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Land Assembly in Amsterdam, 1832-2015

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Abstract

Inner city redevelopment frequently involves the assembly of small lots into bigger ones. We analyze joint lot development and the influence of coordination and transaction costs of land assembly on the exercise of the redevelopment option, using Amsterdam micro housing information for 1832, 1860 and 2015. In all, we have a complete set of building structure and household characteristics for dwellings on almost 30,000 lots for each of these years.

We estimate a logit model to predict joint lot redevelopment, based on structural characteristics of lots and dwellings and on social characteristics of their occupants. The results show that both types of characteristics significantly explain land assembly, and the regression coefficients adhere to the theoretical land assembly literature. This paper contributes importantly to our knowledge of the specific land parcel and structural physical characteristics that impact redevelopment. To our knowledge, this is the first paper to study the joint characteristics of the potentially combinable lots, and to document and quantify the role of social characteristics in land assembly.

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I. Introduction

In historic city centers, where many existing lots are too small for optimal modern uses, redevelopment often involves a combination of lots and owners, creating coordination problems and transaction costs that are likely to influence the exercise of the redevelopment option. This land assembly problem has been studied quite extensively, both theoretically and empirically. However, these studies always analyze single lots instead of lots in combination.[1] Yet land assembly involves the combination of two or more lots. It is therefore likely that not only the characteristics of individual parcels are relevant, but also the joint characteristics of the relevant lots, which determine the possible results of the assembly.

We look at the micro urban form of Amsterdam at three far-removed moments in time: 1832, 1860 and 2015. In doing this, we make three main contributions to the urban economics literature.

First, we analyze the redevelopment of urban lots jointly with their neighbors, explicitly considering the coordination problems this entails.

Second, we explore the very long-run dynamics of urban (re)development at the micro level, which is important for understanding the micro-forces that shape cities. The urban landscape at any point in time is a legacy of development decisions taken over the decades and centuries before. In effect, we investigate whether land owners in the distant past already – implicitly or explicitly – incorporated seemingly modern concepts like highest and best use in their decision making concerning redevelopment.

Third, we not only study the characteristics of lots and dwellings, but also of the people owning and occupying them. When lot owners have matching social characteristics, this possibly reduces coordination costs between these owners, and could make it easier for them to combine their lots if that would make economic sense. Conversely, when owners are also the occupiers of dwellings, joint redevelopment may become costlier, since it necessarily creates moving costs. This would reduce the likelihood of assembly. To our knowledge, owner and occupier characteristics of individual lots have not yet been studied when analyzing land assembly issues.

1 See, for example, Eckart (1985), Strange (1995), Menezes and Pitchford (2004), Cunningham (2013, Hornbeck and Keniston (2014), and Brooks and Lutz (2016).

The empirical analysis in the paper starts with the 1832 cross section of lots in the historic city, i.e. all lots located within Amsterdam's famous half-moon shaped center, which effectively made up the complete city at that time. We estimate a model that predicts the land assembly that occurred between 1832 and 1860, and between 1832 and 2015. This model is based on structural variables, pertaining to the physical characteristics of lots and buildings, and social variables, i.e. characteristics of lot owners and/or occupiers.

Using this model, without the social dimension, we can explain 45 percent of the land assembly that went on between 1832 and 1860. This increases to 53 percent if we include social variables such as the profession and religion of the inhabitants of the dwellings in 1832.

This same model, employing quite limited data from 1832 only, is able to explain up to 27 percent of the cross sectional variation in land assembly activity in Amsterdam's city center in the subsequent 183 years, through 2015. Regarding the effects of the individual variables, we find these to be smaller over this long time period than for the 28 years before 1860. Not very surprisingly, the 1832 owners' characteristics cease to have a significant effect on land assembly over the much longer time period.

In the remainder of this paper we first discuss the literature regarding the assembly and redevelopment of urban land. We subsequently present the data, data sources and variable definitions for the ensuing regressions, as well as statistics regarding these variables. We then discuss the logit and spatial autoregressive models we employ to predict Amsterdam's redevelopment dynamics between 1832 and 2015, and we provide the results of these analyses. A final section concludes.

II. Literature

Cities grow and evolve both by developing land around the city and by redeveloping land within it. Often, redevelopment takes place from the inside out, starting in the urban core. This is the motivation for our study of historic urban Amsterdam. It builds on a small but solid strand of literature aiming to understand when and how urban land is redeveloped and assembled and what the consequences are for land values.

The early literature regarding the economic analysis of urban redevelopment looks mostly at the relationship between the values of the existing structures, demolition costs and vacant land to explain the teardown and redevelopment of urban properties. The theoretical foundation for this literature was laid in three papers – Brueckner (1980), Wheaton (1982) and Braid (2001) – while the seminal empirical paper that first tested these ideas was by Rosenthal and Helsley (1994). They apply the theoretical economic foundation to data of residential property transactions in Vancouver. Their main conclusion is that redevelopment of a property happens when the value of land in its current use is lower than the price of vacant land at that location.

Munneke (1996) models the probability of the redevelopment of a commercial or industrial property, and tests the model's prediction by employing a reduced-form probit model on property transactions data for the Chicago metropolitan area. His findings support those of Rosenthal and Helsley (1994). More recently, Dye and McMillen (2007) do the same for teardowns of homes in Chicago, also employing a probit model.

Titman (1985) and Capozza and Li (1994) choose a different approach, and model the occurrence of (re)development as the exercise of an option under uncertainty concerning future property rents. Capozza and Li use this model to analyze the decision to change the use of – or to redevelop – urban land. The recent literature concerning urban property redevelopment is modeled as the exercise of an option that is embedded in the ownership of properties. Examples are Clapp and Salavei (2010), Clapp, Jou and Lee (2012), Clapp, Eichholtz and Lindenthal (2013), and Munneke and Womack (2015, 2016).

One important characteristic of this literature is that it focuses on individual properties, implicitly in isolation.[2] But city centers typically have a legacy grid of lots that were large enough for historic uses, but that could well be too small for modern ones. Realistically, redevelopment must involve the assembly of different lots into one.

This land assembly issue traces a different strand in the literature. It has been studied theoretically and empirically, explicitly addressing the coordination and transaction costs that are likely to emerge when different lots with different owners are jointly redeveloped. The land assembly literature has not particularly focused on real option theory. Though in principle that theory is relevant for land assembly, as with the other papers in this strand of the literature, we do not seek to test real option theory (which we presume is valid). One

[2] Dye and McMillen (2007) and Munneke and Womack (2015, 2016) do employ variables that measure a property relative to the lot, building area, and age of the properties around it to help predict redevelopment.

reason is that we do not have data on option value, as our valuation data reflects only the usage or occupancy rental value of the existing building. This reflects equilibrium in the space market, but does not reflect the redevelopment option value that is priced in the land or asset market. Furthermore, there is a rich set of issues, not inconsistent with real option theory but not particularly pertaining to it, that arise particularly regarding land assembly. The present paper is focused on these physical and economic issues.

A key result stemming from the theoretical literature is that various market imperfections lead to below-optimal land assembly (O'Flaherty 1994, Strange 1995). The theoretical papers also make predictions on value. One of the main predictions is that the square meter price for smaller lots is higher than for larger lots (Eckart 1985, Strange 1995).

Empirical studies testing these theoretical predictions are sparse. Cunningham (2013) investigates value effects and finds that land that was sold into a successful assembly yields an average premium of 17 percent. In line with the theoretical predictions, both Cunningham and Fu, McMillen and Sommerville (2002) find that the square meter price of lots sold in assembly falls with their size. The latter also find that final sellers into an assembly receive a premium relative to early sellers.

Recently, Brooks and Lutz (2016) focus on the question of whether enough land assembly takes place. To sustain economic growth in cities, urban land should be developed to its highest and best use, and that involves optimal lot size. If there is insufficient land assembly, the economic development of the city will be hampered. Brooks and Lutz analyze lots in Los Angeles County, comparing the prices of land sold into assembly with those of land on which the structure was torn down after purchase. They find a 15 to 40 percent premium for the former, which suggests that urban land markets are subject to frictions that reduce assembly.

Building upon Brooks and Lutz (2016), we argue that for adjacent lots to be jointly redeveloped, the value of the assembled lot needs to exceed the value of the to-be-assembled lots after deducting all assembly-related costs. Only if the value of the assembled property $V_{assembled}$ less the construction cost of the new structure K and the cost related to the assembly process δ is bigger than the value of the to-be-assembled properties, will a developer consider an assembly: $V_{assembled} - K - \delta > \sum P$, where the summation refers to the value of all the properties being assembled (and we note that these need not be vacant lots but might have viable structures that are no longer the highest and best use of the lots).

The following data section suggest variables that can serve as proxies for the potential net present value of the construction project, $V_{assembled} - K$, as well as the assembly related costs, δ, and the value of the to-be-assembled properties, P. This data will provide the basis of our empirical study.

III. Data

To study (re)development activity in the city of Amsterdam over a long span of history, we employ data covering the universe of all lots and buildings in central Amsterdam at three points in time: 1832, 1860, and 2015. We have cadastral maps with underlying information for each of these years. These maps are effectively urban geographic information systems, organizing detailed demographic and dwelling structure information in a spatial way.

Detailed property maps for the entire Netherlands were available for the first time in 1832. When the French annexed the Netherlands in 1810, they introduced French land laws and the French tax system, which relied on an accurate and complete cadastral system in the modern sense. In 1811, property surveying work according to French standards commenced in the Netherlands. After Napoleon's defeat and the end of the French occupation of the Netherlands in 1813, the land tax code and cadaster remained in operation and surveying continued until the entire country was measured by 1831 (Kain and Baigent, 1992). The 1832 cadastral map is a result of that effort.

This map and the data underlying it provide extensive information on all dwellings in the city of Amsterdam for 1832: 28,365 lots, on which 30,047 individual buildings were built. The data's current source is Amsterdam's land register records, digitized by the HISGIS project.[3]

The records provide a detailed picture of the city in three aspects. First, the historical maps provide an accurate snapshot of the demarcations of all lots, buildings, streets, canals within the city walls, and also of the then still undeveloped hinterland. Using GIS techniques,

3 These data have previously been used by Lesger and Van Leeuwen (2012).

we can observe which of the lots have been assembled over time. Also we can calculate each lot's size and shape, the length of its perimeter, its proximity to water and streets, the building's footprint, and the developed area of the lot. These hedonic attributes allow us to partially control for property quality when estimating marginal prices of attributes associated with the assembly of properties. Using these maps, we can also make inferences about possible values $(V_{assembled})$ for any lot combinations by comparing the lot's shape to the shapes of each of its neighboring tracts.

Second, the records provide information on each lot's owner's full name, current address at street level, and occupation. This information sheds some light on the social status of all property owners in Amsterdam in 1832. We will subsequently also use it to proxy for coordination problems resulting from the fact that joint lot development involves different owners. The more different these owners are socially, the bigger these problems are likely to be. Social ties are hypothesized to mitigate the assembly-related costs, δ.

Third, for each lot, an estimate of the market rental yield is reported that has been individually produced and recorded for tax purposes by the city of Amsterdam (Lesger and Van Leeuwen, 2013)[4]. This rental information is available for rental dwellings and owner-occupied dwellings alike, so it does not entail rents that were actually paid, but rather the rents that could have been generated on the basis of the location and structure of the lot and the dwelling(s) built on it. Arguably, this rental value, which we designate as $P_{existing}$, depends on actual rental values. Importantly, as noted previously, $P_{existing}$ reflects only the usage/occupancy value of the existing building, generally excluding the redevelopment option value that might reside in the ownership of the property asset (which includes the land value). Observable rents derive from equilibrium in the space market or rental market, not directly or independently from the property asset market.

The next available cadastral map is from 1860. Most importantly, the structural information on the built environment is updated in this map, providing us with a second snapshot of lot demarcations, buildings, streets and canals. In the 1860 map, this information is augmented with social data on all residents (not just the owners) based on the 1851-1853

4 Keverling Buisman and Muller (1979) provide guidance for the use of historical mortgage and land registry archives. The value assessment could be appealed by the owner (Kruisinga, 1997), which was probably beneficial for the quality of the assessment process. Our value observations concern the final valuations.

census, including each occupant's name, and their date and place of birth, occupation and religion (Fryske Akademy, 2014). The 1860 data does not cover rental values.

Combined, these two data sources provide a unique historic snapshot on the micro-urban form of a major city in the mid-19th century. We are not aware of any other available dataset comprising detailed information on building structures, property rents and owner or occupant characteristics and demographics covering an entire city going that far back, and providing such a degree of coverage.

We combine these two historic datasets with information on lot and building boundaries for today's Amsterdam. This information is from the modern Dutch cadaster (Kadaster, 2015). It includes data on allowed land use according to current zoning, as well as the number and type of units within multi-unit structures. Again, we know the exact longitude and latitude of all lots, buildings, streets and canals, and all the boundaries between them. Current buildings often span several historic lots since cadastral lot boundaries are not necessarily merged when land is assembled for larger projects. Using GIS, we identify and aggregate all lots that jointly host a building and consider the joint lots as the relevant unit of observation in the subsequent analyses. In effect, we combine the lots for the purpose of this study. In contrast, in 1832 the newly drawn lot boundaries closely resembled the then-current economic realities, as all buildings stood on just one parcel. This illustrates that redevelopment, which evidences an evolution of the highest and best use of the site, has often entailed the replacement of smaller with larger-footprint structures across the 19th and 20th centuries.

Table 1 presents summary statistics for core variables describing Amsterdam's built environment in 1832 and 2015. The median lot size for privately owned developed lots increased from 68.5 m^2 in 1832 to 105.9 m^2 in 2015 reflecting the trend towards larger-footprint structures. For buildings, the median footprint rose from 46.1 m^2 to 79.5 m^2 in the same time period. While the median percentage of the developed land area in Amsterdam's city center did not change much in the last 183 years, the development became more evenly distributed. The standard deviation decreased slightly from 30.3 percent to 26.6 percent as the share of both relatively thinly and also fully developed lots dropped somewhat. Despite lots being merged into larger tracts through the years, the shape of lots does not change in terms of overall stretch or compactness. The ratio of the perimeter squared over the area does not differ much between 1832 lots and their modern counterparts. The trend toward larger lots within finite blocks, however, reduces the number of neighbors per lot somewhat. In 1832, a lot shared boundaries with on average 4.3 other lots, compared to 3.7 in 2015.

=== *insert Table 1 about here* ===

Not reported in the table is information about the dwellings' owners. The ownership of Amsterdam's real estate in 1832 was widely dispersed, with 60 percent of all owners possessing only one dwelling, 19.5 percent owning two and 7.9 percent with three. Jointly, these small-scale investors accounted for 59 percent of the total stock. The three largest private investors together owned about 1 percent of all properties, and the maximum number of dwellings owned by a single investor was 145.[5]

The data for 1832 include estimates of property rents that were made for tax purposes. For all dwellings, including owner-occupied ones, a market rent was estimated on the basis of which the owners of the properties were taxed. On the basis of these 1832 rent estimates, Amsterdam can be roughly structured into four areas. Figure 1 provides a clear picture of this.

The medieval core of the city comprises the areas named "Burgwallen Oude Zijde, Nieuwe Zijde and Nieuwmarkt" in Figure 1. This part of the city featured a mix of relatively small commercial and residential properties whose property rental estimates were distributed around the city-wide median but which displayed a large variation. To the West and South of the core, the belt of three prestigious canals hosted mostly residential lots that were larger, and had a higher and more homogeneous value than the medieval core. Beyond the rich canals, the wedge in the Northwest was home to small and low-value quarters for the working class, mixed with larger industrial sites. The Southeast of the city had not been fully built-up in 1832 and property values were at the lower end of the distribution. Very large lots there still needed to be subdivided for development and some were even used for urban vegetable gardens.

=== *insert Figure 1 about here* ===

[5] The municipal government was not a dominant landowner in the part of Amsterdam we study. In 1898, the city of Amsterdam introduced a system of long-term land lease in the areas that were newly developed after that year, but that did not pertain to the parcels in our sample.

IV. Physical and Social Characteristics Relevant for Land Assembly

We first want to study the predictability of urban redevelopment, focusing on the joint redevelopment of neighboring lots. Joint redevelopments are highly important for the development dynamics of historic city centers. Such redevelopments are complicated, since they involve economic decision making and coordination between different owners. We employ a logit regression model where the odds in favor of a pair of neighboring lots being merged for redevelopment are simultaneously explained by structural determinants specific to these lots and the possible resulting lots after assembly, as well as by measures of social ties and differences between the lot owners.

Lots i and j are defined to be neighbors if their boundaries are not further than 3 meters apart, which allows for redevelopment across the narrow footpaths cutting through Amsterdam's blocks in 1832. For the 1832-1860 period, a joint development for i and j is recorded whenever a 1860 building links both 1832 lots. For 1832-2015, a joint development is observed if more than half of the area of each 1832 lot intersects with a single 2015 cadastral lot or if both lots are connected by a building in 2015.

Figure 2 shows the evolution of land assembly for a typical example block facing the Herengracht canal, Amsterdam's most prestigious address since the 17^{th} century. The North-East side of the block faces the canal, and the South-West faces a back street. The buildings on these back streets would typically consist of stables, workshops, and lower-quality housing for servants and laborers. The remaining two sides of the block face side streets, connecting the Herengracht to its neighboring canal. Here, dwellings tended to have shops on the ground level with residential use above. Lot sizes reflect these differences in quality, with the larger lots facing the canal. While many lots today still feature the same boundaries as in 1832, a clear trend of forming larger lots by combining multiple smaller lots can be observed. But in 2015, after almost two centuries of stepwise redevelopment, the lots on the canal were still the largest ones. Block-wide redevelopments only rarely occurred in Amsterdam.[6]

=== *insert Figure 2 about here* ===

[6] The overwhelming majority of redevelopment and assembly was between private persons. Urban renewal at a large scale did not take place in the center (and thus in our sample of parcels), with two exceptions. The first is the land on top of and adjacent to the subway, that was built in the 1970s. This follows a track on the east side of the river Amstel. The second is the former Jewish quarter.

The way lots were combined through time is illustrated further in Figure 3. This graph displays density plots of lot areas for the 1832 and 2015 cross sections, and it clearly shows that most of the land assembly took place between very small lots. The solid line depicts the situation in 1832, when half the lots were smaller than 68.5 square meters. The most common lots at the time measured around 30 square meters. But due to ongoing land assembly, the smaller lots got bigger, and by 2015, the median lot size was 106 square meters. The graph also shows that land assembly among larger lots was rare, and that very large lots of 300 square meters or more remain the exception.

=== *insert Figure 3 about here* ===

Based on our definitions of redevelopment, we draw maps of the redevelopment intensity in Amsterdam between 1832 and 1860 and between 1832 and 2015. These maps are depicted in Figure 4. The left panel shows redevelopment for the 28 years after 1832. This mostly shows activity in the medieval central city and in the Jordaan, to the North-West of the center. A few larger lots have been redeveloped in the East.

The map in the right-hand panel of Figure 4 shows far more redevelopment activity, and more systematic patterns in its occurrence across the city. Not surprisingly, given the fact that the eastern parts of the city still had quite a few vacant lots, redevelopment has been strongest in that area: On the canals to the east of the Amstel river, in the former Jewish neighborhood, in the Plantage, and in the former eastern harbor district behind the navy yards in the Northeast. Besides that, we observe much redevelopment in the medieval city center and in the Western neighborhood called the Jordaan. Even in places that look historic today, redevelopment behind the facades has been quite extensive, for example in different parts of the old city center, along the inner side of the Herengracht, on the Prinsengracht, in the northern parts of the Jordaan, and in the area south of the Rozengracht.

In contrast, redevelopment has been very limited in most blocks on the major canals, and in the better-quality areas of the Jordaan and the old center.

=== *insert Figure 4 about here* ===

For each possible pair of lots, we calculate the combined area, the number of all other neighboring lots and the sum of the property tax values and the percentage of developed area (all in 1832). The redevelopment intensity is expected to be high for pairs where initial building values are low (in terms of absolute building value per square meter), since this implies a lower strike price for the redevelopment option, and thus greater profitability of redevelopment.[7] The shape of the initial lots and the potentially resulting lots when they would be merged is characterized as the ratio of the lot perimeter squared over the lot area. This "stretch" measure is small for compact shapes like squares or circles and increases for longer or more irregular tracts. Proximity to water is estimated by the share of the lot perimeter that is closer than 20 meter to one of Amsterdam's canals.[8]

We also incorporate the relative size of one lot in each possible pair to assess whether size matters in a relative sense. The relative weight of each constituent of a combined lot is measured by the Herfindahl index[9] for lot area. In addition, lots that are not developed to the best use are more likely to be subsequently redeveloped (Munneke, 1996). This motivates the definition of the binary variable *Same use*: Whenever the initial use classification of lots *i* and *j* differ, at least one lot is likely to be not at the optimal use for that location.

The social ties and differences between owners are proxied by a range of binary variables. First, we assess whether pairwise lots are owned by the same person: If that is the case, coordination costs will be minimal, incentives perfectly aligned and information asymmetries do not arise. To a lesser degree, if owners have strong social ties, coordination between them is expected to be easier. We proxy for these social ties by looking whether owners are living in the same street or have the same trade.

The religious affiliations of the owners has unfortunately not been recorded in 1832. For owner-occupied properties, the religious denominations of the heads of households as reported in the 1851-1853 census serves as a proxy for religious ties between owners. For rental properties, the religion of the tenants is presumed to be correlated with that of the owners. Of course this would not be a perfect correlation, but should hold substantially. The most frequent denominations were Dutch protestant (38%), Roman catholic (19%) and Jewish (7%).

The systematic persecution and murder of Amsterdam's Jewish population during the German occupation in 1940-45 deeply scarred the city. Against the background of the

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7 See, for example, Rosenthal and Helsley, 1994; and Clapp, Eichholtz and Lindenthal, 2013.

8 Alternative values for these parameters have been explored in robustness tests.

9 $Herf.\ area_{i,j} = (area_i/area_{i,j})^2 + (area_j/area_{i,j})^2$.

monstrosity of the Holocaust with millions being killed, the void left in the city's urban fabric seems an irrelevant aspect. Still, it irreversibly changed the built environment of Amsterdam. At the end of World War II, the homes of Jews had seen their residents deported to death camps and were often destroyed themselves by Amsterdammers scavenging for firewood during the hunger winter of 1945 (Van der Zee, 1982). For the 1832-2015 time period, we therefore expect that houses inhabited by Jewish heads of households in 1832 have a higher likelihood of being jointly redeveloped. For redevelopments between 1832-1860, however, no such differences are expected.

Table 2 presents the summary statistics for all variables at the pair-of-neighbors level, with Panel A providing information for the structural characteristics of lots and dwellings, and Panel B the social characteristics of their occupants. The table shows that joint redevelopment was not very common by 1860, but very common starting sometime after 1860 as it is quite common between 1832 and 2015. Forty-two percent of all 1832 lots had been redeveloped in combination with another lot by 2015. Most such lots had the same use as their neighbors, since we observe same use in 73 percent of lot pairs.

Socially, we observe that 16 percent of neighboring lots have the same owner. If the owners are not the same, they share the same occupation in 14 percent of all cases, and the same religion in 33 percent of cases.

=== insert Table 2 about here ===

V. Modeling redevelopment dynamics

The range and depth of the above described data on the physical and social characteristics relevant for land assembly is a unique contribution of this paper, and allows a pioneering predictive model of land assembly and redevelopment. Combining economic and social factors, we estimate the following logistic regression equation:

$$ln\left(\frac{P(Dev)_{i,j}}{1-P(Dev)_{i,j}}\right) = \alpha + \beta_{econ}X_{i,j} + \beta_{social}Social_{i,j} + \beta_{spatial}Block_{i,j} + \epsilon_{i,j}, \qquad (1)$$

in which the natural logarithm of the odds ratio of the probability *P(Dev)* of the joint redevelopment of lots *i* and *j* is explained by an intercept α and a linear combination of vectors of economic variables $X_{i,j}$, social variables $Social_{i,j}$ and dummy variables $Block_{i,j}$ for each of the city's blocks in 1832. The vectors of regression coefficients are denoted as β_{econ}, β_{social}, and $\beta_{spatial}$ and the error term is ε. Despite finely grained spatial control variables for each of the 647 blocks in the city, the residuals might not be free of within-blocks spatial dependence, warranting the use of robust standard errors. A reduced variant of the equation leaving out the social factors is additionally estimated for both time periods, leading to 4 sets of regression estimates in total.

The model described in Equation (1) above is descriptive in nature, and quite parsimonious by necessity due to data limitations. To test the robustness of the results, we therefore do the analysis also by employing a spatial autoregressive (SAR) model. Indeed, joint count statistics ("same color" statistics larger than expectation at 0.01 confidence levels) confirm a strong spatial dependence in redevelopments of pairs of neighboring lots, both for the 1832-1860 and the 1832-2015 period. To test the robustness of the regression estimates, we re-estimate Equation (1) as a spatial autoregressive logistic regression model, explicitly considering spatial dependencies between neighboring pairs. Specifically, we implement a linearized GMM logit model (Klier and McMillen, 2008) for a binary dependent variable and an underlying latent variable in a SAR lag form:

$$Y^* = \rho W Y^* + \beta X + u \qquad (2)$$

The spatial weight matrix W is defined to be 1 for pairs of lots within a distance of 150 meters and 0 otherwise. W is row-normalized and symmetric in terms of non-zero elements.

VI. Results of the redevelopment prediction analysis

Results for the baseline logit regression model in Equation (1) and for the spatial autoregressive model (2) are provided in Tables 3 and 4, respectively. Regarding overall predictive power of the models, we provide McFadden R^2s for the logit model in Table 3. These show that the model explains up to 53 percent of the variation in redevelopment activity between 1832 and 1860, and that the social characteristics of the 1832 owners play an important role in that explanatory power. Interestingly, our model explains up to 27 percent of redevelopment activity during the 183-year period from 1932 to 2015 even though the model is necessarily rather simple. Not surprisingly, social factors in 1832 play a lesser role for this very long time period.

We will discuss the results on the individual variables reported in these tables simultaneously below. We first assess the effect of the current value of the combined lot pair. The 1832 tax value of the combined lot is a proxy for the strike price of the redevelopment option, so a higher tax value would reduce the likelihood of exercise. This is indeed what we find: a negative coefficient for the 1832 value in all but one of the model specifications in Tables 3 and 4.

=== *insert Table 3 and Table 4 about here* ===

As Amsterdam developed, the demand for bigger buildings on bigger lots has grown. This may be due to improved building technology, higher household wealth, larger organizations, or the fact that higher buildings tend to have a larger footprint than smaller ones. This implies that larger lots as of 1832 already were closer to the current optimum, and are therefore less likely to be combined and redeveloped with neighboring lots. And his is what the data shows. We find a highly significant negative effect of size on joint redevelopment likelihood, and it is consistent for the logit and the spatial autoregressive model.[10] This results contrasts with Brooks and Lutz (2016), who find a positive relationship between lot size and the likelihood of assembly. The cause of this difference may have to do with our sample, which concerns a historic city center. Despite the land assembly that obviously has been going on, this part of Amsterdam still looks and feels historic, and large-scale redevelopment has been rare. So larger lots were more likely to be undisturbed. Brooks and Lutz (2016) and Cunningham (2012) study US cities, where redevelopment tends to be on a larger scale, and possibly needs larger parcels to even get started.

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But size matters also in a relative sense. The Herfindahl index for lot area describes how lots in a pair differ in size. If they are very different, it is more likely that one of them has a suboptimal size, which would make it more profitable to redevelop the pair, and the redevelopment option would be worth more. A high Herfindahl implies a big size difference, so we expect to find a positive relationship with the odds of joint redevelopment. This is indeed what we see in all model specifications, although the effect is much weaker for the 183-year time period than for the 28-year period.

We already saw that lot size codetermines the odds of assembly, but a further interesting result is that shape matters too. We look at the "stretch" of the individual lots, which is a proxy for a suboptimal lot shape. Putting such a lot together with another lot may bring the

10 The magnitude of the effect is as follows: A 1 percent increase in area is a ~ 0.01 increase in ln(area, combined). Multiplied with -0.3 (the coefficient in Table 4, Model 4), the effect is -0.003. The antilog is then ~0.997, so the odds ratio of P(dev)/(1-P(dev)) should be multiplied by 0.997 (or reduced by 0.3%).

combination closer to the optimum shape, so we would expect a positive relationship between stretch and the likelihood of redevelopment. And this is what we find. The stretch coefficient is positive and highly significant in all specifications, both in the logit model and in the spatial autoregressive model. But it only makes sense to combine a sub-optimally shaped lot with an adjacent lot if the result is closer to the optimal shape. In other words, if the shape of a lot pair has high stretch also, it would not be very beneficial to make that particular combination. Here also, this intuition is borne out by the results. The stretch of a lot pair has a negative relationship with the likelihood of their joint redevelopment. That effect is highly significant in all specifications.

We also look at whether a lot is located in the middle of a block or on its periphery. A peripheral location implies more fixed boundaries (with streets and canals), and less neighboring lots, so less possibilities for joint redevelopment with other lots. That means distance from a block's center should be negatively related to redevelopment likelihood, and that is what we find: a negative and significant coefficient in all specifications. We do not find clear results regarding proximity to water or regarding the percentage of a lot that was already developed in 1832.

Just as we found for different lot sizes, if two adjacent lots have different uses, then one of these lots is likely to have a suboptimal use, and this would increase the chance of redevelopment. This notion is borne out by our findings of a negative relationship between the same use dummy and the development likelihood, although the effect is not very strong, and not always significant.

The social effects are also mostly in line with intuition and our a priori reasoning. As we stated before, social characteristics may decrease or increase coordination costs for land assembly and thereby make exercise of the redevelopment option more or less likely. The most obvious case of reduced coordination costs is when two adjacent lots have the same owner. Indeed, we find that this is associated with much better odds of joint redevelopment, no matter what the model specification is. Interestingly, we even find that the effect is still positive and significant for the 1832 to 2015 period.

We also find that the likelihood of joint redevelopment goes up when two owners have the same occupation and/or the same religion. The effect is quite weak for occupation, but very strong for religion, both in the logit model and in the spatial autoregressive model. Interestingly, it is even stronger than the effect of the same-owner dummy. Having the same religion implies being part of the same social network. This would breed trust and lower coordination costs, and would increase the likelihood of a the joint exercise of a profitable option. As expected, the effect strongly dissipates for the 1832-2015 period. Nevertheless, it is quite interesting that the religion of neighbors in 1832 does still have some significant effect on joint lot redevelopment over the subsequent 183 years!

Regarding ownership, we find that lots occupied by the city are more likely to be assembled. Conversely, owner-occupation reduces the likelihood of assembly. This may be because assembly would involve more transaction and transition costs for the seller due to the need to move. But it is also possible that rental dwellings were in inferior condition relative to owner-occupied ones, which would make their redevelopment more likely.

The last variables in the regression are dummies describing whether one or both lots' heads of household were Jewish in 1832. As stated above, we expect that this did not affect the likelihood of lot assembly and redevelopment between 1832 and 1860, given that we already control for religion. However for the period between 1832 and 2015, we expect a greater likelihood of assembly for lots with Jewish owners, due to the deportation and subsequent murder of Amsterdam's Jewish population during the German occupation. That is indeed what we find, and the effect is strongest for lot pairs for which both heads of household were Jewish in 1832.

Last, the WY variable in the spatial autoregressive model in Table 4 indicates strong and positive spatial correlation. This implies that redevelopment did not occur in isolation. Often, more than two lots were combined, and we observe redevelopment hotbeds in the medieval city center, in the South East, and in the far West, which is in line with what we saw visually in Figure 3. The suggestion is that changes in highest and best use tend to affect areas or districts, rather than single individual properties. This is in line with recent findings by Munneke and Womack (2015, 2016). Cities are not random collections of atomized lots, but rather are constellations of districts, neighborhoods, and areas.

As a robustness check of the land assembly consequences of lot size, we also study the effect non-parametrically. We run Equation (1) again using the full specification as in Model 5, Table 4, with one difference. Instead of including lot size as a continuous variable, we group all lots in quintiles based on size – with the smallest lots in the first quintile – and create dummy variables for all 15 pairwise combinations of these quintiles. The regression coefficients for these dummy variables provide insight into the absolute and relative importance of lot size in all possible assembly pairs. Table 5A provides these coefficients (the regression coefficients for the other variables are not reported, since these do not markedly differ from those included in Table 4), and 5B their antilogs. For example, the odds ratio of two lots from quintile 1 and 2 being developed is exp(-0.10), so only 90.5 percent of the odds ratio of the base case of two small lots that are both from quintile 1.

=== *insert Table 5 about here* ===

Table 5A shows again that larger lots are significantly less likely to be assembled than smaller ones, and that greater inequality between the lots in any given adjacent pair increases the likelihood of assembly. The effects are continuous and highly significant.

VII. Concluding remarks

This paper breaks new ground in urban economics by looking at the very long-term dynamics of redevelopment activity in a major city, focusing in depth on the specific characteristics that have influenced land assembly in Amsterdam during 1832-2015. We employ a logit model based on information from 1832 to predict micro developments for the periods 1832-1860 and 1832-2015. The results are robust to alternative model choices.

We find that much of the land assembly that has occurred in the last 183 years can be predicted, and that land owners rationally contemplated "highest and best use" long before it was ever part of the professional real estate lexicon. Not only the physical characteristics of the lots, but also the social characteristics of their owners and occupiers in 1832 turn out to be predictive for the likelihood of assembly, although the social characteristics tend to have explanatory power largely for the 1832-1860 period only. Some of the model's salient variables underscore the relevance of real option theory in our understanding of redevelopment, though a comprehensive and rigorous test of real option theory is beyond the scope of the present paper. Small lots and lots with suboptimal shapes are more likely to get redeveloped. Social ties between owners, for example by sharing a joint religion or profession, likely reduce coordination costs for joint lot development, and therefore also increase the odds of redevelopment. Lots that were owned by Jewish citizens in 1832 are significantly more likely to be assembled in 2015, probably because of the World War II genocide.

Probably the most important lesson of this paper is that land assembly should preferably be studied by analyzing both individual and combined inner-city lots. This is in line with how urban redevelopment actually takes place, and our results show that this approach is warranted by the data. Moreover, our results imply that it is important to take account of social characteristics of lot owners besides just the physical characteristics of the lots.

References

Braid, R.M., 2001, Spatial Growth and Redevelopment with Perfect Foresight and Durable Housing, *Journal of Urban Economics* 49(3), 425-452.

Brooks, L., Lutz, B., 2016, From Today's City to Tomorrow's City: An Empirical Investigation of Urban Land Assembly, *American Economic Journal: Economic Policy* 8(3), 69-105.

Brueckner, J.K., 1980, A Vintage Model of Urban Growth, *Journal of Urban Economics* 8, 389-402.

Capozza, D.R., Li, Y., 1994, The Intensity and Timing of Investment: The Case of Land, *American Economic Review* 84(4), 889-904.

Clapp, J.M., Eichholtz, P.M.A., Lindenthal, T., 2013, Real Option Value over a Housing Market Cycle, *Regional Science and Urban Economics* 43(6), 862-874.

Clapp, J.M., Jou, J.B., Lee, T., 2012, Hedonic Models with Redevelopment Options under Uncertainty, *Real Estate Economics* 40(2), 197-216.

Clapp, J.M., Salavei, K., 2010, Hedonic Pricing with Redevelopment Options: A New Approach to Estimating Depreciation Effects, *Journal of Urban Economics* 67(3), 362-377.

Cunningham, C., 2013, Estimating the Holdout Problem in Land Assembly, Federal Reserve Bank of Atlanta Working Paper 2013-19.

Dye, R.F., McMillen, D.P., 2007, Teardowns and Land Values in the Chicago Metropolitan Area, *Journal of Urban Economics* 61, 45-63.

Eckart, W., 1985, On The Land Assembly Problem, *Journal of Urban Economics* 18, 364-378.

Fryske Akademy, 2014, HISGIS-project Amsterdam. Available at http://www.hisgis.nl/hisgis/gewesten/amsterdam/

Fu, Y., McMillen, D., Somerville, T., 2002, Land Assembly: Measuring Holdup, University of British Columbia Working Paper.

Hornbeck, R., Keniston, D., 2014, Creative Destruction: Barriers to Urban Growth and the Great Boston Fire of 1872, Harvard University Working Paper.

Kadaster, 2015, BAG Basisregistraties Adressen en Gebouwen. Available at http://www.kadaster.nl/BAG

Kain, R.J.P., Baigent, E., 1992, *The Cadastral Map in the Service of the State*, Chicago, University of Chicago Press.

Keverling Buisman, F., Muller, E., 1979, “Kadaster-Gids”. Gids voor de raadpleging van hypothecaire en kadastrale archieven uit de 19e en de eerste helft van de 20e eeuw (Den Haag 1979).

Klier, T., McMillen, D.P., 2008, Clustering of Auto Supplier Plants in the United States. *Journal of Business & Economic Statistics* 26, 460–471.

Kruisinga, P., 1997, De kadastrale legger en aanverwante bronnen. *Broncommentaren*, Instituut voor Nederlandse Geschiedenis, 17-74.

Lesger, C., Van Leeuwen, M.H.D., 2012, Residential Segregation from the Sixteenth to the Nineteenth Century: Evidence from the Netherlands, *Journal of Interdisciplinary History*, XLII:3, 333-369.

Lesger, C., Van Leeuwen, M.H.D., 2013, Residentiële segregatie in vroeg-moderne steden. *Tijdschrift voor Sociale en Economische Geschiedenis* 10(1), 71-101.

McMillen, D.P., 2015, SpatialProbit: Parametric Spatial Probit Modules. R package version 1.0.

Menezes, F., Pitchford, R., 2004, The Land Assembly Problem Revisited, *Regional Science and Urban Economics* 34, 155-162.

Munneke, H.J., 1996, Redevelopment Decisions for Commercial and Industrial Properties, *Journal of Urban Economics* 39, 229-253.

Munneke, H.J., Womack, K.S., 2015, Neighborhood Renewal: The Decision to Renovate or Tear Down, *Regional Science and Urban Economics* 54(1), 99-115.

Munneke, H.J. and Womack, K.S., 2016, Valuing the Redevelopment Option Component of Urban Land Values, *Real Estate Economics*, forthcoming.

O’Flaherty, B., 1994, Land Assembly and Urban Renewal, *Regional Science and Urban Economics* 24(3), 287-300.

Rosenthal, S.S., Helsley, R.W., 1994, Redevelopment and the Urban Land Price Gradient, *Journal of Urban Economics* 35(2), 182-200.

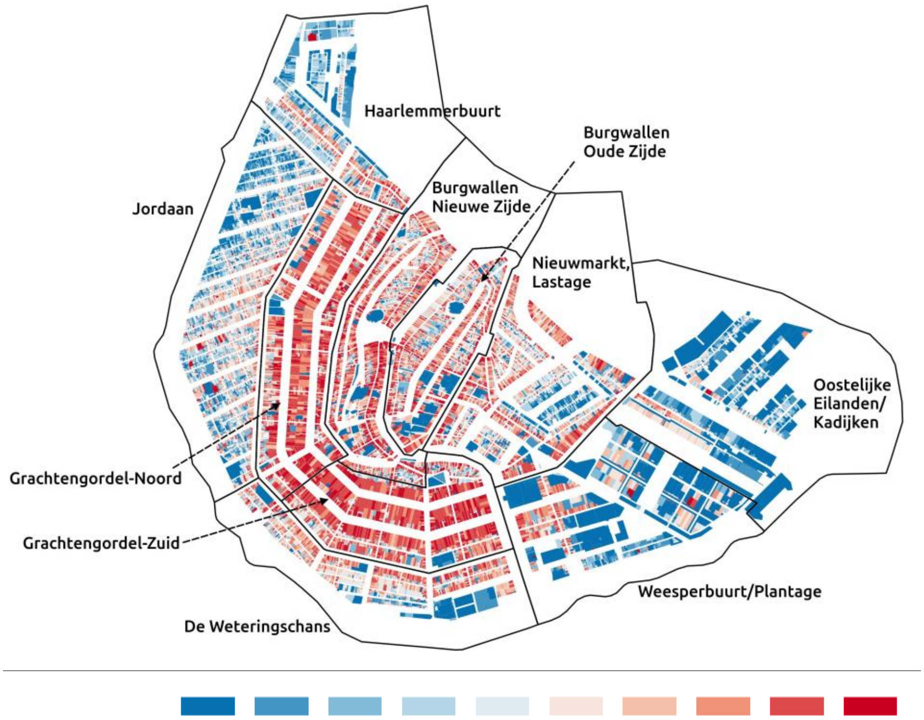
Strange, W.C.., 1995, Information, Holdouts and Land Assembly, *Journal of Urban Economics* 38, 317-332.

Titman, S., 1985, Urban Land Prices under Uncertainty, *American Economic Review* 75(3), 505-514.

Wheaton, W.C., 1982, Urban Spatial Development with Durable but Replaceable Capital, *Journal of Urban Economics* 12, 53-67.

Zee, H.A. van der, 1982, The Hunger Winter: Occupied Holland, 1944-1945. J. Norman & Hobhouse, London.

Figure 1: Spatial Distribution of Property Values in 1832 Central Amsterdam

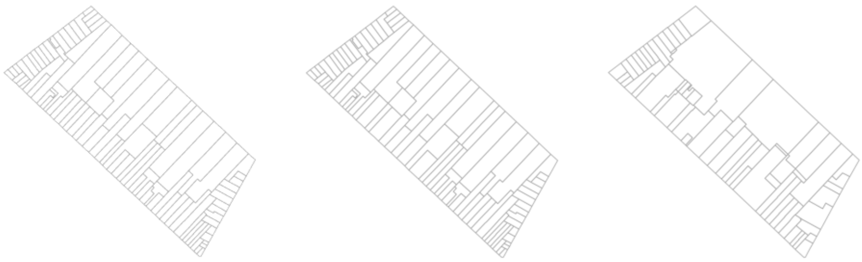


Percentile	< 10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	> 90

Notes: The map shows a snapshot of property rental value based on rents that were assessed by the city for tax reasons, for rental properties and owner-occupied properties alike. The rental values are divided by the property footprint, to account for different building sizes. The source is the 1832 cadastral map of Amsterdam.

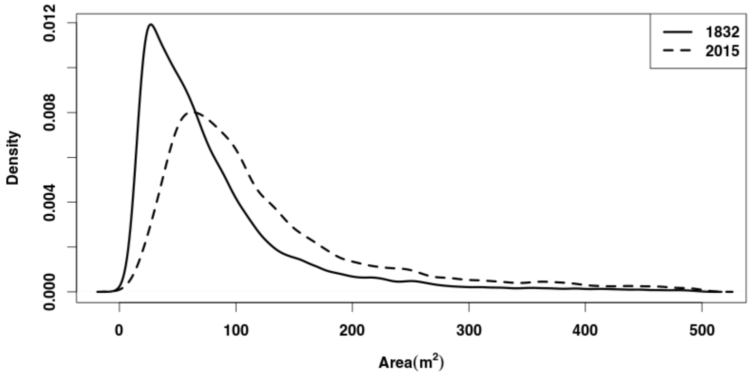
Figure 2: Example of lot-by-lot land assembly for one block on the Herengracht canal

1832 *1860* *2015*



Notes: This figure displays the evolution of land assembly at the example of a single block on the Herengracht canal. The North-East side of this block faces the canal. While many lots today still feature the same boundaries as in 1832, a clear trend towards larger lots by combining multiple smaller lots can be observed. Historically, block-wide redevelopments only rarely occurred in Amsterdam.

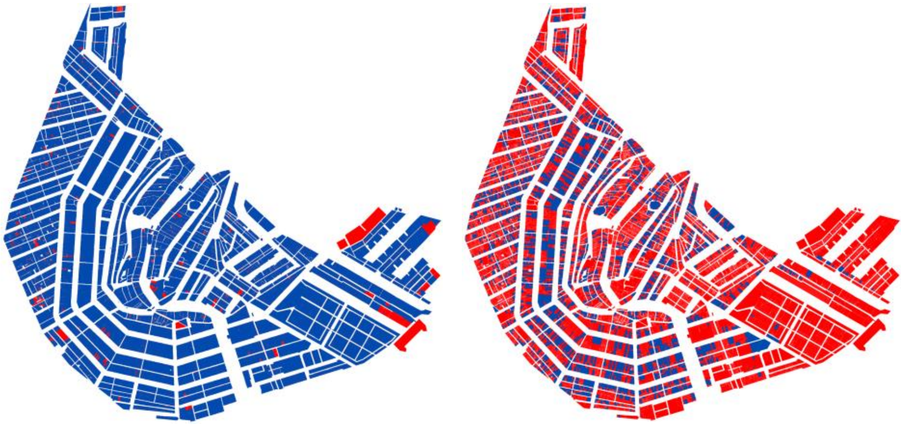
Figure 3: Estimated Density Plots of Lot Areas, 1832 versus 2015



Notes: Over the last 180 years, the distribution of lot size in central Amsterdam has shifted towards significantly larger lots, as visualized by the estimated density functions of lots size above. In 1832 (solid line), half of the lots were smaller than 68.5 m^2. By 2015 (dashed line), the median of lot size reaches 105.9 m^2. Exceptionally large lots of 400 m^2 or more remain uncommon

Figure 4: Pairwise lot redevelopments

1832-1860	*1832-2015*



Notes: These maps provide information on the pairwise redevelopment of lots between 1832 and 1860, and between 1832 and 2015. Redeveloped lots are denoted in red, unchanged lots in blue. The maps are based on Amsterdam's cadastral maps for 1832, 1860, and 2015.

Table 1: Lot and Building Characteristics, 1832 versus 2015

Variable	*Year*	*25th percentile*	*Median*	*Mean*	*75th percentile*	*SD*
Lot area (m^2)	1832	37.9	68.5	121	128.8	152.9
	2015	65.6	105.9	173.9	205.6	178.7
Building footprint (m^2)	1832	27.6	46.1	67.2	76.2	125.4
	2015	50.2	79.5	172.1	138.8	555.3
Developed area (% of lot)	1832	58.1%	90.7%	76.5%	100.0%	30.3%
	2015	63.7%	89.1%	77.5%	98.8%	26.6%
Stretch ($perimeter^2$/area)	1832	17.5	21	23.6	26.6	8.7
	2015	18.6	21.9	23.9	26.9	7.5
# neighboring lots	1832	3	4	4.3	5	2.1
	2015	2	3	3.7	5	1.7

Notes: This table compares characteristics of buildings and lots in Amsterdam's city center for 1832 and 2015, based on the cadastral maps for these years.

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Table 2*: Summary Statistics for Pairs of Neighboring Lots*

Variable	*Min*	*Mean*	*Median*	*Max*	*SD*
A. Structural Characteristics					
Joint development 1832-1860	0	0.02	0	1	0.14
Joint development 1832-2015	0	0.42	0	1	0.49
log(# neighboring lots)	0	2.19	2.20	3.04	0.40
log(tax value 1832, individual lot)	0	4.97	5.05	8.07	1.00
log(tax value 1832, combined lot)	0	5.52	5.75	8.23	1.34
log(area, combined)	2.06	5.07	4.98	10.72	0.88
Lot area, Herfindahl index	0.49	0.58	0.53	1	0.11
Stretch, individual lot	2.75	3.15	3.11	4.96	0.27
Stretch, combined lot	2.59	3.40	3.39	6.26	0.44
Share area developed, combined lot	0	0.77	0.86	1	0.25
Share of perimeter close to water	0	0.32	0	1	0.57
Same use, two lots	0	0.73	1	1	0.44
B. Social Characteristics					
Same owner	0	0.16	0	1	0.37
Same occupation	0	0.14	0	1	0.35
Same religion, head of household	0	0.33	0	1	0.47
# lots with Jewish head of household	0	0.13	0	2	0.43
# lots owned by city	0	0.03	0	2	0.20
# lots owner occupied	0	0.46	0	2	0.64

Notes: Overall, 59,468 unique combinations of neighboring lots exist in 1832. This table provides pairwise and individual information regarding the structural state of the lots, as well as social characteristics of the head of the household occupying the dwelling built on the lot. Data are from the 1832, 1860 and 2015 cadastral maps. The base year is always 1832.

Table 3*: Logit Regression Estimates for Joint Redevelopment of Neighboring Lots*

Variable	*1832–1860*						*1832–2015*			
	Model 1		*Model 2*		*Model 3*		*Model 4*		*Model 5*	
ln(# neighboring lots)	-0.30	*	-0.37	**	-0.39	**	0.21	***	0.20	***
	(0.05)		(0.02)		(0.02)		(0.00)		(0.00)	
ln(tax value 1832, combined)	-0.20	***	0.03		0.01		-0.10	***	-0.06	***
	(0.00)		(0.68)		(0.90)		(0.00)		(0.00)	
ln(area, combined)	-0.52	***	-0.44	***	-0.42	***	-0.69	***	-0.63	***
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
Lot area, Herfindahl index	4.70	***	3.86	***	3.91	***	1.06	***	0.78	***
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
Avg. stretch, individual lots	1.73	***	1.09	***	1.09	***	1.13	***	0.97	***
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
Stretch, combined lot	-2.00	***	-1.42	***	-1.42	***	-1.58	***	-1.39	***
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
% area developed, combined	-0.22		-0.34		-0.32		-0.13	.	-0.12	
	(0.43)		(0.23)		(0.26)		(0.09)		(0.13)	
Share of perimeter close to water	0.12		0.14		0.14		-0.18	***	-0.17	***
	(0.19)		(0.16)		(0.15)		(0.00)		(0.00)	
Same use type	0.18	.	0.12		0.11		-0.02		-0.03	
	(0.09)		(0.34)		(0.40)		(0.39)		(0.34)	
Same owner			4.17	***	4.21	***			1.17	***
			(0.00)		(0.00)				(0.00)	
Same occupation			0.17		0.16				0.24	***
			(0.52)		(0.53)				(0.00)	
Same religion, head of household			3.55	***	3.61	***			0.02	
			(0.00)		(0.00)				(0.32)	
Owner occupier: 1 lot			-0.20		-0.22				0.06	**
			(0.20)		(0.17)				(0.02)	
Owner occupier: 2 lots			0.15		0.14				0.01	
			(0.56)		(0.59)				(0.85)	
Owned by city: 1 lot			1.12	***	1.08	***			0.25	***
			(0.00)		(0.00)				(0.00)	
Owned by city: 2 lots			1.61	***	1.52	***			-0.21	
			(0.00)		(0.00)				(0.30)	
Owner Jewish: 1 lot			-16.88	***					0.08	
			(0.00)						(0.23)	

Owner Jewish: 2 lots		-2.17 ***			0.26 ***
		(0.00)			(0.00)
Intercept and block fixed effects	YES	YES	YES	YES	YES
McFadden pseudo-R^2	0.44	0.53	0.53	0.25	0.27

Notes: This table provides results for logistic regression estimates based on Equation (1). The number of observations is 59,468. Spatial dummy variables are based on 647 blocks in 1832. P-Values in parenthesis. Stars (***,**,*) mark significance at 1%, 5% and 10% confidence levels.

Table 4: Spatial Logit Regression Estimates for Joint Redevelopment of Neighboring Lots

Variable	*1832–1860*			*1832–2015*	
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*
(Intercept)	0.58	-6.15 ***	2.92 ***	3.49 ***	2.85 ***
	(0.57)	(0.00)	(0.00)	(0.00)	(0.00)
ln(# neighboring lots)	-0.14	-0.20 *	0.10 ***	0.08 **	0.11 ***
	(0.22)	(0.06)	(0.00)	(0.01)	(0.00)
ln(tax value 1832, comb.)	-0.10 **	0.03	-0.13 ***	-0.18 ***	-0.13 ***
	(0.01)	(0.50)	(0.00)	(0.00)	(0.00)
ln(area, comb.)	-0.31 ***	-0.29 ***	-0.37 ***	-0.40 ***	-0.35 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Lot area, Herf. index	3.64 ***	3.30 ***	0.88 ***	1.27 ***	0.87 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Avg. stretch, ind. lots	0.95 ***	0.82 ***	0.85 ***	0.98 ***	0.83 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Stretch, comb. lot	-1.53 ***	-1.26 ***	-1.09 ***	-1.25 ***	-1.08 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
% area developed, comb.	0.15	0.09	-0.12 *	-0.12 **	-0.08
	(0.52)	(0.66)	(0.06)	(0.05)	(0.18)
Share of perimeter close to water	-0.05	-0.08	-0.10 ***	-0.10 ***	-0.09 ***
	(0.41)	(0.30)	(0.00)	(0.00)	(0.00)
Same use type	0.05	-0.10	-0.06 **	-0.07 ***	-0.07 ***
	(0.60)	(0.33)	(0.01)	(0.01)	(0.00)
Same owner		5.67 ***	0.96 ***		0.96 ***
		(0.00)	(0.00)		(0.00)
Same occupation		0.73 ***	0.23 ***		0.23 ***
		(0.00)	(0.00)		(0.00)
Same religion, HoH		5.33 ***	0.08 ***		0.06 **
		(0.00)	(0.00)		(0.01)
Owner occupier: 1 lot		-0.39 ***	0.02		0.03
		(0.01)	(0.47)		(0.25)
Owner occupier: 2 lots		-0.18	-0.05		-0.04
		(0.45)	(0.16)		(0.32)
Owned by city: 1 lot		0.99 ***	0.16 **		0.15 **
		(0.00)	(0.01)		(0.01)
Owned by city: 2 lots		0.55 **	-0.21		-0.22

		(0.04)	(0.25)		(0.24)
Owner Jewish: 1 lot		n.a.			0.22 ***
		(0.00)			(0.00)
Owner Jewish: 2 lots		-0.45			0.46 ***
		(0.26)			(0.00)
Neighborhood dummies	YES	YES	YES	YES	YES
WY	0.69 ***	0.38 ***	0.42 ***	0.40 ***	0.44 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: This table provides results for the Klier-McMillen (2008) linearized GMM logit model for a 0-1 dependent variable and an underlying latent variable of the form $Y^* = \rho\, WY^* + X\, \beta + u$. Estimated using the "spgmm/logit"-procedure from McMillen's (2015) "SpatialProbit"-package for the R environment (McMillen, 2015). The number of observations is 59,468. P-Values in parenthesis. Stars (***,**,*) mark significance at 1%, 5% and 10% confidence levels.

Table 5: Nonparametric modeling of lot size-effect on joint redevelopment odds ratio

		Quintile area, Lot 1				
		Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
		a) Regression coefficients				
Quintile area, Lot 2	Quintile 2	-0.10 *	-0.32 ***			
		(0.05)	(0.00)			
	Quintile 3	-0.43 ***	-0.61 ***	-0.93 ***		
		(0.00)	(0.00)	(0.00)		
	Quintile 4	-0.69 ***	-0.92 ***	-1.12 ***	-1.29 ***	
		(0.00)	(0.00)	(0.00)	(0.00)	
	Quintile 5	-0.92 ***	-1.07 ***	-1.25 ***	-1.36 ***	-1.55 ***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
		b) Antilogs of regression coefficients				
	Quintile 2	90.5%	72.6%			
	Quintile 3	65.1%	54.3%	39.5%		
	Quintile 4	50.2%	39.9%	32.6%	27.5%	
	Quintile 5	39.9%	34.3%	28.7%	25.7%	21.2%

Notes: The table presents coefficients and p values (in parentheses) from an estimation of Equation 1. In this variant, the size of the two lots is not captured by one continuous variable (as in e.g. Model 5, Table 4). Instead, the individual lots are classified by their size quintile and dummy variables are assigned to the 15 unordered combinations of quintiles. The coefficients for other hedonic and social attributes are not reported.

The odds ratio of two neighboring lots from quintile 1 and 2 being developed is *exp(-0.10)* or only 90.5% of the odds ratio of the base case of two small lots both from quintile 1. For two large lots from quintile 5, the odds ratio is only 21.2% of the base case. The average lot size per quintile (m^2) are 21.9, 41.4, 66.0, 103.7, and 361.8, respectively.