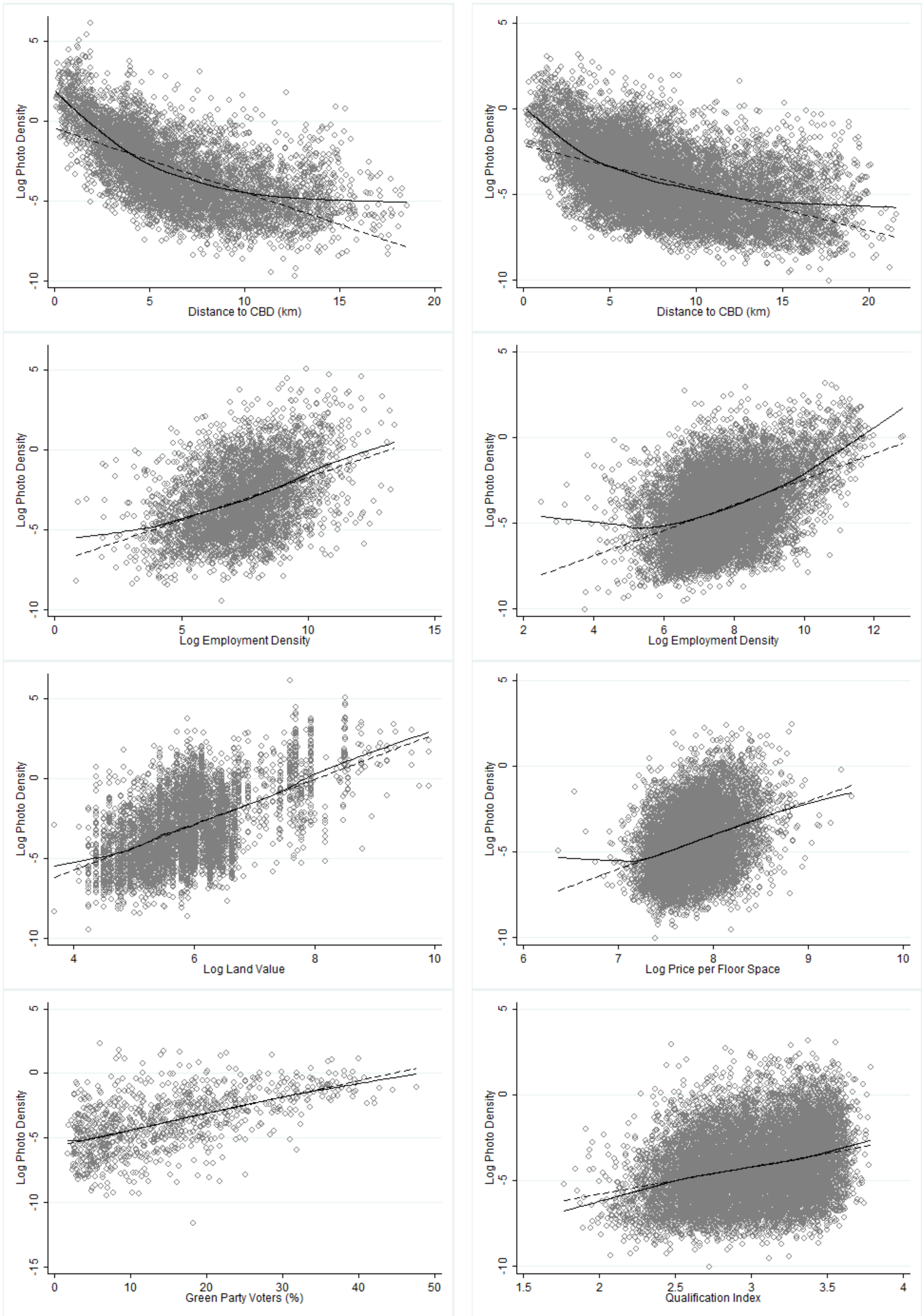
Berlin **London**



Notes: Maps show photo densities as defined in equation (1) for Berlin (left) and London (right).

Fig. 3 Photo Density Distribution in Berlin and London

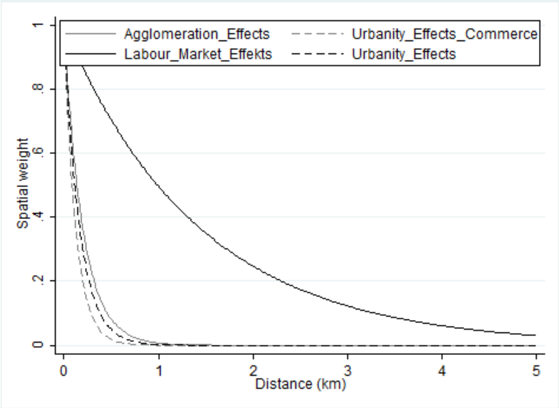
Berlin **London**



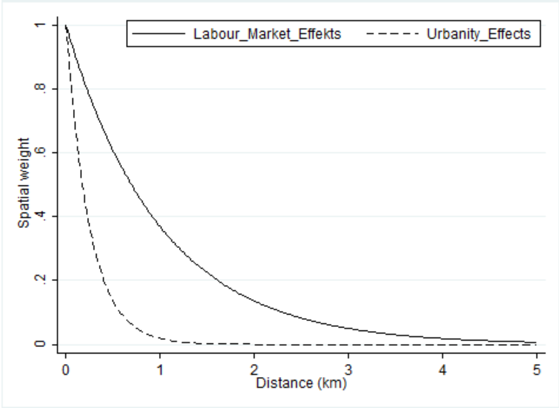
Notes: Own illustration. Left (right) illustrations refer to Berlin (London). Dashed lines are linear predictions; solid lines represent the locally weighted regressions fit.

Fig. 4 Decay Parameters

Berlin

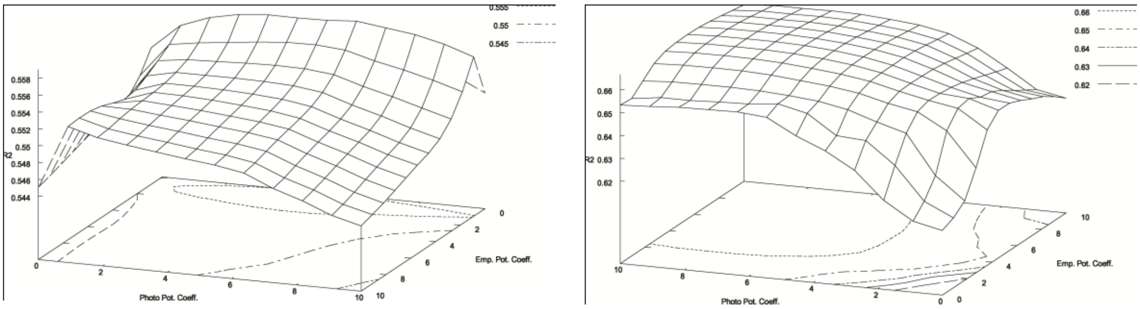


London



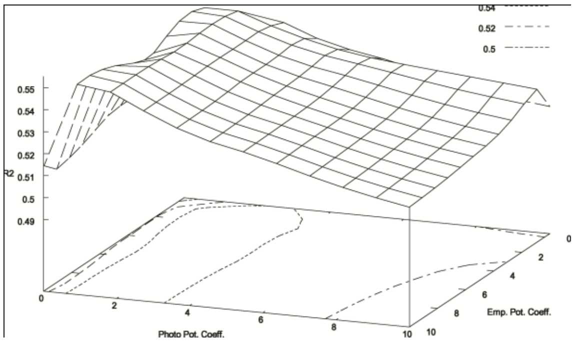
Notes: Decay parameters are identified in separate grid-searches for residential and commercial properties for Berlin (left). Estimation results are in Table 6, (3) and Table 9, (3). Baseline results for London (residential, right) are in Table 8, (4),

Fig. 5 Grid Search over Decay Parameters Berlin



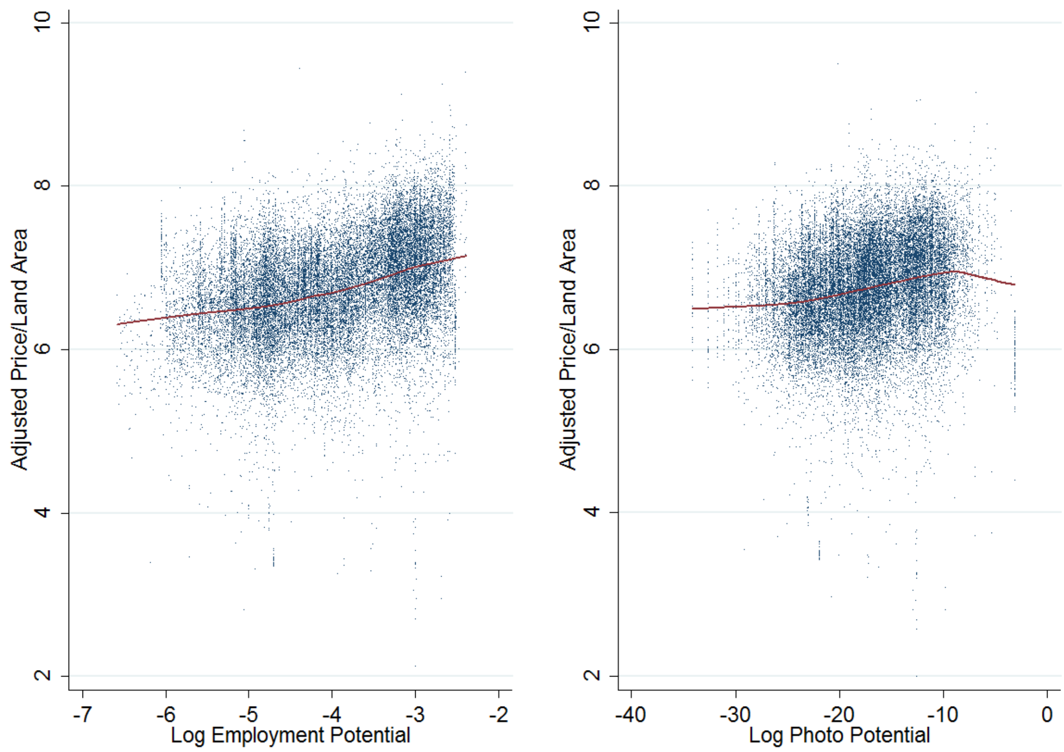
Notes: 3D surfaces illustrate R2 (on z-axes) from grid searches on photo potentiality (x-axes) and employment potentiality (y-axes) decay parameters for residential (left) and commercial (properties).

Fig. 6 Grid Search over Decay Parameters London



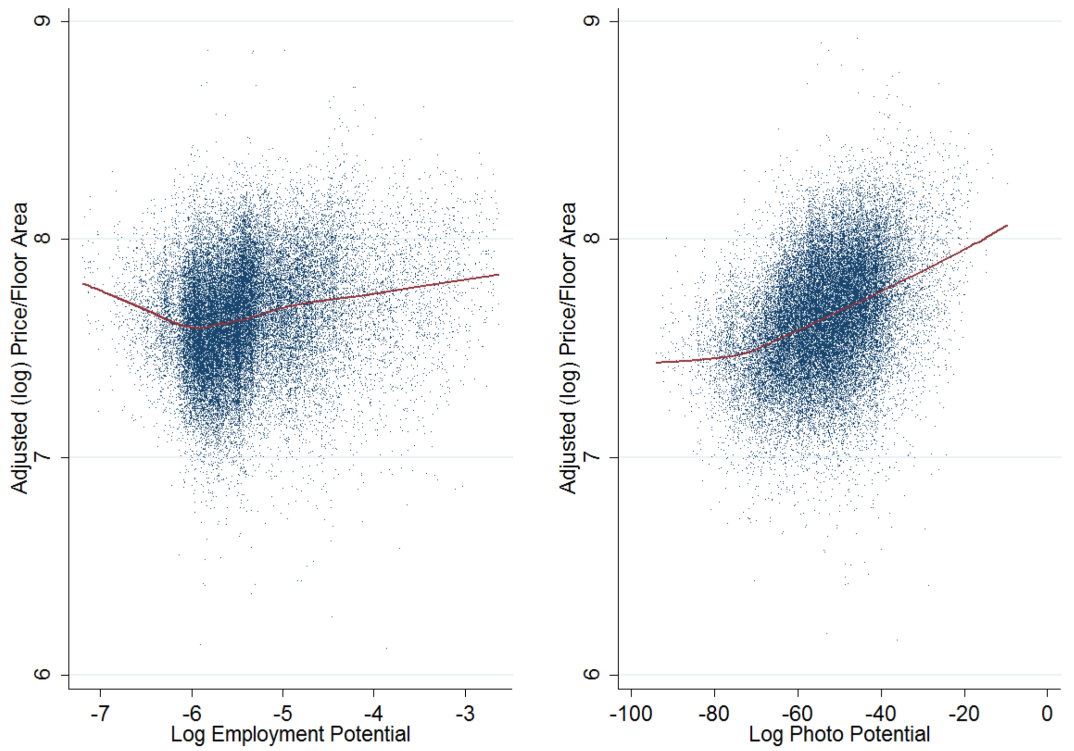
Notes: 3D surfaces illustrate the R2 (on z-axes) from a grid search on photo potentiality (x-axes) and employment potentiality (y-axes) decay parameters for residential properties.

Fig. 7 MLOWESS Regressions - Berlin



Notes: Graphs show the results of multi-variate lowess regressions of adjusted (log) price/land area on (log) Employment and Photo Potentialities using the methodology for generalized additive models (Hastie & Tibshirani, 1990).

Fig. 8 MLOWESS Regressions - London



Notes: Graphs show the results of multi-variate lowess regressions of adjusted (log) price/floor area on (log) Employment and Photo Potentialities using the methodology for generalised additive models (Hastie & Tibshirani, 1990).

Tables

Tab. 1 Photos by type and year

	Berlin			London		
	All	Residents	Tourists	All	Residents	Tourists
2002	2,216	672	797	10,043	3,707	3,963
2003	4,414	1,248	1,591	17,909	5,869	7,654
2004	9,128	1,443	3,861	39,910	10,995	18,449
2005	24,335	5,497	9,676	81,840	37,850	24,397
2006	76,875	21,424	28,204	226,447	110,342	58,297
2007	135,456	33,774	44,101	427,319	182,256	104,473
2008	187,859	48,497	49,895	486,999	218,655	109,278
2009	193,481	52,653	54,908	558,936	237,177	112,587
Total	633,764	165,208	193,033	1,849,403	806,851	439,098

Notes: Differences between totals and the sum of residents and tourists exist because some pictures could not be assigned to either category

Tab. 2 Descriptive Statistics

	No Photos		All Photos		Residents		Tourists	
Berlin	mean	SD	mean	SD	mean	SD	mean	SD
Photo density index	0.00	0.00	0.89	8.17	1.28	23.24	1.97	11.09
Distance to CBD (km)	10.36	3.20	6.61	3.57	6.23	3.52	4.86	3.10
Distance to Station (km)	0.96	0.63	0.61	0.49	0.57	0.46	0.48	0.40
Primary Road (Dummy)	0.19	0.39	0.20	0.40	0.19	0.39	0.21	0.41
Pop. Dens. (1000/km^2)	7.78	10.51	14.06	16.31	14.42	16.58	15.62	17.52
Emp.Dens. (1000/km^2)	0.85	3.53	4.97	23.23	5.51	23.56	7.70	29.63
Park (Dummy)	0.59	0.49	0.70	0.46	0.70	0.46	0.73	0.44
Water(Dummy)	0.09	0.29	0.17	0.37	0.18	0.38	0.22	0.41
Cont. Sig. Building (Count)	0.00	0.05	0.05	0.27	0.06	0.30	0.09	0.37
Mon. Density	2.44	9.27	6.61	15.97	6.89	16.02	9.18	18.88
Music Nodes (Count)	0.00	0.04	0.05	0.34	0.06	0.38	0.10	0.48
Cultural Nodes (Count)	0.00	0.05	0.02	0.17	0.02	0.19	0.04	0.24
Top 20 Tourist (Dummy)	0.00	0.03	0.02	0.14	0.02	0.14	0.04	0.19
Gov. District (Dummy)	0.00	0.00	0.00	0.07	0.01	0.08	0.01	0.10
Berlin Wall (Dummy)	0.01	0.10	0.05	0.22	0.06	0.23	0.07	0.26
N (Statistical Blocks))	5689		5860		4613		2616	
London								
Photo Density (per km2)	0.00	0.00	0.14	0.69	0.19	0.96	0.29	1.45
Distance to CBD (km)	11.96	4.00	8.16	4.09	7.86	4.00	6.91	3.92
Distance to Station (km)	2.90	2.66	1.48	1.80	1.39	1.71	1.03	1.40
Primary Road (Dummy)	0.17	0.38	0.28	0.45	0.29	0.45	0.33	0.47
Emp.Dens. (1000/km^2)	1.89	3.81	5.17	12.25	5.62	13.09	8.54	17.78
Pop. Density (1000/km2)	1.68	1.94	12.45	9.14	12.34	9.08	12.10	10,00
Thames (Dummy)	0.01	0.08	0.04	0.20	0.05	0.21	0.07	0.26
Water (Dummy)	0.07	0.25	0.08	0.27	0.08	0.28	0.09	0.28
Park (Dummy)	0.09	0.29	0.11	0.31	0.11	0.32	0.13	0.34
Cont. Sig. Building (Count)	0.00	0.04	0.03	0.26	0.03	0.28	0.06	0.39
Hist. Sig. Building (Count)	0.00	0.00	0.01	0.16	0.01	0.17	0.02	0.24
Cultural Node (Count)	0.00	0.04	0.04	0.31	0.04	0.33	0.08	0.47
Music Nodes (Count)	0.00	0.03	0.04	0.37	0.05	0.40	0.09	0.56
Top 20 Tourist (Dummy)	0.00	0.00	0.00	0.05	0.00	0.06	0.01	0.08
N (Output Areas)	2966		10799		9303		4544	

Notes: All Photos/Residents/Tourists are the group of blocks/output areas that contain at least one recorded picture taken (by residents or tourists). Non-photo is the group of the remaining blocks and output areas.

Tab. 3 Determinants of Photo Activity (Berlin)

	(1) Photo Activity (0,1)	(2) Log Photo Density	(3) Log Photo Density Residents	(4) Log Photo Density Tourists	(5) Resident Photo (0,1)	(6) Tourist Photo (0,1)
	Logit	OLS	OLS	OLS	Logit	Logit
Distance to CBD (km)	-0.240***	-0.324***	-0.250***	-0.353***	0.124***	-0.112***
	(0.008)	(0.008)	(0.009)	(0.014)	(0.001)	(0.002)
Distance to Station (km)	-0.440***	-0.501***	-0.504***	-0.513***	0.062***	-0.079***
	(0.045)	(0.052)	(0.061)	(0.103)	(0.011)	(0.012)
Primary Road (Dummy)	-0.446***	0.523***	0.596***	0.596***	0.043***	0.046***
	(0.058)	(0.059)	(0.065)	(0.088)	(0.010)	(0.009)
Log Employment Density (per km^2)	0.127***	0.016*	-0.008	0.012	-0.002	0.000
	(0.007)	(0.008)	(0.009)	(0.013)	(0.001)	(0.001)
Log Population Density (per km^2)	-0.041***	-0.027***	-0.015	-0.058***	0.051***	-0.042***
	(0.007)	(0.007)	(0.008)	(0.011)	(0.001)	(0.001)
Park (Dummy)	0.067	-0.009	-0.012	0.158	-0.130***	0.040***
	(0.048)	(0.051)	(0.056)	(0.082)	(0.008)	(0.008)
Water(Dummy)	0.585***	0.546***	0.383***	0.317**	-0.081***	0.006
	(0.073)	(0.067)	(0.070)	(0.097)	(0.007)	(0.007)
Signature Building Con-temporary (Count)	1.367***	0.681***	0.470***	0.549***	-0.102***	0.013***
	(0.257)	(0.091)	(0.088)	(0.104)	(0.005)	(0.003)
Log Monument Density (% at block area)	0.070***	0.023**	0.005	0.020	-0.028***	0.031***
	(0.008)	(0.007)	(0.008)	(0.011)	(0.001)	(0.001)
Music Nodes (Count)	1.775***	0.401***	0.462***	0.068	0.097***	-0.073***
	(0.474)	(0.068)	(0.071)	(0.082)	(0.003)	(0.003)
Cultural Nodes (Count)	0.737**	0.541***	0.446**	0.322	-0.039***	0.030***
	(0.282)	(0.161)	(0.145)	(0.166)	(0.008)	(0.006)
Top 20 Tourist Highlight (Dummy)	1.427**	0.923***	0.776***	0.816***	-0.002	-0.071***
	(0.506)	(0.168)	(0.172)	(0.184)	(0.011)	(0.009)
Berlin Wall (Dummy)		0.954***	0.372	0.802**	-0.073***	-0.179***
		(0.283)	(0.259)	(0.270)	(0.017)	(0.014)
Government District (dummy)	0.911***	0.218	-0.081	0.426**	-0.243***	0.012
	(0.185)	(0.117)	(0.118)	(0.152)	(0.009)	(0.007)
Unit	Blocks	Blocks	Blocks	Blocks	Photos	Photos
Observations	11520	5860	4613	2616	633635	633635
R^2		0.441	0.342	0.405		
AIC	12100.0	23070.6	17821.8	10498.6	691571.5	759674.9

Notes: Robust standard errors are in parenthesis. All coefficients correspond to marginal effects (at the man for logit models. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Tab. 4 Determinants of Photo Activity (London)

	(1) Photo Activity (0,1)	(2) Log Photo Density	(3) Log Photo Density Residents	(4) Log Photo Density Tourists	(5) Resident Photo (0,1)	(6) Tourist Photo (0,1)
	Logit	OLS	OLS	OLS	Logit	Logit
Distance to CBD (km)	-0.267***	-0.200***	-0.175***	-0.140***	0.027***	-0.033***
	(0.008)	(0.005)	(0.006)	(0.008)	(0.001)	(0.001)
Distance to Station (km)	-0.025*	-0.016	0.019	-0.072***	0.140***	-0.267***
	(0.013)	(0.011)	(0.013)	(0.020)	(0.002)	(0.005)
Primary Road (Dummy)	0.310***	0.140***	0.139***	-0.114*	0.055***	-0.127***
	(0.060)	(0.035)	(0.037)	(0.051)	(0.004)	(0.005)
Log Employment Density (per km2)	0.459***	0.446***	0.380***	0.339***	-0.069***	0.062***
	(0.029)	(0.016)	(0.017)	(0.021)	(0.001)	(0.002)
Log Population Density (per km2)	-1.280***	-0.185***	-0.107***	0.235***	0.128***	-0.100***
	(0.047)	(0.024)	(0.026)	(0.034)	(0.001)	(0.002)
Thames River (Dummy)	1.384***	0.866***	0.751***	0.275**	-0.281***	0.112***
	(0.241)	(0.073)	(0.075)	(0.090)	(0.004)	(0.005)
Water(Dummy)	0.139	0.076	0.152**	-0.225**	0.307***	-0.162***
	(0.094)	(0.055)	(0.057)	(0.080)	(0.007)	(0.009)
Park (Dummy)	0.248**	0.429***	0.386***	0.460***	-0.017***	0.120***
	(0.082)	(0.053)	(0.057)	(0.074)	(0.005)	(0.006)
Signature Building Contemporary (Count)	0.310	0.058	0.120	0.151	0.056***	-0.045***
	(0.545)	(0.066)	(0.063)	(0.082)	(0.001)	(0.001)
Signature Building Historic (Count)		0.069	-0.054	0.347*	-0.074***	0.045***
		(0.131)	(0.121)	(0.168)	(0.002)	(0.002)
Cultural Nodes (Count)	0.362	0.274**	0.304***	0.271**	0.015***	-0.011***
	(0.423)	(0.083)	(0.085)	(0.084)	(0.001)	(0.001)
Music Nodes (Count)	1.785**	0.342***	0.374***	0.240***	0.043***	-0.018***
	(0.576)	(0.068)	(0.070)	(0.059)	(0.001)	(0.001)
Top 20 Tourist Highlight (Dummy)		1.632***	1.381***	2.262***	-0.692***	0.418***
		(0.276)	(0.283)	(0.307)	(0.004)	(0.004)
Unit	OA	OA	OA	OA	Photos	Photos
Observations	13676	10799	9303	4544	1957081	1957081
R^2		0.356	0.292	0.328		
AIC	11423.5	41066.0	35375.5	17212.4	2555030.7	2038041.7

Notes: Robust standard errors are in parenthesis. All coefficients correspond to marginal effects (at the man for logit models. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Tab. 5 Structural Interpretation

Response Variable	Coefficient Interpretation: Residents	Commerce
Price/Floor Space Population or Employees/Floor Space Unit	$\beta = \frac{(1-\alpha)}{1+(\hat{b}+\hat{c})}$ $\gamma = \frac{\hat{b}\,(1-\alpha)}{1+\hat{b}+\hat{c}}$ $1-\alpha-\beta-\gamma = \frac{\hat{c}\,(1-\alpha)}{1+\hat{b}+\hat{c}}$	$\theta = (1-\omega)\hat{b}$ $\lambda = (1-\omega)\hat{c}$
Price/Land Area Land Value / Land Area Capital to Land Ratio Population or Employees / Land Area	$\beta = \frac{1-\alpha}{1+(\hat{b}+\hat{c})(1-\delta)}$ $\gamma = \frac{(1-\alpha)(1-\delta)\hat{b}}{1+(\hat{b}+\hat{c})(1-\delta)}$ $1-\alpha-\beta-\gamma = \frac{(1-\alpha)(1-\delta)\hat{c}}{1+(\hat{b}+\hat{c})(1-\delta)}$	$\theta = (1-\omega)(1-\delta)\hat{b}$ $\lambda = (1-\omega)(1-\delta)\hat{c}$
Floor Space Index (Floor Space/Land Area)	$\beta = \frac{(1-\alpha)}{1+\frac{1-\delta}{\delta}(\hat{b}+\hat{c})}$ $\gamma = \frac{(1-\alpha)(1-\delta)\hat{b}}{\delta+(1-\delta)(\hat{b}+\hat{c})}$ $1-\alpha-\beta-\gamma = \frac{(1-\alpha)(1-\delta)\hat{c}}{\delta+(1-\delta)(\hat{b}+\hat{c})}$	$\theta = \frac{(1-\omega)(1-\delta)\hat{b}}{\delta}$ $\lambda = \frac{(1-\omega)(1-\delta)\hat{c}}{\delta}$

Tab. 6 Baseline Estimates – utility effects – Berlin

	(1) Log Price/m² Land Area	(2) Log Price/m² Land Area	(3) Log Price/m² Land Area	(4) Log Price/m² Floor Area	(5) Land Value/m² Land Area	(6) Log Ratio Capital/Land	(7) Log Floor Space Index	(8) Log Floor Space Index	(9) Log Pop./m² Housing Space	(10) Log Pop./m² Land Area
Log Employment Potential	0.331***		0.240***	0.022**	0.310***	0.244***	0.287***	0.646***	0.114***	0.513***
	(0.007)		(0.008)	(0.007)	(0.004)	(0.015)	(0.008)	(0.035)	(0.019)	(0.020)
Log Photo Potential		0.177***	0.024***	0.002	0.028***	0.026***	0.026***	0.033***	0.012***	0.045***
		(0.004)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.005)	(0.003)	(0.003)
Protected Monument (Dummy)	0.012	0.017	0.007	0.123***		0.072*	-0.203***	-0.214***		
	(0.020)	(0.019)	(0.019)	(0.016)		(0.030)	(0.017)	(0.017)		
Emp. Pot. x Construction Year								-0.002***		
								(0.000)		
Photo Pot. x Construction Year								-0.000		
								(0.000)		
Hedonic Controls	YES	YES	YES	YES		YES	YES	YES		
Time Effects	YES	YES	YES	YES	YES	YES	YES	YES		
Time x East Effects	YES	YES	YES	YES	YES	YES	YES	YES		
Observation units	Trans.	Trans.	Trans.	Trans.	Trans.	Trans.	Trans.	Trans.	Blocks	Blocks
Observations	29153	29153	29153	29153	29151	25885	29153	29060	7392	7392
R^2	0.533	0.531	0.538	0.648	0.661	0.421	0.755	0.760	0.026	0.315
AIC	52814.9	52914.6	52475.7	43249.2	17664.1	73485.9	49573.2	48703.9	19893.8	20269.2
Decay Access (T^E)	0.7		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Decay Urbanity (T^P)		1	6	6	6	6	6	6	6	6
β	27.85%	29.71%	28.60%	31.26%	27.78%	28.53%	25.48%	28.29%	28.42%	25.58%
γ	4.15%		3.09%	0.68%	3.87%	3.14%	5.99%	3.18%	3.25%	5.90%
$1-\alpha-\beta-\gamma$		2.29%	0.31%	0.06%	0.34%	0.33%	0.54%	0.53%	0.33%	0.52%
$\gamma/(1-\alpha)$	12.96%		9.65%	2.11%	12.11%	9.80%	18.71%	9.94%	10.14%	18.44%
$(1-\alpha-\beta-\gamma)/(1-\alpha)$		7.17%	0.97%	0.20%	1.06%	1.04%	1.67%	1.65%	1.04%	1.62%
Effect of change in accessibility/urbanity from 1st to 99th percentile										
Access on										
Land Rent	116.18%		84.23%	16.88%	108.85%	85.83%	183.49%	87.78%	88.93%	179.68%
Housing Rent	52.28%		37.90%	7.60%	48.98%	38.62%	82.57%	39.50%	40.02%	80.86%
Space consumption	-34.33%		-27.48%	-7.06%	-32.88%	-27.86%	-45.23%	-28.32%	-28.58%	-44.71%
Urbanity on										
Land Rent		138.64%	55.17%	10.32%	62.57%	59.54%	107.44%	95.18%	69.40%	104.33%
Housing Rent		62.39%	24.83%	4.64%	28.16%	26.80%	48.35%	42.83%	31.23%	46.95%
Space consumption		-38.42	-19.89%	-4.44%	-21.97%	-21.13%	-32.59%	-29.99%	-23.80%	-31.95%

Notes: Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Tab. 7 Urbanity Decomposition & Gentrification Models – Berlin

	(1) Log Price/m² Land Area	(2) Log Price/m² Land Area	(3) Log Price/m² Floor Area	(4) Log Price/m² Floor Area	(5) Log Price/m² Land Area
Log Employment Potential	0.239***	0.212***	0.038***	0.013	0.217***
	(0.010)	(0.012)	(0.008)	(0.009)	(0.012)
Log Photo Potential	0.015***	0.012***	0.005***	0.001	0.012***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Protected Monument (Dummy)	0.006	-0.013	0.090***	0.074***	-0.014
	(0.019)	(0.020)	(0.014)	(0.015)	(0.019)
Log Heritage Potential		0.026***		0.009***	0.026***
		(0.003)		(0.002)	(0.003)
Log Architecture Potential (Contemporary)		0.004***		0.010***	0.004***
		(0.001)		(0.001)	(0.001)
Log Cultural Potential (Mainstream)		-0.003**		-0.002*	-0.003***
		(0.001)		(0.001)	(0.001)
Log Music Node Potential		0.004***		0.002**	-0.004***
		(0.001)		(0.001)	(0.001)
Log Music Node Pot x Time Trend					0.002***
					(0.000)
Hedonic Controls	YES	YES	YES	YES	YES
Time Effects	YES	YES	YES	YES	YES
Time x East Effects	YES	YES	YES	YES	YES
X/Y Coordinates	YES	YES	YES	YES	YES
Location Effects	YES	YES	YES	YES	YES
Neigh. Effects	YES	YES	YES	YES	YES
Observations	29153	29153	29153	29153	29153
R2	0.558	0.560	0.692	0.695	0.563
AIC	51585.9	51324.7	39652.1	39210.8	51108.3
Decay Access *(T^E)*	0.7	0.7	0.7	0.7	0.7
Decay Urbanity *(T^P)*	6	6	6	6	6
β	28.72%	29.07%	30.68%	31.56%	29.44%
γ	3.09%	2.77%	1.17%	0.41%	2.38%
1-α-β-γ	0.19%	0.15%	0.15%	0.04%	0.17%
γ /(1- α)	9.65%	8.66%	3.66%	1.27%	7.45%
(1-α-β-γ)/(1- α)	0.60%	0.48%	0.47%	0.12%	0.55%
Effect of change in accessibility/urbanity from 1st to 99th percentile					
Access on					
Land Rent	83.88%	74.40%	29.82%	10.03%	63.19%
Housing Rent	37.74%	33.48%	13.42%	4.51%	28.43%
Space consumption	-27.40%	-25.08%	-11.83%	-4.32%	-22.14%
Urbanity on					
Land Rent	29.82%	27.10%	24.79%	6.10%	30.28%
Housing Rent	13.42%	12.20%	11.16%	2.75%	13.63%
Space consumption	-11.83%	-10.87%	-10.04%	-2.67%	-11.99%
Changes relative to benchmark					
Accessibility (*γ*)	-0.42%	-11.67%	67.63%	-40.60%	-24.98%
Urbanity (*1-α-β-γ)*	-38.62%	-50.88%	140.25%	-40.87%	-45.11%

Notes: Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Tab. 8 Accessibility and Urbanity Effects (London)

	(1) Log Price/m² Floor Area	(2) Log Price/m² Floor Area	(3) Log Price/m² Floor Area	(4) Log Price/m² Floor Area	(5) Log Price/m² Floor Area	(6) Log Price/m² Floor Area	(7) Log Price/m² Floor Area
Log Employment Potential	0.192***		0.050***	0.075***	0.135***	0.137***	0.137***
	(0.002)		(0.001)	(0.003)	(0.011)	(0.003)	(0.003)
Log Photo Potential		0.057***	0.044***	0.010***	0.004***	0.003***	0.003***
		(0.001)	(0.003)	(0.000)	(0.001)	(0.000)	(0.000)
Log Architecture P. (Historic)						0.002***	0.002***
						(0.000)	(0.000)
Log Architecture P. (Contemporary)						-0.002***	-0.002***
						(0.000)	(0.000)
Log Cultural P. (Mainstream)						0.002***	0.002***
						(0.000)	(0.000)
Log Music Node Potential						0.004***	0.002**
						(0.001)	(0.001)
Log Music Node Pot x Time Trend							0.000***
							(0.000)
Hedonic Controls	YES	YES	YES	YES	YES	YES	YES
Year Effects	YES	YES	YES	YES	YES	YES	YES
X/Y Coordinates					YES	YES	YES
Location Effects					YES	YES	YES
Neigh. Effects					YES	YES	YES
Observations	35881	35881	35881	35881	35858	35858	35858
R^2	0.510	0.551	0.555	0.541	0.710	0.715	0.715
AIC	7069.1	3916.2	3640.9	4775.3	-11781.8	-12324.2	-12389.7
Decay Access (T^E)	0.9		4	1	1	1	1
Decay Urb. (T^P)		1	1	4	4	4	4
β	26.84%	30.28%	29.26%	29.51%	28.09%	28.06%	28.07%
γ	5.16%		1.28%	2.20%	3.79%	3.85%	3.84%
$1-\alpha-\beta-\gamma$		1.72%	1.47%	0.29%	0.12%	0.08%	0.08%
$\gamma/(1-\alpha)$	16.12%		3.99%	6.87%	11.83%	12.05%	12.01%
$(1-\alpha-\beta-\gamma)/(1-\alpha)$		5.36%	4.58%	0.90%	0.38%	0.26%	0.26%
Effect of change in accessibility/urbanity from 1st to 99th percentile							
Access on							
Land Rent	134.92%		34.46%	53.13%	96.07%	97.92%	97.55%
Housing Rent	60.71%		15.51%	23.91%	43.23%	44.06%	43.90%
Space cons.	-37.78%		-13.43%	-19.29%	-30.18%	-30.59%	-30.51%
Urbanity on							
Land Rent		155.94%	137.92%	113.29%	50.41%	34.51%	34.76%
Housing Rent		70.17%	62.06%	50.98%	22.68%	15.53%	15.64%
Space cons.		-43.24%	-38.30%	-33.77%	-18.49%	-13.44%	-13.53%
Changes relative to benchmark							
Accessibility (γ)					+88.84%	+84.32%	+83.63
Urbanity ($1-\alpha-\beta-\gamma$)					-55.51%	-69.54%	-69.32%

Notes: Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Tab. 9 Productivity Effects - Berlin

	(1) Log Price/m² Land Area	(2) Log Price/m² Land Area	(3) Log Price/m² Land Area	(4) Log Price/m² Floor Area	(5) Log Land Value/m²Land Area	(6) Log Ratio Capital/Land	(7) Log Ratio Floor Space/Land Area	(8) Log Ratio Floor Space/Land Area	(9) Log Emp./m² Office Space	(10) Log Emp./m² Land Area
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	2SLS	2SLS
Log Employment Potential	0.541***		0.300***	0.141***	0.473***	0.330***	0.160***	-0.158*	0.211***	0.827***
	(0.033)		(0.044)	(0.038)	(0.034)	(0.062)	(0.026)	(0.080)	(0.054)	(0.046)
Log Photo Potential		0.116***	0.055***	0.034***	0.045***	0.053***	0.021***	0.023	0.019**	0.013*
		(0.009)	(0.009)	(0.008)	(0.006)	(0.010)	(0.005)	(0.014)	(0.007)	(0.005)
Protected Monument (Dummy)	0.252***	0.267***	0.244***	0.267***	0.102**	0.233**	-0.023	0.004		
	(0.049)	(0.050)	(0.048)	(0.042)	(0.033)	(0.079)	(0.027)	(0.028)		
Log Emp. Pot. x Construction year								0.002***		
								(0.001)		
Log Photo Pot. x Construction year								-0.000		
								(0.000)		
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Hedonics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Year x East	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
Observations	1657	1657	1657	1657	1657	1432	1657	1657	5600	6239
R^2	0.653	0.655	0.665	0.573	0.618	0.577	0.501	0.516	0.145	0.492
AIC	3712.5	3703.7	3656.7	3228.5	2457.7	4124.3	1493.7	1446.8	18437.4	19685.5
Decay Access (T^E)	4		5	5	5	5	5	5	5	5
Decay Urbanity (T^P)		6	8	8	8	8	8	8	8	8
θ	4.06%		2.25%	2.11%	3.55%	2.47%	2.40%	4.88%	3.17%	12.41%
λ		0.86%	0.41%	0.51%	0.34%	0.40%	0.31%	0.28%	0.29%	0.20%
Effect of change in accessibility/urbanity from 1st to 99th percentile										
Access on										
Land rent	293.67%		175.26%	164.04%	276.09%	192.57%	186.46%	380.11%	271.67%	1064.31%
Office space rent	146.83%		87.63%	82.02%	138.04%	96.28%	93.23%	190.05%	135.84%	532.16%
Space/Employee	-59.49%		-46.70%	-45.06%	-57.99%	-49.05%	-48.25%	-65.52%	-57.60%	-84.18%
Urbanity on										
Land rent		262.80%	170.65%	211.72%	140.02%	164.81%	129.70%	116.37%	143.49%	98.49%
Office space rent		131.40%	85.32%	105.86%	70.01%	82.41%	64.85%	58.18%	71.74%	49.24%
Space/Employee		-56.79%	-46.04%	-51.42%	-41.18%	-45.18%	-39.34%	-36.78%	-41.77%	-33.00%

Notes: Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.00$.

Tab. 10 Urbanity Decomposition – Berlin Commercial

	(1) Log Price/m² Land Area	(2) Log Price/m² Land Area	(3) Log Price/m² Floor Area	(4) Log Price/m² Floor Area
Log Employment Potential	0.196***	0.217***	0.080	0.119**
	(0.049)	(0.049)	(0.044)	(0.045)
Log Photo Potential	0.057***	0.074***	0.036***	0.056***
	(0.009)	(0.009)	(0.008)	(0.008)
Protected Monument (Dummy)	0.205***	0.187***	0.221***	0.204***
	(0.047)	(0.047)	(0.041)	(0.040)
Log Heritage Potential		0.206***		0.174***
		(0.044)		(0.037)
Log Architecture Potential (Contemp.)		-0.006		-0.011
		(0.011)		(0.010)
Log Cultural Potential (Mainstream)		-0.023***		-0.021***
		(0.006)		(0.005)
Log Music Node Potential		-0.015		-0.016*
		(0.009)		(0.008)
Hedonic Effects	YES	YES	YES	YES
YES Year x East Effects	YES	YES	YES	YES
Location effects	YES	YES	YES	YES
Observations	1657	1657	1657	1657
R^2	0.689	0.706	0.614	0.639
AIC	3597.5	3514.5	3174.2	3044.5
θ	1.47%	1.63%	1.20%	1.79%
λ	0.43%	0.55%	0.55%	0.84%
Effect of change in accessibility/urbanity from 1st to 99th percentile				
Access on				
Land rent	114.15%	126.88%	93.34%	139.47%
Office space rent	57.08%	63.44%	46.67%	69.74%
Space/Employee	-36.34%	-38.82%	-31.82%	-41.09%
Urbanity on				
Land rent	176.74%	230.13%	226.61%	349.54%
Office space rent	88.37%	115.06%	113.31%	174.77%
Space/Employee	-46.91%	-53.50%	-53.12%	-63.61%
Changes relative to benchmark				
Accessibility (θ)	-34.87%	-27.60%	-43.10%	-14.98%
Urbanity (λ)	+3.57%	+34.86%	+7.03%	+65.09%

Notes: Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Tab. 11 Sorting (Berlin)

	(1)	(2)	(3)	(4)
	Expenditure share at housing consumption			
	Accessibility	Accessibility	Urbanity	Urbanity
Employment Potential	0.486***	0.154***		
Photo Potential			-0.638***	-0.657***
Age Index		-0.001		0.037***
Purchasing Power		-0.244***		-0.049***
Share FDP/Die Grünen		0.164***		0.030**
Nationality: Non-German (%)		0.229***		0.085***
Observations	28714	28714	28714	28714
R^2	0.234	0.328	0.406	0.418
AIC	-123258.2	-125104.3	-239814.5	-243700.2

Notes: Standardized beta coefficients. Standard errors in parentheses. Standard errors are bootstrapped using 100 replications . * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

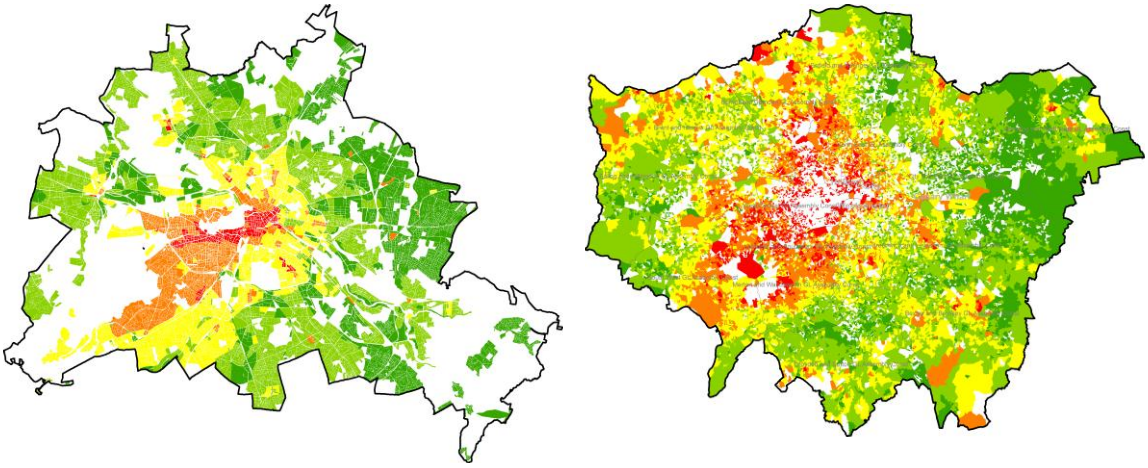
Tab. 12 Sorting (London)

	(1)	(2)	(3)	(4)
	Expenditure share at housing consumption			
	Accessibility	Accessibility	Urbanity	Urbanity
Employment Potential	0.157***	0.035***		
Photo Potential			0.182***	0.112***
Age Index		-0.149***		0.012*
Income Estimate		0.046***		-0.070***
Qualification Index		0.315***		0.309***
Ethnic group: White (%)		-0.261***		-0.022**
Observations	35858	35858	35858	35858
R^2	0.025	0.226	0.033	0.108
AIC	-125838.2	-134108.6	-425979.4	-428871.1

Notes: Standardized beta coefficients Standard errors in parentheses. Standard errors are bootstrapped using 100 replications. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Appendix

Figure A1 Land Values



Notes: Berlin (left) data are assessed land values (from the Committee of Valuation experts). London (data) is the residual land prices estimated based on Nationwide Building Society property transaction data in auxiliary regressions.

Estimating Delta

From the zero profit condition in the construction sector we know that:

$$\Pi = \psi(x)H(x) - \Omega L - K = 0$$

$$\frac{\psi(x)H(x)}{L} = \frac{1}{(1-\delta)}\Omega(x)$$

First order conditions of the housing production function (20) imply:

$$\frac{K}{(L)} = \frac{\psi(x)S(x)-\Omega(x)L}{L} = \frac{\delta}{1-\delta}\Omega(x)$$

I estimate δ separately for residential and commercial properties in two alternative approaches. First, I run a regression of property transaction prices per land area on assessed pure land values (1) and (2). Second, I approximate the capital to land ratio by the ratio of property prices net of the assessed land value of a property to the land area (3) and (4).

TAB A1 Estimated Output Elasticity of Land (Berlin)

	(1) Price (€) /Land (m²)	(2) Price (€) /Land (m²)	(3) Capital (€) /Land (m²)	(4) Capital (€) /Land (m²)
Land Value	2.38***	1.98***	1.23***	1.08***
(per m²)	(0.03)	(0.07)	(0.03)	(0.06)
Constant	225.48***	3091.87***	239.04***	2907.63***
	(10.27)	(247.82)	(10.63)	(222.91)
Land Use	Residential	Commerce	Residential	Commerce
Observations	25489	1209	25489	1209
R^2	0.237	0.429	0.072	0.216
AIC	412488.6	24620.3	414216.3	24364.2
Implied 1-δ	0.42	0.50	0.45	0.48

Notes: Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A2 - Variables Description

Berlin	
Dependent Variables	
Log Price/Land Area	Ratio of the Property transaction price in € to the area of the corresponding plot of land. Transaction data from the Committee of Valuation Experts (GAA).
Price/Floor Area	Ratio of the Property transaction price in € to the total floor area. transaction data from the GAA.
Land Value/Land Area	Land value per square meter land area. Assessed by the GAA.
Capital/Land	Ratio of total property price net of land value to the area of the corresponding plot of land. Based on transaction data from the GAA.
Floor space index (FSI)	Ratio of the total floor area to the area of the corresponding plot of land. Transaction data from the GAA.
Population/Housing Space	Ratio of the 2005 population (from the Berlin Statistical Office) to the total floor area in a statistical block unit. Total floor area is approximated by the typical local FSI (from the GAA) multiplied by the block land area (computed in GIS).
Population/Land Area	Ratio of the 2005 population (from the Berlin Statistical Office) in a statistical block unit to the block land area (computed in GIS).
Employment/Office Space	Ratio of the 2003 workplace employment (from the Berlin Statistical Office) to the total floor area in a statistical block unit. Total floor area is approximated by the typical local FSI (from the GAA) multiplied by the block land area (computed in GIS).
Employment/Land Area	Ratio of the 2003 workplace employment (Berlin Statistical Office) in a statistical block unit to the block land area (computed in GIS).
Independent Variables	
Year Effects	Set of yearly dummy variables (based on transaction data from the GAA)
Year x East Effects	Yearly dummy variables multiplied by a dummy variable for properties located in former East-Berlin (created in GIS).
X/Y Coordinates	X- and Y-coordinate in projected meter units (Soldner Coordinates). Transaction data from the GAA
Hedonic Effects	Set of property variables shown in Table A3a. Part of the transaction data from the GAA.
Location Effects	Set of locational variables created in GIS based on the Urban and Environmental Information System (Senatsverwaltung für Stadtentwicklung Berlin, 2006) including: Local Noise level in db, distance to nearest U-Bahn or S-Bahn station, distance to the nearest industry area, distance to the nearest main street, distance to the nearest green area and distance to the nearest water area.
Neighbourhood Effects	Set of neighborhood variables including: purchasing power per capita (estimates from the GFZ, postcode level), share of non-Germans at total population, share of age groups at total population (0-6, 6-15, 15-18, 18-27, 45-55, 55-65, 65+) (Berlin Statistical Office, block level)
London	
Dependent Variable	
Price/Floor Area	Ratio of the Property transaction price in € to the area of the corresponding plot of land. Transaction data from the Nationwide Building Society (NBS).
Independent Variables	
Year Effects	Set of yearly dummy variables (based on transaction data from the NBS).
X/Y Coordinates	X- and Y-coordinate in projected meter units (British National Grid). Reprojected in GIS from geographic coordinates (latitudes & longitudes)
Hedonic Effects	Set of property variables shown in Table A3b. Part of the transaction data from the NBS.
Location Effects	Set of locational variables created in GIS including: distance to the nearest underground/dockland light railway station, distance to the nearest river, distance to the nearest park, rail line within 250m (dummy), primary road within 250m.
Neighborhood Effects	Set of neighborhood variables including: share of white population at total population (2001 census, output area level), average income (2001 census, ward level), average key stage 2 test score (average output area scores, interpolated in GIS), shares of age groups at total population (0-9, 10-15, 16-19, 20-29, 45-59, 60-74, 75+,2001 census, output area level)

Table A3a Hedonic Estimates Berlin

	(1)		(2)	
	Coeff.	S.E.	Coeff.	S.E.
Log Employment Potential	0.240***	(0.008)	0.300***	(0.044)
Log Photo Potential	0.024***	(0.001)	0.055***	(0.009)
Protected Monument (Dummy)	0.007	(0.019)	0.244***	(0.048)
Property located at frontage (Dummy)	-0.032	(0.035)	-0.259	(0.204)
Property located at corner (Dummy)	0.083*	(0.036)	0.084	(0.205)
Property located at multiple frontages (Dummy)	-0.150***	(0.041)	-0.050	(0.209)
Demoted property (Dummy)	-0.195***	(0.048)	-0.509*	(0.254)
Backyard property (Dummy)	-0.024	(0.038)	-0.431	(0.306)
Building Age (Years)	-0.009***	(0.001)	-0.005**	(0.002)
Building Age squared	0.000***	(0.000)	0.000	(0.000)
Condition: good (Dummy)	0.455***	(0.012)	0.678***	(0.054)
Condition: good (Dummy)	-0.530***	(0.013)	-0.325***	(0.072)
Flat roof (Dummy)	-0.261***	(0.015)	-0.184*	(0.080)
Pent roof (Dummy)	-0.059**	(0.021)	-0.189	(0.126)
Span roof (Dummy)	-0.354***	(0.013)	0.019	(0.115)
Berlin roof (Dummy)	0.046***	(0.012)	0.303***	(0.074)
Hipped roof (Dummy)	-0.343***	(0.015)	-0.051	(0.179)
Mansard roof (Dummy)	-0.206***	(0.021)	0.705*	(0.322)
Domed roof (Dummy)	-0.400***	(0.027)		
Attic flat (Dummy)	0.134***	(0.008)	0.188***	(0.045)
Elevator (Dummy)	0.233***	(0.023)	0.199***	(0.050)
Basement (Dummy)	0.272***	(0.014)	-0.016	(0.066)
Underground car park (Dummy)	0.441***	(0.104)	-0.028	(0.214)
Seller: (Public) authority (Dummy)	-0.329***	(0.023)	-0.435***	(0.094)
Seller: Housing Association (Dummy)	-0.058***	(0.014)	-0.349***	(0.089)
Seller: (Private) Juristic Person (Dummy)	0.120***	(0.009)	0.134**	(0.047)
Buyer: (Public) Authority (Dummy)	-0.229*	(0.096)	0.174	(0.176)
Buyer: Housing Association (Dummy)	0.094	(0.073)	-0.744	(0.871)
Buyer: (Private) Juristic Person (Dummy)	0.175***	(0.010)	0.353***	(0.067)
Charge for local public infrastructure	-0.115***	(0.012)	1.182***	(0.130)
Property is not occupied by renter	0.115***	(0.011)	0.183	(0.101)
Share (%) secondary structure at sales price	-4.311***	(0.567)	-2.679	(1.682)
Month (1-12 Trend)	-0.000	(0.001)	0.024***	(0.005)
Constant	7.850***	(0.052)	10.446***	(0.309)
Year Effects	YES		YES	
Year x East Effects	YES		YES	
Sample	Residential		Commercial	
Observations	29153		1657	
R^2	0.538		0.665	
AIC	52475.7		3656.7	

Notes: Dependent variable is price (€) per land area (m^2) in both models. Baseline models are columns (3) in Tables (6) and (9). Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table A3b - Hedonic Estimates London

	(1)	
	Coeff	S.E.
Log Employment Potential	0.097***	(0.003)
Log Photo Potential	0.005***	(0.000)
Building Age (Years)	0.001***	(0.000)
Building Age squared	-0.000***	(0.000)
Central Heating (Full)	0.035***	(0.007)
Central Heating (Partial)	0.030**	(0.010)
Garage (Single or Double)	0.034***	(0.005)
Parking Space	0.058***	(0.004)
Property Type: Detached	0.054***	(0.012)
Property Type: Semi-Detached	-0.027**	(0.008)
Property Type: Terraced	-0.075***	(0.008)
Property Type: Cottage	0.045	(0.026)
New Property	0.165***	(0.010)
Property sells under leasehold	-0.013	(0.008)
Year Effects	Yes	
Observations	35881	
R^2	0.533	
AIC	5358.0	

Notes: Dependent variable is price (€) per floor space (m^2). Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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