The Static City?
Amsterdam 1832-2015

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Abstract

Inner city redevelopment frequently involves the combination of lots, but the existing literature analyzes redevelopment on a single-lot basis only. The key contribution of our paper is that it explicitly investigates the structural and social determinants of multilot developments. We show that the additional coordination and transactions costs resulting from joint lot development influence the exercise of the redevelopment option.

We first estimate a logit model that aims to predict joint lot redevelopment, based on structural characteristics of dwellings and social characteristics of their owners, using Amsterdam housing information for 1832, 1860 and 2015. In all, we have a complete set of structural and household characteristics for the universe of dwellings in Amsterdam in these years.

Our model can explain 59 percent of redevelopment activity between 1832 and 1860, with a significant influence of the social factors beside the structural ones. Moreover, using only information from 1832, the model explains up to 27 percent of the redevelopment activity for the subsequent 183 years.

A subsequent spatial hedonic pricing model estimates marginal prices for the structural characteristics associated with the real option to jointly redevelop.

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I. Introduction

From an American or Asian perspective, European cities can appear sclerotic. Cities like Paris, Barcelona, London, Rome and Amsterdam have beautiful historic centers where tourists happily gather. But the question is whether they are dynamic enough to foster the economic vitality that cities uniquely enjoy and that they need to prosper.

The consensus among urban economists is that cities work best when land can be (re)developed to its highest and best use. In that case, urban land can play its most productive role as a production factor. Authors like Jacobs (1984), Romer (1986), Glaeser and Kerr (2009), and Glaeser (2011) illustrate how important cities are as growth hubs for our economies, either because of network externalities and knowledge spillovers, access to a diversely skilled labor force, or through the immediate presence of consumer demand. Glaeser (2011) also suggests that too many monuments and too much protection of historic urban landscapes is detrimental for urban economic success, and for the adaptability of cities to changing circumstances. Seen in that way, most European cities appear to do it all wrong, and that also seems to hold for Amsterdam: By outward appearance, Amsterdam's city center looks ancient. A large part of the center's street grid is still as it was designed in the 17th century, and many current buildings appear quite the same as then.

Yet the question is whether outside appearances are not just that. It may be possible that behind the ancient facades, redevelopment and modernization are going on, and that they are going on in a systematic and predictable way. We test that idea by looking at the micro urban form of Amsterdam at three far-removed moments in time: 1832, 1860 and 2015, and in doing that, we make two main contributions to the urban economics literature.

The main contribution is in the fact that we analyze the redevelopment of urban properties jointly with their neighbors, explicitly taking account of the coordination problems this entails. The existing literature explaining urban redevelopment (I. a. Capozza and Li, 1994; Dye and McMillen, 2007; Munneke, 1996; Rosenthal and Helsley, 1994) invariably studies urban properties individually. But 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, and therefore also its value.

Second, we explore the very long-run dynamics of urban (re)development at the micro level, something that has not been done before, but which is important for our understanding of the micro-forces that shape our cities in the long run. Interestingly, these forces appear to adhere to real option theory, and we show that variables salient for redevelopment help explain the cross section of housing rents and values in 1832 and 2005-2008, respectively.

The empirical analysis in the paper starts with the 1832 cross section of lots in the historic city, i.e. of all lots located within Amsterdam's famous half-moon shaped center, which effectively made up the complete city at that time, and we estimate a model that aims to predict the redevelopment that has been going on there between 1832 and 1860 and between 1832 and 2015. This model is based on structural and social variables likely to influence the exercise of the redevelopment option.

Using this model we can explain 45 percent of the redevelopment that went on between 1832 and 1860 with structural covariates only. The explanatory power increases to 59 percent when we include the social variables, like the profession and religion of the inhabitants of the dwellings in 1832. Most of the variables have the sign that a real options framework would predict.

More astonishing is that this same model, employing quite limited data from 1832 only, is able to explain up to 27 percent of the cross sectional variation in redevelopment activity in Amsterdam's city center in the subsequent 183 years. Given that we find evidence of pairwise redevelopment on 42 percent of all lots during this time period, and that almost all of that redevelopment took place long after 1832, this is quite surprising. Regarding the effects of the individual variables, we do find these to be smaller over this long time period than for the 28 years before 1860. Not very surprisingly, the importance of the 1832 owners' characteristics loses its significance over such a long time period.

We subsequently employ the variables that turn out to be salient for Amsterdam's redevelopment in a spatial autoregressive model, and we test that model on rent data in 1832. We find that rental values are in line with lot size and the degree to which lots were already optimally developed in 1832. We also find evidence for real option value, especially concerning the shape of the 1832 lots.

In the remainder of this paper we will first discuss the literature regarding the redevelopment of urban land. We will subsequently present the data, data sources and variable definitions for the ensuing regressions, as well as statistics regarding these variables. We will then discuss the logit and spatial autoregressive models we employ to predict Amsterdam's redevelopment dynamics between 1832 and 2015, and will provide the results of these analyses. Next, we will present the spatial autoregressive pricing model we use to explain rental values in 1832. This section will also provide regression results concerning these values. The paper ends with concluding remarks.

II. Literature

Cities grow both by developing land around the city and continuously optimize the use of space by redeveloping land within it. This paper focuses on the latter, and it builds on a small but solid strand of literature aiming to understand when and how urban land is redeveloped. The main conclusions from this literature are that urban redevelopment is systematically and predictably related to the value of the existing bundle of a building and the land it stand on, the demolition costs, and the price of vacant land at a certain location. On top of that, a literature has emerged that analyzes the effect of this redevelopment – and the option to redevelop – on the value of properties. This literature shows that the redevelopment option is priced.

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 on data of residential property transactions in Vancouver. Their main conclusion is that redevelopment of a property happens when the value of the existing building and the land it stand on 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. They find that the rents in both uses affect the timing and intensity of redevelopment.

The literature concerning the value effects of urban property redevelopment mostly studies this problem using the real options approach introduced by Titman (1985) and Capozza and Li (1994). The decision to redevelop is modeled as the exercise of an option that is embedded in the ownership of properties, and therefore also reflected in their prices, even if these options are not exercised. Recent examples are Clapp and Salavei (2010), Clapp, Jou and Lee (2012), Clapp, Eichholtz and Lindenthal (2013), and Munneke and Womack (2014), who show that the redevelopment option is priced in hedonic models, and that its value behaves according to the predictions generated by real options theory. For example, an increase in the variance of the underlying stochastic process also increases the value of the option component.

One important characteristic of the existing literature on urban redevelopment, both when predicting its occurrence, and when assessing its value effects, is that it regards all properties individually. But especially in historic city centers, with their legacy grid of lots that were large enough for historic uses, but too small for modern ones, redevelopment commonly involves the combination of different lots into one new property. One may apply the economic framework discussed above to a group of properties as if it was a single one, but that would neglect the coordination and transaction costs that are likely to emerge when different lots with different owners are jointly redeveloped. These costs probably affect the likelihood that the option for a joint redevelopment is exercised, and they will therefore also affect the value of that option. This paper aims to investigate precisely that issue.

III. Data

To study (re)development activity in the city of Amsterdam in the long run, we employ cadastral maps and associated data for the universe of all lots and buildings in central Amsterdam at three points in time: 1832, 1860, and 2015.

Detailed property maps for the entire Netherlands were available for the first time in 1832. When France annexed the Netherlands in 1810, land laws and taxes were updated to the Napoleonic system, which relied on an accurate and complete cadastral system in the modern sense. Already 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 up in 1831 (Kain and Baigent, 1992).

The 1832 cadastral map is a result of that effort. For Amsterdam, the cadastral map and additional census data has been digitized by the HISGIS project (Fryske Akademy, 2014).[1] The level of detail and the scale of the dataset is impressive: Amsterdam has been divided up in 28,365 lots on which 30,047 individual buildings had been built in 1832 (20,282 of which were classified as purely residential). The data does not only comprise information on all structures but also on all residents – a wealth of information which is hardly available for modern cities.

The records provide a detailed picture of the city in three dimensions. 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, 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. This allows us to compare the lot's shape to the shapes of each of its neighboring tracts, which we will use extensively in the regressions in the subsequent sections of the paper.

Second, the map provides 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

1These data have previously been used by Lesger and Van Leeuwen (2012).

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.

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 *et al.*, 2013)[2]. 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.

The next available cadastral map is from 1860. Its underlying information is more extensive in some aspects and less so in others. 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 (so not just the owners) as reported in the 1851-1853 census, including each dweller's name, date and place of birth, occupation and religion (Fryske Akademy, 2014) On the other hand, the 1860 map does not provide any information on individual property (rental) values.

Combined, these two data sources provide a unique historic snapshot on the micro-urban form of a major city. We are not aware of any other available dataset comprising detailed information on building structures, property rents and owner identifiers 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, 2015a, 2015b) and 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 these. Current buildings often span several historic lots since 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

2 Keverling Buisman and Muller (1979) provide guidance for the use of historical mortgage and land registry archives.

subsequent analyses. By 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 towards highest and best use often entails redevelopment towards projects with larger volumes.

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 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, it got developed more evenly: The standard deviation decreased from 30.3 percent to 26.6 percent as the share of both relatively thinly and also fully developed lots dropped. Despite lots being merged into larger tracts throughout 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 towards larger lots, 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 spread, with 60 percent of all owners owning only one dwelling, 19.5 percent owning two and 7.9 percent owning 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.

For property rents and values, we have two snapshots: one database of property rents for 1832, based on the same survey data we discussed above, and one for housing transaction prices between 2005 and 2008.

The data for 1832 concerns estimates of property rents that were made for tax purposes. For all dwellings, including 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 rents, Amsterdam can be roughly structured into four areas. The left-hand panel of Figure 1 provides a clear picture of this.

The medieval core 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 which 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 still needed to be subdivided for development and some were even used for urban vegetable gardens.

Modern property values are displayed in the right-hand panel of Figure 1. This graph reports the median transaction price per square meter for freehold apartments for each of Amsterdam's modern-day neighborhoods. These numbers are calculated from a database of residential property transaction prices for the years from 2005 through 2008 obtained from the Dutch Realtors' Association (NVM). The total number of observed transactions for that period is 9,728. The sample covers exactly the same area as the 1832 cross section, but back then, this area comprised almost all of the city of Amsterdam while today it has become the center of a much expanded city.

Comparing the two panels in Figure 1, we can observe some stark changes in relative property values. Most importantly, value has shifted away from the medieval center to the former working-class neighborhoods in the West and the South. On the other hand, we observe a surprising persistence in relative neighborhood property values in the upscale canal belt. The neighborhoods in the East persist in relatively low property value.

=== insert Figure 1 about here ===

IV. Predicting redevelopment dynamics

We first want to study the predictability of urban redevelopment, focusing on the joint redevelopment of neighboring lots. Joint redevelopments are especially interesting events since they are likely to be highly important for the development dynamics of historic city centers, and they are complicated, since they involve the 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 is simultaneously explained by economic determinants specific to these lots and 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 meter 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.

Based on these 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 2, and 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 West of the center. Some larger lots have been redeveloped in the East.

The map in the right-hand panel 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 a lot of 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 2 about here* ===

For each 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 building values are low, since this implies a low strike price of the redevelopment option (Clapp *et al.*, 2013; Rosenthal and Helsley, 1994). 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. The micro-location of the lot within its block is partially controlled for by measuring the distance of the lot to the centroid of the entire block, normalized by the average distance for each block. Proximity to water is approximated by the share of the lot perimeter that is closer than 20 meter to one of Amsterdam's canals.

We also incorporate the relative size of one lot in each pair to assess whether size matters in a relative sense. The relative weight of each constituent of a combined lot is measured by Herfindahl indices[3] for lot areas and property values. 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 religion of the owners has unfortunately not been recorded in 1832. For owner-occupied properties, the religion of the heads of households as reported in the

3For instance, $\textit{Herf. } area_{i,j} = (area_i/area_{i,j})^2 + (area_i/area_{i,j})^2$.

1851-1853 census serves as a proxy for religious ties between owners. For let properties, the religion of the tenants is hypothesized to be correlated with the owners – not perfectly, but positively. The most frequent denominations were Dutch protestant (38%), Roman catholic (19%) and Jewish (7%).

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 until 1860, but very common between 1832 and 2015: 42 percent of all 1832 lots had been redeveloped in combination with another lot by 2015. Most 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* ===

Combining economic and social factors, we estimate the following logistic regression equation:

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

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 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 by necessity of data limitations quite parsimonious, so we may have an omitted variable bias. To test for the robustness of the results, we therefore do the analysis also by employing a spatial autoregressive (SAR) model. Indeed, join 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 on pairs of lots being direct neighbors. For instance, if lots *a* and *b* are neighbors and *b* is adjacent to *c*, then the cell in *W* corresponding to pairs *(a,b)* and *(b,c)* will be 1. *W* is row-normalized and symmetric in terms of non-zero elements.

Results for the baseline logit regression model in Equation (1) and for the spatial autoregressive model are provided in Table 3 and Table 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 59 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. However, what's even more astounding is that our rather simple model explains up to 27 percent of redevelopment activity during the 183-year period until 2015. Not surprisingly, social factors in 1832 do not play a very important role for this very long time period.

We will discuss the results on the individual regressors 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 our societies grow richer, people consume more space. Apartments that housed complete families in the 19th century are now occupied by singles. The need for bigger buildings on bigger lots has grown proportionally. That implies that larger lots are already closer to the optimum, and are therefore less likely to be combined and redeveloped with neighboring lots. Again, this logic is confirmed by the data. 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.[4]

But lot area 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, and 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.

Furthermore, lot shape matters also. 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 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 suboptimally 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, and 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 options 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 almost all specifications. We do not find clear results regarding proximity to water and the percentage of a lot that was already developed in 1832.

4 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 -0.34 (the coefficient in Table 4, Model 4), the effect is -0.0034. The antilog is then ~0.9966, so the odds ratio of P(dev)/(1-P(dev)) is reduced by 0.34%.

Just as we found for different lot sizes, if two adjacent lots have different uses, than 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. As we stated before, social characteristics may decrease or increase coordination costs for joint lot development and thereby make exercise of the development 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. Surprisingly, 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. In fact, we are very surprised to find that the religion of neighbors in 1832 even has any significant effect on joint lot redevelopment during the next 183 years at all.

Last, the WY variable in the spatial autoregressive model in Table 4 shows 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, the Plantage in the East, and the Jordaan in the West, which is in line with what we saw in Figure 2.

V. The value effects of redevelopment

Do property values at lot level reflect the option to jointly redevelop two lots? The marginal prices of real options can be estimated in hedonic frameworks (Clapp *et al.*, 2012). For the 1832 cross section of tax values, we formulate a spatial hedonic pricing equation including variables that have been associated with pairwise redevelopment[5].

The fact that we look at estimated rent values in 1832 is not a problem for our analysis – as long as tax assessors recognize the value of embedded options. If marginal prices for hedonic attributes linked to the redevelopment option are found to be positive and significant, then this simultaneously confirms that market values indeed reflect real options, and that 19th century appraisers did not look at properties in isolation. Instead, value co-depends on the configuration of neighboring tracts.

The available information on the properties in 1832 is relatively scarce: no hedonic attributes for the buildings other than their type (e. g. residential) has been recorded. On top of that, however, we calculate additional information such as lot and building footprint area, (micro-)location, lot shape or proximity to water from the cadastral maps, and we do that for each lot and its neighbors.

With only parsimonious hedonic information available and much of the hedonic attributes and location specific amenities remaining in the dark, it is not surprising to find strong spatial correlations in error terms from a basic linear regression. We therefore estimate a spatial autoregressive lag (SAR) model:

$$\ln\left(rental\,value_i\right)^* = Y_i^* = \alpha + \rho W Y^* + \beta_{lot} X_i + \beta_{neigh} N_i + \beta_{combi} C_i + \beta_{spatial} D_i + u_i \qquad (3)$$

The dependent variable *ln(rental value)* is regressed against the weighted natural logarithm of rental values of adjacent lots *(WY*)*, a vector of lot-specific variables X, characteristics of adjacent lots *N,* mean values for all possible combinations of lot i with its neighboring lots and spatial dummy variables. The intercept is denoted as α, the *β's* are vectors of regression estimates, ρ is the estimate of spatial correlation and *u* is the error term.

Table 5 presents the regression estimates for Equation (3) with and without additional dummy variables for neighborhoods estimated with the “lagsarlm” procedure from the spdep package in R (Bivand, 2014).

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

As expected, larger lots and bigger buildings lead to higher rental values, as

5 In a working paper Munneke and Womack (2015) estimate a spatial hedonic pricing equation aiming at the value of real options for single lots.

the coefficients for the natural logarithm of lot area and the share of this area developed are both positive and statistically significant. This is not different from what we would find in many modern cities. We also find that purely residential dwellings carry a premium over mixed-use or commercial properties.

In terms of micro-location with blocks, properties at the periphery of blocks tend to be more valuable as positive coefficients for the distance to the blocks centroid and negative coefficients for the number of neighboring lots (which tend to be central) indicate. Proximity to water is associated with higher property values as well. Again, this is in line with existing results for modern cities.

The hedonics of adjacent lots co-determine property values: If surrounding properties are, on average, of the same use and stand on lots that have a large share of their area developed, values increase significantly, since these lots are likely to be developed closer to their optimum. The coefficient for neighboring development density is almost as big as the coefficient for the development density of the lot, which is another indicator for strong spatial dependence.

The shape of lots is closely intertwined with location-specific amenities and the coefficient on the *stretch* variable for the lot changes signs when spatial controls are added. When turning to the shape of a potential combination of lot *i* with its neighbors, however, a strong real option value effect becomes visible: Large and irregularly shaped combinations carry negative coefficients, while the option to develop into a compact (low stretch) shape is positively priced. Interestingly, the discount on lots with relatively long perimeters compared to their size decreases as lots become larger. If a sufficient lot size is reached, a stretched shape does not impose strong constraints on the building that could be developed if lots were merged.

Rental values of small lots next to large lots tend to be higher than large lots next to small ones, since the coefficients for the Herfindahl index for area carry a positive sign, but the interaction term with lot area is negative. This could indicate that small lot owners can extract a relatively large part of the value premium when negotiating a joint development with a larger neighbor. On the other hand, we cannot rule out the alternative explanation that large lots with high value buildings on them provide positive externalities to their smaller neighbors.

The coefficients of spatial dependence is highly significant, despite neighboring lot characteristics already being controlled for explicitly and spatial dummies covering neighborhood characteristics.

VI. Concluding remarks

This paper explores new terrain in urban economics by looking at the very long-term dynamics in (re)development activity and its effects on the cross section of location value in a major city, Amsterdam. We first employ a logit model based on structural and social information from 1832 to predict micro developments for the periods 1832-1860 and 1832-2015. Most importantly, we analyze redevelopment not on an individual lot basis, but explicitly model redevelopment of combinations of inner-city lots, which is in line with how urban redevelopment is actually taking place.

Despite the outward appearance of a continuous historical urban landscape, and despite the regulatory limits to (re)development in Amsterdam's city center, we find that a lot of redevelopment has been going on in the last 183 years, and that we can predict a large part of it: our logit model, using data from 1832 only, explains an astonishing 27 percent of development activity over that very long time period. For the 28-year period between 1832 and 1860, the model explains up to 59 percent of development activity, with the social characteristics of the 1832 lot owners playing a substantial role in the overall explanatory power. Some of the logit model's salient variables underscore the relevance of real option theory in our understanding of redevelopment, even in the 19th century. Small lots and lots with suboptimal shapes are more likely to get redeveloped, and social ties between owners, likely reducing coordination costs for joint lot development, also increase the odds of redevelopment.

The paper then turns to value effects, and aims to explain the cross section of location value in Amsterdam using the variables that turned out to be salient in the initial analysis. For this, we use a spatial autoregressive model explaining rents in 1832. The conclusions of this model show that rental values are in line with economic sense: larger lots and lots that are developed closer to their optimum carry more value. We also observe some option value effects for lots that have suboptimal shapes. Last, the model also shows that spatial effects do indeed play an important role in 1832 rental values.

Our findings show that the outward appearance of a static urban landscape is misleading and that there has been much more dynamism than meets the eye. Moreover, these dynamics are systematic and predictable, and they adhere to the real options theory that was established a century and a half later.

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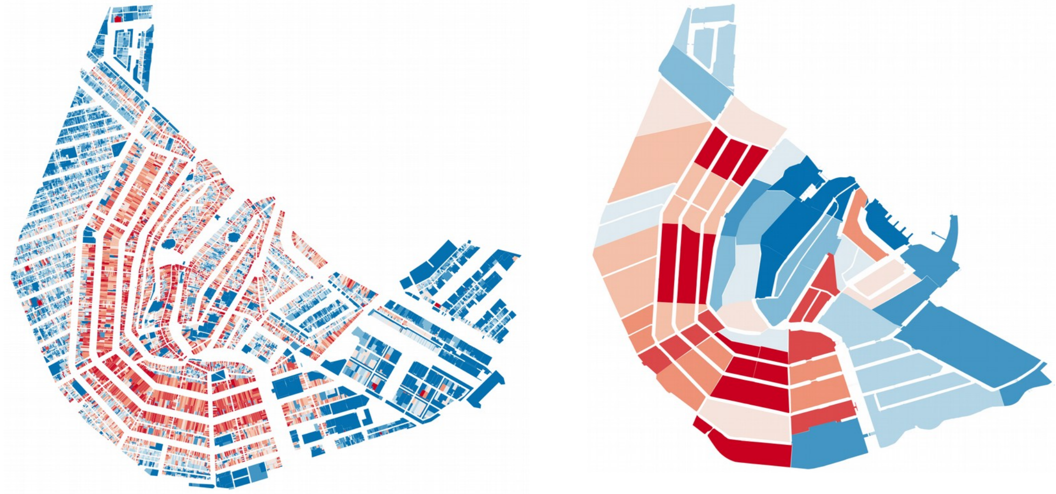
Figures and Tables

Figure 1: Spatial Distribution of Property Values in Central Amsterdam

1832 Tax value/Building footprint	**2005-2008** Sales price/interior floor space, Median for neighborhoods, apartments

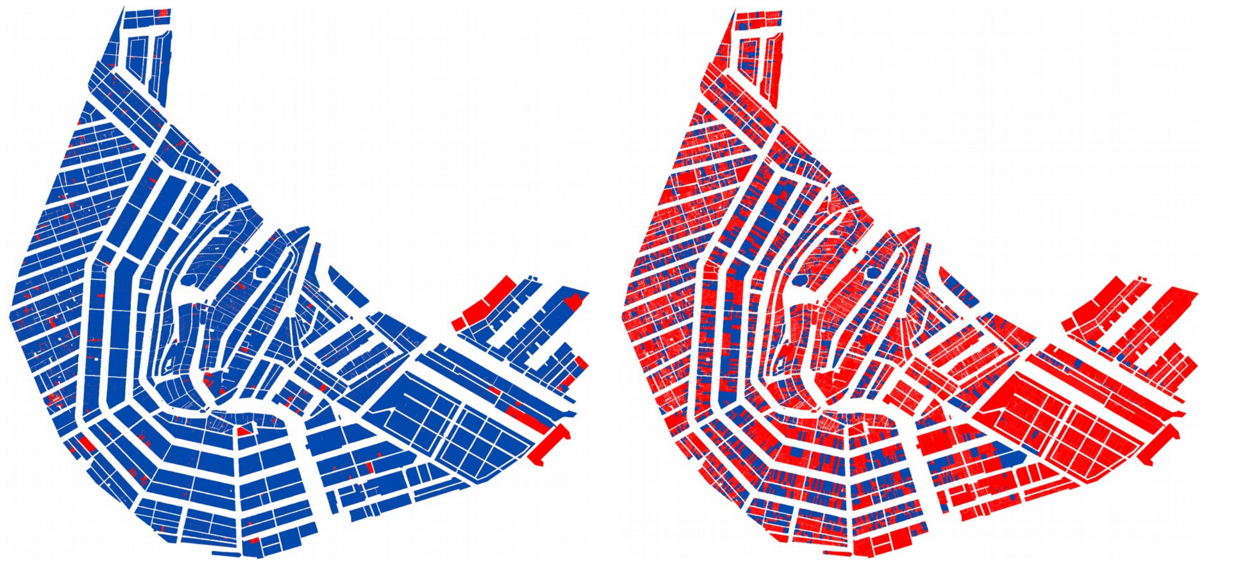


Percentile	< 10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	> 90

Notes: The maps show two snapshots of property value for 1832 and 2005-2008. The 1832 snapshot is based on property rents that were assessed by the city for tax reasons for rental properties and owner-occupied properties alike. The source is the 1832 cadastral map of Amsterdam. The 2005-2008 snapshot is based on a sample of 9,728 freehold housing transactions from the Dutch Realtors' Association NVM.

Figure 2: 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.

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, combined)	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
Tax value 1832, Herfindahl index	0.50	0.61	0.54	1	0.15
ln(Avg stretch, lots i and j)	2.75	3.15	3.11	4.96	0.27
ln(Stretch, combined lots)	2.59	3.40	3.39	6.26	0.44
Distance to block centroid, normalized	0.02	0.95	0.95	2.44	0.41
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	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 address	0	0.24	0	1	0.43
Same religion, head of household	0	0.33	0	1	0.47

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. "Stretch" is calculated as the ratio of the lot perimeter squared over the lot area.

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

Variable	*1832-1860*		*1832-2015*	
	Model 1	*Model 2*	*Model 3*	*Model 4*
log(tax value 1832, combined)	-0.19 ***	0.00	-0.08 ***	-0.05 ***
	(0.00)	(0.94)	(0.00)	(0.00)
log(area, combined)	-0.54 ***	-0.50 ***	-0.73 ***	-0.66 ***
	(0.00)	(0.00)	(0.00)	(0.00)
Lot area, Herf. index	4.73 ***	3.93 ***	1.16 ***	0.87 ***
	(0.00)	(0.00)	(0.00)	(0.00)
ln(Avg. Stretch, ind. lots)	1.55 ***	1.03 ***	1.07 ***	0.92 ***
	(0.00)	(0.00)	(0.00)	(0.00)
ln(Stretch, combined lots)	-1.95 ***	-1.45 ***	-1.57 ***	-1.38 ***
	(0.00)	(0.00)	(0.00)	(0.00)
log(# neighboring lots)	-0.40 **	-0.37 **	0.15 ***	0.15 ***
	(0.01)	(0.03)	(0.00)	(0.00)
Distance to block centroid, norm.	-0.66 ***	-0.46 ***	-0.33 ***	-0.26 ***
	(0.00)	(0.00)	(0.00)	(0.00)
Share area developed, combined lot	-0.24	-0.50 *	-0.09	-0.10
	(0.40)	(0.06)	(0.26)	(0.19)
Share of perimeter close to water	0.25 ***	0.15	-0.11 ***	-0.13 ***
	(0.01)	(0.17)	(0.00)	(0.00)
Same use	0.20 *	-0.16	-0.03	-0.04
	(0.06)	(0.22)	(0.34)	(0.18)
Same owner		2.22 ***		1.05 ***
		(0.00)		(0.00)
Same address		-0.95 ***		0.00
		(0.00)		(0.92)
Same occupation		0.08		0.07 *
		(0.57)		(0.10)
Same religion, head of household		3.65 ***		0.05 **
		(0.00)		(0.02)
(Intercept)	-19.96	-22.67	22.28 **	21.71
	(0.99)	(0.92)	(0.03)	
Spatial controls for blocks	YES	YES	YES	YES
McFadden Pseudo R^2	0.45	0.59	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. "Stretch" is calculated as the ratio of the lot perimeter squared over the lot area. 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*	
log(Tax value 1832, combined)	-0.05		-0.01		-0.21	***	-0.15	***
	(0.27)		(0.73)		(0.00)		(0.00)	
log(Area, combined)	-0.30	***	-0.28	***	-0.39	***	-0.34	***
	(0.00)		(0.00)		(0.00)		(0.00)	
Lot area, Herf. index	3.32	***	3.34	***	1.42	***	1.02	***
	(0.00)		(0.00)		(0.00)		(0.00)	
ln(Avg. Stretch, lots *i* and *j*)	1.33	***	1.19	***	0.79	***	0.73	***
	(0.00)		(0.00)		(0.00)		(0.00)	
ln(Stretch, combined lots)	-1.82	***	-1.61	***	-1.22	***	-1.07	***
	(0.00)		(0.00)		(0.00)		(0.00)	
log(# neighboring lots)	0.27	**	0.49	***	-0.10	***	-0.03	
	(0.04)		(0.00)		(0.00)		(0.30)	
Distance to block centroid, norm.	-0.01		0.02		-0.22	***	-0.15	***
	(0.92)		(0.86)		(0.00)		(0.00)	
Share area developed, combined lot	0.01		0.04		0.05		0.08	
	(0.96)		(0.87)		(0.34)		(0.17)	
Share of perimeter close to water	-0.11	*	-0.07		-0.09	***	-0.09	***
	(0.08)		(0.30)		(0.00)		(0.00)	
Same use	-0.02		-0.22	**	-0.06	***	-0.06	**
	(0.82)		(0.03)		(0.00)		(0.01)	
Same owner			0.66	***			0.76	***
			(0.00)				(0.00)	
Same address			-0.18				0.06	**
			(0.27)				(0.04)	
Same occupation			0.51	***			0.05	
			(0.00)				(0.12)	
Same religion, head of household			2.43	***			0.11	***
			(0.00)				(0.00)	
(Intercept)	1.18		-1.94	**	4.18	***	3.08	***
	(0.12)		(0.01)		(0.00)		(0.00)	
WY	0.98	***	0.78	***	0.19	***	0.31	***
	(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 "splogit"-procedure from the "McSpatial"-package for the R environment (McMillen, 2013). "Stretch" is calculated as the ratio of the lot perimeter squared over the lot area. The number of observations is 59,468. P-Values in parenthesis. Stars (***,**,*) mark significance at 1%, 5% and 10% confidence levels.

Table 5: Spatial Autoregressive Lag Model Estimates, Property Rental Values, 1832

Variable	*Model 1*	*Model 2*
(Intercept)	-0.01 *	-0.03 *
	(0.06)	(0.06)
ln(area)	1.46 ***	1.68 ***
	(0.00)	(0.00)
Share of lot area developed	1.07 ***	1.01 ***
	(0.00)	(0.00)
Use: purely residential	0.47 ***	0.40 ***
	(0.00)	(0.00)
Log(# neighboring lots)	-0.83 ***	-0.62 ***
	(0.00)	(0.00)
Share of perimeter close to water	0.12 ***	0.10 ***
	(0.00)	(0.00)
Distance to block centroid, norm.	0.15 ***	0.16 ***
	(0.00)	(0.00)
ln(stretch)	-0.08 **	0.41 ***
	(0.01)	(0.00)
ln(area)*ln(stretch)	0.03 ***	-0.07 ***
	(0.00)	(0.00)
Attributes of neighboring lots (mean values)		
Share of lot area developed	0.83 ***	0.58 ***
	(0.00)	(0.00)
Same use	0.26 ***	0.24 ***
	(0.00)	(0.00)
Attributes of combined lots (mean values)		
ln(mean stretch, combined lots)	-0.89 ***	-1.03 ***
	(0.00)	(0.00)
ln(mean area, combined lot)	-0.71 ***	-0.81 ***
	(0.00)	(0.00)
ln(mean stretch, comb.)*ln(mean area, comb.)	0.22 ***	0.24 ***
	(0.00)	(0.00)
Mean Herfindahl index, area	3.92 ***	3.52 ***
	(0.00)	(0.00)
ln(area, lot) * Mean Herfindahl index, area	-1.08 ***	-0.91 ***
	(0.00)	(0.00)
Spatial Dummies	NO	YES
ρ	0.10 ***	0.07 ***
	(0.00)	(0.00)

Notes: Regression estimates from a spatial autoregressive model specified in Equation 3. “Stretch” is calculated as the ratio of the lot perimeter squared over the lot area. N=25,502.