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Skyscraper Height

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Abstract This paper investigates the determinants of skyscraper height. First a simple model is provided where potential developers desire not only profits but also social status. In equilibrium, height is a function of both the costs and benefits of construction and the heights of surrounding buildings. Using data from New York City, I empirically estimate skyscraper height over the 20th century. Via spatial regressions, I find evidence for height competition, which increases during boom times. In addition, I provide estimates of which buildings are economically "too tall" and by how many floors.

Keywords Skyscrapers · Building height · Status · New York City

JEL Classification D44 · N62 · R33

Introduction

Skyscrapers are not simply tall buildings. They are symbols and works of art. Collectively they generate a separate entity—the skyline—which has its own symbolic and aesthetic importance. With increased globalization and international development, cities world over seek to build skyscrapers as a way to announce their newly created economic strength and to put their cities "on the map" (Gluckman 2003). As such, skyscrapers not only provide profits but also social status. For this reason, height has a strategic component. If developers prefer to have their buildings stand out in the skyline or to be taller than others, then they must consider the height of surrounding buildings.

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Buildings such as the Bank of Manhattan (now 40 Wall Street) (1930), the Chrysler (1930) and the Empire State (1931) illustrate the symbolic and strategic importance of skyscrapers. At the time of their completions each was the world's tallest building, and their developers were explicit about their intention to be the world record holder, despite each being taller than the profit maximizing height (Tauranac 1995).[1]

These famous accounts of height competition are deeply embedded in New York City folklore, and, as such, it is taken as given that developers naturally aim to outdo each other by building taller than their rivals. Presumably, builders by their very nature (be they corporate or speculative) have outsized egos and therefore have a need to use their structures as monuments to themselves or their corporations (Helsley and Strange 2008). The economics of construction, however, strongly suggest that, after some point, the marginal costs of additional floors far outweigh the additional rents that can accrue from them. Thus height competition can result in buildings that are economically "too tall."[2,3]

Despite the legion of popular accounts on skyscraper height, there has been no systematic empirical study of the degree to which builders engage in height competition, with the one notable exception of Helsley and Strange (2008), discussed in more detail below. To the best of my knowledge, this is the first paper that tests whether skyscraper builders, are, in fact, engaging in height competition.

In order to study skyscraper height, I first provide a simple model, with the aim of generating some testable implications. I model a height market within a region or city—with a focus on skyscrapers in general, rather than on just the record breaking ones. Here, developers bid for the right to develop a plot of land. The winning developer chooses a height that will maximize his utility, which is a combination of the economic returns from the project plus a benefit derived from the relative ranking of the building's height.

[1]Besides a possible "ego prize," the tallest developer can reap extra rents from an observation deck, a top floor restaurant, etc. Thus it is possible that the desire to be the tallest building can, in some respects, be a rational response to the economic environment.

[2]To the best of my knowledge, no work has explored the relationship between rents and height. However, it seems reasonable to assume that rents, in general, rise either linearly or at a diminishing rate (with possible discrete jumps for the region's tallest building). There is strong evidence that, after some height, costs increase at an increasing rate (Clark and Kingston 1930; Chau et al. 2007). Furthermore, one could argue that adding extra height creates a rent premium for all floors. However, it is more likely that rent premiums emerge from the quality of the building as a whole (such as its architectural style and interior amenities) rather than from the height per se (Vandell and Lane 1989; Colwell and Ebrahim 1997; Doiron et al. 1992).

[3]Though beyond the scope of this paper, "too tall" buildings, can present both costs and benefits to cities themselves. For example, a super-tall tower can present situations where the long run social benefits are greater than the private benefits. The Empire State Building is an example of this because of its iconic stature. Too tall buildings can also add additional infrastructure and congestion costs. Investigating these issues are left for future work.

That is, the developer also includes his desire for social status when choosing a height.

To simplify matters, I assume that the land market for developable plots is a type of first-price sealed-bid auction, where developers submit bids, and the highest bidder wins the right to develop the land and pays his bid. This is a relatively simple variation of the standard zero-profit condition for land allocation. Typical models assume that land is allocated to its most valuable use, which, in part, is based on transportation costs and agglomeration economies (see DiPasquale and Wheaton 1995, for example). While these models can demonstrate *what* factors generate land use, they do not generally demonstrate *who* gets to build on the land. By introducing heterogeneity in builder preferences, the model gives an equilibrium for a type of status game, where the developer who gains access to the land has the largest relative preference for status among the bidders.

In dense real estate markets, developers are forced to act in secrecy, since any information about their intentions can lead to holdouts (Strange 1995) and the speculative bidding up of land prices before their final use is determined. Often shell corporations do the bidding on behalf of the developer (Samuels 1997). As such, it is a reasonable assumption that builders' preferences for a development project are unknown by the others during the time that the plot is "on the market."

The model is then tested on one of the world's most important skyscraper cities, New York, over the 20th century. I have created a data set that contains a sample of 458 skyscrapers completed between 1895 and 2004. Since it is virtually impossible to collect data on actual construction costs and income flows, I use several economic variables that measure the costs and benefits of construction.

Using a spatial econometric model, I am able to estimate the degree to which builders add extra height as a function of their rivals' height. I find evidence that builders positively respond to the height decisions of nearby buildings, which supports the height competition hypothesis. Furthermore, from the regressions, I am able to estimate which buildings are economically "too tall" and by how many floors. Also, I estimate the annual average additional height added to the skyline due to height competition. The results suggest that height competition becomes greater during boom periods, when, presumably, the opportunity cost of seeking social status is lower.

The rest of this papers is as follows. The next section gives a review of the relevant literature. The third section presents the land allocation game and the optimal height decision. The fourth section discusses the relevant issues for New York City. Discussion of the data and the empirical results follow in the fifth section. The next section uses the estimates to make some predictions about which buildings are "too tall;" also given are the time series for "status height" over the 20th century. Finally the Conclusion offers some concluding remarks. Two appendices provide additional information.

Related Literature

Despite the attention given to skyscrapers by the popular media, there have been only very few studies directly addressing their economics. One of the most cited works is that of Clark and Kingston (1930). During the building boom of late 1920s, there was a vigorous debate about whether tall buildings like the Chrysler and Empire State were built as monuments rather than money makers.

Clark and Kingston estimate the construction costs and income flows from a hypothetical office building of various heights. They placed their building across the street from Grand Central Station, the center of the midtown business district; using land prices, construction costs and rent data from 1929, they conclude that a 63 story building would provide the highest return.[4] Their aim was to demonstrate that skyscrapers, at their heart, were economically rational investments.[5] In fact, they also estimated that a 100 story building would provide a net return of 7.08%. Though they did not directly address height competition, their findings were aimed at silencing the critics of the day, who were suggesting that it was rampant.

A recent paper by Helsley and Strange (HS) (2008) models height competition between builders. They investigate a two-person game, where each player aims to build a city's tallest building. In the sequential-move version of their model one builder can add extra height to preempt the other builder from winning the height race. In the simultaneous move version, in equilibrium, each builder assigns a positive probability to building a "too tall" building that is taller than the profit maximizing amount. They demonstrate that when players value being the tallest for its own sake (such as a desire for social status), the contest can dissipate profits. My study is related to that of Helsley and Strange in that I investigate the degree to which competition among builders can affect the skyline, as well as cause non-profit maximizing building. But unlike their paper, my objective is broader, investigating the determinants of skyscraper height within an urban height market over time.

In general, the HS model represents the exceptional cases rather than the commonplace one. For example, their work seeks to explain the record breaking races that have been witnessed over the 20th century, such as the one in New York City in the late-1920s/early-1930s and one in Asia in the late-1990s/early-2000s. Furthermore, in general, their model does not have height

[4]Their fictional plot size of 81,000 ft^2 would be in the 87th percentile for plot size in my data set; it would be in the 91st percentile for plot size for buildings completed before 1950. For comparison, the Empire State Building has a plot area of 91,351 ft^2 (with 102 floors), and the Chrysler Building's plot area is 37,525 ft^2 (with 77 floors).

[5]Their building's estimated return on investment was "rational" given 1929 land and rent values. However, if Clark and Kingston had forecasted that rents would soon turn down from their 1929 peaks (and vacancy rates were to go up), 63 stories would most likely not have been the optimal height. As is famously noted, after the opening of the Empire State Building in 1930, it become known as the "Empty State Building" because of the Great Depression (Tauranac 1995).

as strategic complements. If builders are competing against each other within a particular real estate market, one would expect builders to positively respond to the heights of buildings around them.

Barr (2010) looks at the market for height in Manhattan over the period 1895 to 2004 by investigating the time series of the number of skyscraper completions and the average height of these completions. The paper finds that skyscraper completions and average heights, in general, over the 20th century are consistent with profit maximization; the desire to add extra height to stand out does not appear to be a systematic determinant of height at the aggregate market level. That is to say, there has been no upward trend in average heights over the last century. The work here is different in that I look directly at the determinants of building height at the building level, asking what fraction of individual building height can be accounted for by economics, land use regulation and height competition.

Barr's (2010) findings suggest, however, that height competition, if it exists, is "localized" across both time and space. The work here finds evidence that height competition appears to occur between specific builders and in times when the opportunity cost of adding extra height is not that great, i.e., during boom times. Thus the intensity of height competition appears to vary greatly from year to year, and even from neighborhood to neighborhood. As such, this competition does not aggregate up to the market level.

The paper here also draws from recent work on the economics of social status. In particular is the paper of Hopkins and Kornienko (2004), who consider a consumption game that includes status. Their paper assumes that status enters into agents' utility function by way of a status ranking function (cumulative density function), which determines their relative position in the consumption hierarchy. Their model provides a symmetric equilibrium that maps income to consumption. They find that, in equilibrium, spending on the status good increases relative to the nonstatus good, but everyone's ranking is determined simply by their location in the income distribution. This paper is similar in that I assume builders value status for its own sake, and that the height decision has a strategic component, especially in the bidding process. Developers look to their neighbors when deciding how tall to build. The quest for social status can dissipate profits and in turn provide only a temporary high position in the height hierarchy.

The Model

Here I provide a simple model for the optimal height decision.[6] The model is a type of auction game. I assume that each plot of land is sold to the highest bidder, who pays his bid to the seller. Each bidder's valuation of the plot

[6]Note that I use the word "optimal" to represent the height that provides the maximum return to the builder. I do not investigate the effects of height on social welfare.

comes from the profit and relative status that can be earned from developing the land; this valuation is private information because it is a function of an i.i.d. private "signal" about how much the developer values social status. The winning bidder then chooses a height that maximizes his utility. I also assume that each time a plot comes up there is a new auction and a new realization of N bidders. The equilibrium is symmetric, with each bidder using the same bid function. As mentioned in the Introduction, the aim of the model is to offer some testable hypotheses about the effect that the desire for social status might have on height. The causes of building height can be many and varied; as such, building height may emerge from other factors beyond ego that are not addressed in the model.

The Height Decision

First, I begin with the optimal height decision, then show that given this height decision by each potential builder, there is an equilibrium in the auction game. Here agent i, $i = 1, ..., N$, has a utility function given by

$$u_i(h) = \pi(h, \theta) + \lambda_i F(h, \eta) - l,$$

where $\pi(h)$ is the developer's profit that can be earned from building a skyscraper of height h. For simplicity, assume that lots are fixed in size and normalized to one. Assume that the profit function is continuous in h, concave, single-peaked, and for $h \in \left[0, \tilde{h}\right]$, $\pi(h) \geq 0$ and $\pi(0) = \pi\left(\tilde{h}\right) = 0$. The profit function represents the net income flows of the building less the construction costs. l is the cost of land. Assume that all potential developers know the profit function and that it is the same for all developers.[7] The parameter $\theta \geq 0$ summarizes the economy-wide and site-specific factors that affect a building's profitability, such as access to public transportation, zoning regulations, proximity to the business district core, as well as site-specific construction costs. (Note that θ will only be included in the profit function when relevant for the discussion.) Further $\pi'(\theta) > 0$. Assume for now that θ is relatively large so that development is potentially attractive to all developers.

λ_i is the developer's private value that is placed on his status or relative ranking in the height hierarchy; it is i.i.d. across agents and the cumulative distribution function, $G(\lambda)$, has a closed, bounded and continuous support, $\left[0, \overline{\lambda}\right]$, with $G(0) = 0$ and $G\left(\overline{\lambda}\right) = 1$. To simplify the analysis, assume that $\overline{\lambda}$ is small enough if that if an agent with value $\overline{\lambda}$ was to bid and win, he would still have utility at or above his reservation level. In addition, all agents know $G(\lambda)$.

Assume that $F(h)$ is a continuous, strictly monotonic cumulative density function with $F(0) = 0$ and $F\left(\overline{h}\right) = 1$, where $\overline{h}$ is the current tallest building in

[7] Also, I make the simplification that expectations about future income streams don't play a role. Clearly whether expectations are myopic or rational, for example, can impact building height, but this is not investigated here.

the city or region. That is, $F(h, \eta)$ is the contribution to a builder's utility based on his relative rank in the height hierarchy. η is some competitive benchmark height of rivals (i.e., η is a parameter that is taken as given at the time a builder makes a height decision). Further assume that $F\left(h, \eta'\right) \leq F(h, \eta)$, for $\eta' > \eta$ (i.e., the distribution with η' stochastically dominates the one with η).

Note that I don't fix a specific definition of $F(h, \eta)$ at this time, as it could have different interpretations. For example, $F(h, \eta)$ can represent the utility gain from comparison with all completed skyscrapers (within some neighborhood or the entire region); the utility gain from comparison with recently completed skyscrapers; or the utility gain from comparison with buildings currently under construction.

Holding θ constant, let's say that agent i with status parameter λ_i wins the right the develop the land. He would then choose a height, h^*, such that $h^* = \arg\max_{h \in R_+} u_i(h)$:

$$u_i'\left(h^*\right) = \pi'\left(h^*\right) + \lambda_i f\left(h^*\right) = 0, \tag{1}$$

where $f(h) = F'(h) > 0$. Denote h^* as the "status height."

In the case where status does not matter, the developer would simply choose an optimal height that maximized the net return from height. Define this height as the "competitive" outcome (or "economic height") which is given by $h^c = \arg\max_{h \in R_+} \pi(h)$. Given this utility function and maximization problem, it is straightforward to show that (1) there exists a unique status height for each λ; (2) the height chosen by the developer is larger than if status were not relevant; and (3) that the utility maximizing skyscraper height is monotonically increasing in λ. These are stated formally; all proofs are given in Appendix A.

Lemma 1 *For* $\lambda \in \left[0, \overline{\lambda}\right]$, *there is a unique value of* h, h^*, *such that* $h^* = \arg\max_{h \in R_+} u_i(h)$.

Lemma 2 $h^* > h^c$ *for* $\lambda \in \left(0, \overline{\lambda}\right]$; $h^* = h^c$ *for* $\lambda = 0$.

Lemma 3 h^* *is strictly increasing with* λ.

In summary, this subsection has shown that for a given developer who is going to develop a plot of land, he will build taller than the "competitive" height due to the desire to have a place in the height hierarchy. Furthermore, this height is increasing in the value he places on social status.

Economic Conditions, Status Competition and Height

Above it was assumed that the parameter θ is large enough that status can be relevant in the decision about how tall to build. θ, however, summarizes the economic viability of a particular plot. If the economic climate is not strong (say there is low demand for building space or the nature of the plot is unfavorable) then this will affect the return. Assuming that $\partial\pi/\partial\theta > 0$,

$\partial^2\pi/\partial h\partial\theta > 0$, and $\pi(0) = 0$, then it is straightforward to show that as the value of θ increases, so does the utility maximizing height of the building:

Lemma 4 $dh^*/d\theta > 0$.

Furthermore, η is a parameter that represent the height decision of competitors. It is natural to assume that a developer's height choice and his rivals' height choices are strategic complements, i.e., $\partial^2 F/\partial h\partial\eta > 0$. That is to say, as rivals' heights increase, a developer finds that increasing his own height increases his utility. This would arise in a setting where social status was important. If a builder seeks to stand out among his rivals then he would need to increase his height in order to be competitive in the status game. Strategic complementarities give rise to positive reaction functions.

Lemma 5 $dh^*/d\eta > 0$.

In summary, this subsection has shown that height increases with improvements in the economic climate as well as rivals' actions. Though the model is static, there is also a dynamic implication. Let's say there is an exogenous increase in θ due to an improved economic climate. This will cause all builders to increase their utility maximizing height. In turn, each builder will then have greater height competition because it will cause η to rise. This, in turn, will cause an additional increase in building heights. This additional height is driven in part from the lower opportunity cost of competition. Since projects are now more profitable, some of this extra profit can be dissipated to increase the social status of individual builders.

Social status, however, can be fleeting because future builders will aim to build above the current buildings in the skyline. The length of time a builder keeps his place in the height hierarchy depends, in part, on the economic climate. If boom times are followed by downturns, then social status competition would most likely diminish, increasing the length of time a builder keeps his place in the height hierarchy.

The Land Allocation Game

Above, I discussed the height decision of a builder, conditional on having the right to develop a plot of land. Now I demonstrate how land is allocated. Building on the standard assumption in urban economics that land is allocated to its most valuable use, here, it is shown that if developers value the land for both profits and status, and that land is "auctioned off" to the highest bidder, then there exists a symmetric equilibrium, where each agent's bid is a function of his own private valuation, which is a function of the common, publicly-known profit and the private, randomly-determined value for status.

Given that potential buyers know there is private variation in the valuation, they need to strategically consider their bids. No rational developer would bid more than the plot is worth to him (assuming no purely speculative land purchases). Any bid below his maximum value introduces a tradeoff: an increase in the bid will increase the probability of winning, but will also reduce the possible gains from the project. This introduces the familiar first-price sealed-bid auction mechanism for allocating the plot.

Assume a common reservation value, $r \geq 0$, which is the lowest value of utility a developer is willing to accept from a skyscraper project. Further, for this section, assume that for all plots θ is large enough so that a skyscraper will always be built. Let l_i^* be developer $i's$ land valuation from choosing an utility maximizing height:

$$l_i^* = \pi\left(h^*\right) + \lambda_i F\left(h^*\right) - r.$$

Further, denote $l^c = \pi\left(h^c\right) - r$ as the value that developers would place on the land if status were not an issue. Without status, the plot would sell for l^c, since in a competitive market land values would provide the builder with zero economic utility (or profits if $r = 0$). Further assume that $F\left(h\right)$ is common knowledge, the builders know there are N builders interested in the property, and that they all know the distribution of λ.

It is straightforward to show that l^c is the lower bound on income that any seller would receive for the plot. Further, it can be shown that land values are strictly rising in λ. I assume for the sake of simplicity that λ has a uniform distribution with support $\left[0, \bar{\lambda}\right]$, where, again, $\bar{\lambda}$ is assumed to be not so large that a developer with $\lambda = \bar{\lambda}$ who takes ownership of the plot would still have a utility at least as large as r. The properties of the land values are stated formally and their proofs are given in Appendix A.

Lemma 6 *l^* is monotonically increasing in λ; $l^* = l^c$ when $\lambda = 0$.*

Lemma 7 *Given the monotonicity of l^*, the minimum and maximum land values for a plot is l^c and $\bar{l}^* = \pi\left(h^*\right) + \bar{\lambda} F\left(h^*\right) - r$, respectively.*

Lemma 8 *Given that $\lambda \sim U\left[0, \bar{\lambda}\right]$, the probability distribution function for land valuations is given by*

$$k\left(l^*\right) = \left\{ \begin{array}{c} \frac{1}{\bar{\lambda} F(h^*)}, l \in \left[l^c, \bar{l}^*\right] \\ 0, \ otherwise \end{array} \right\},$$

with a cdf of

$$K\left(l^*\right) = \frac{l^* - l^c}{\bar{\lambda} F\left(h^*\right)}, l \in \left[l^c, \bar{l}^*\right].$$

It is straightforward to show that there exists a symmetric equilibrium, where each agent uses the same bid function $\beta = \beta\left(l^*\right)$.

Proposition 1 *Given each agent's land valuation function, and N bidders, there exists a unique, symmetric equilibrium of the land auction game such that $\beta\left(l^*\right) = \frac{(N-1)l^* + l^c}{N}$.*

Notice that $\beta(l^*) = \frac{(N-1)l^*+l^c}{N}$ is a weighted average of the land values with and without status. For example, if $N = 2$, then $\beta(l^*) = \frac{1}{2}(l^* + l^c)$; as $N \to \infty$, $\beta(l^*) \to l^*$. This result suggests that land values are higher in markets where there is status competition; this is mostly likely to occur in global cities where economic competition and agglomeration economies are the greatest.

New York City

Given the discussion of skyscraper height above, here I empirically investigate the determinants of skyscraper height as given by the model, using New York as an example. The aim is to estimate the role of economics versus the quest for status. Here I discuss the relevant historical issues for estimating skyscraper height in New York. Then I discuss the empirical model, the data and the results.

At its widest point, Manhattan island is about 3 mi across and about 13 mi long, comprising a total of about 23 mi^2. In 1811, in an effort to rationalize its street pattern, the city implemented a gridplan, which standardized street and lot sizes. Standard blocks measured 200 ft wide (north–south) and ranged from 400 to 920 ft long (east-west). Lots were generally 25 ft wide and 100 ft long. These small lot sizes were deemed, at the time, suitable for individual homes or shops. Because lot sizes were relatively small, as the city became built up, acquiring larger lots for tall buildings became more difficult. By the late-19th century, this created an incentive for developers to use each lot more intensely by building higher due to the artificially produced scarcity of large plots (Willis 1995).

Building Technology Over the course of the 19th century, a series of innovations eliminated the technological barriers to height. First, was the development of steel beams, which removed the need for load-bearing masonry walls. Instead, a steel cage could be constructed, with a thin brick or stone facade. The implementation of electric elevators in the 1880s eliminated height constraints in regard to vertical transport. Also, the widespread use of the elevator safety break (invented in 1853) eliminated the fear that the elevator might plummet to the ground (Landau and Condit 1996).[8] In sum, by around 1890, the problem of *engineering height* was essentially solved in the sense that very tall buildings were now technologically possible. At that point skyscraper height decisions were primarily due to economics and status.

To be sure, skyscraper technology has continued to improve over the course of the 20th century. New lighter materials, such as glass, have been

[8]Other important innovations include the development of caissons for digging through lower Manhattan's quicksand to reach bedrock. Engineers also had to learn how to brace skyscrapers against the fierce winds. New building machines, such as cranes and derricks, had to be built. In addition, new methods of heating, cooling, lighting and plumbing were created (Landau and Condit 1996).

substituted for heavier ones, such as stone and brick; computer-aided design has allowed engineers to develop more efficient building systems. The use of better boring and drilling methods allow for skyscrapers in areas with less than idea subsoil conditions. Air conditioning and florescent lighting have made for more comfortable interior environments (*Science Illustrated* 2009).[9]

Bedrock As Landau and Condit (1996) write, "In theory, the geology of Manhattan Island is ideal for skyscrapers. The island's sunken, glaciated bedrock system, made up of metamorphic rock that constitutes the Manhattan prong of the New England Province, is for the most part good bearing rock" (p. 24). On the southern tip bedrock lies below a bed of quicksand and clay, and is, on average, 63.6 ft below street level (with a standard deviation of 31.8 ft), based on the sample here. In midtown, the bedrock lies quite close to the surface, and on some parts of the island one can see outcroppings, such as in Central Park (the midtown mean depth is 16.3 ft, with a standard deviation of 10.6 ft). Between downtown and midtown, however, there is a steep drop in the bedrock levels (such as in Greenwich Village).

Though the depth to this bedrock varies greatly from north to south, the placement of this rock relatively near the surface, it has been argued, has affected, if not determined, the location of skyscrapers throughout out the island (Landau and Condit 1996). Here, I implicitly test this theory by including the depth to bedrock for each plot. If bedrock was an important determinant of height, I would expect to see a negative relationship between the two, since the depth needed to dig to bedrock would presumably affect the cost of building and therefore the optimal height.

Zoning By the turn of the 20th century, many New Yorkers were concerned that the unregulated growth of skyscrapers, and the metropolis in general, were causing several urban problems, such as excessive congestion and the casting of shadows onto existing structures. As a response, in 1916, New York City approved a comprehensive zoning plan, which was the first of its kind in the nation. The plan established three types of use zones or districts—residential, business and unrestricted—to promote the separation of these economic activities.

In regard to building height, the zoning plan created different height districts, which did not limit height per se, but rather established rules governing how tall a building could go before it had to be setback. For example, parts of midtown were designated as a "two times" district; a building could rise

[9] In the empirical section below, I do not directly address the issue of technological change and how it has affected building height over the 20th century. I do, however, use an indirect measure by including an index of real building materials costs. This index peaked in 1979. Between 1979 and 2003, real constructions costs fell 15%. In 2003, the index was roughly the same value as it was in 1947.

to a height of two times the width of the street before it had to set back.[10] In addition there were no height restrictions on any portion of the building that occupied 25% or less of the plot area. These regulations promoted the so-called wedding cake style of architecture. For Manhattan, the setback multiples ranged from 1.25 to 2.5, and the number was positively related to the density that already existed as of 1916.

In 1961, New York City enacted a new comprehensive zoning plan, which was designed to correct some of the perceived mistakes of the original plan, as well as to regulate new developments, such as the rise of the automobile throughout the first half of the 20th century.[11] The 1961 plan, like its predecessor, did not limit height per se, but rather placed limits on the so-called floor area ratio (FAR).

The maximum allowable FAR is a limit on the total buildable space, and is given as a multiple of the plot area. A FAR of 10, for example, means that a developer can build 10,000 ft^2 of usable space for every 100 ft^2 of plot area. In the downtown and midtown office districts, maximum FARs were set at 15. In addition, to promote the development of public amenities, such as plazas, the zoning regulations allowed for a 20% FAR bonus if the developer provided an amenity. Starting in the late-1960s, negotiated FAR bonuses also became common, as developers sought additional bonuses by negotiating with the mayor and the Department of City Planning to provide additional amenities, such as rehabilitated subway stations or extra park space.

By creating a maximum FAR for each building, the new zoning code promoted the market for air rights. Owners of buildings, such as landmarks and theaters, that needed funds, could sell the unused floor areas that, in theory, existed above the building. Purchasers of the air rights could then gain additional buildable space for a nearby development. Air rights were initially instituted to protect landmarks such as Grand Central Station (after the demolition of the original Pennsylvania Railroad Station in 1963). Today, however, the air rights market is not limited to just a select few buildings, but rather is applicable to many buildings in Manhattan (with the caveat that the rights be sold to adjacent or nearby properties).

Status and Ego After the Civil War, the American economy became increasingly national in scope due to the reduction of production, transportation and communication costs. The new industrial economy required a class of office workers to organize and process the large amounts of information

[10] "In a two times district no building shall be erected to a height in excess of twice the width of the street, but for each one foot that the building or a portion of it sets back from the street line four feet shall be added to the height limit of such building or such portion thereof" (Building Zoning Resolution, 1916, Section 8(d)).

[11] One intention of 1961 plan was to reduce the maximum allowable population density. Under the 1916 zoning rules, the city would have been able to house a maximum population of 55.6 million. The 1961 zoning code was designed to house a maximum of 12.3 million (Bennett 1960). In 2006, the population of New York City was 8.21 million (http://www.census.gov).

(Chandler 1977). Because New York was the center of much of this economic activity, major corporations established their headquarters there. With the vast amounts of wealth being generated by the new economic activity, corporations sought to project this wealth onto the skyline itself.

Corporate executives were keenly aware of the role that skyscrapers could play for them and their respective company's image. Newspaper publishing, congregated downtown, near City Hall, was perhaps the first industry, in the 1870s, to engage in the strategic use of height. As Wallace (2006) writes, "In early newspaper buildings, architecture reasserted itself in monumental tributes to the power of the printing press and its most assertive masters, New York City newspaper publishers. Newspaper buildings attempted to communicate the supremacy of the press generally and their own paper specifically" (p. 178).[12]

In 1910, for example, F. W. Woolworth told the *New York Times* about his soon-to-be-built eponymous tower, "I do not want a mere building, I want something that will be an ornament to the city" (*NY Times* 1910). In 1928, Darwin P. Kinglsey, president of the New York Life Insurance, said at the opening of his company's new tower, "The skyline of New York is singularly beautiful because it expresses power; it strikes a new note of power....[O]ur objective has been to express in this building the power that makes the New York skyline beautiful..." (*NY Times* 1928).

Even today, developers, be they speculative or corporate, are still interested in projecting their ambitions onto the skyline. Noted builder, Donald Trump, in 1998, told the *New York Times* when announcing his new residential building Trump World Tower, "I've always thought that New York should have the tallest building in the world....It doesn't. But now, it has the tallest and most luxurious residential building in the world" (Bagli 1998).

Empirical Analysis

The model demonstrates that the building height on a specific site will be a function of the income that can be generated, the cost of building, and the utility value of status. In particular, the model shows that a skyscraper's height is a positive function of rivals' height. To test the model, I have created a data set that contains site-specific and economy-wide variables. Because this paper represents the first long-run measurement of building height, data that might be available for a short-run period, such as rents and construction costs, are not available for the entire sample period. For this reason, I have used several

[12] In regard to the 1875 *New York Tribune* building, Wallace (2006) writes, "The nine-story height insured that the tower would be taller than any existing New York office building and was thus neither an arbitrary choice of height nor one based on the functional space requirements of the newspaper. The design of the *Tribune* building was primarily governed by the enhanced public image that would be garnered for the newspaper and only tangentially by the potential economic benefits of building tall" (p. 179).

variables that proxy for the supply and demand for height, as well as land values. As will be shown below, these variables are important determinants of height.

The solution to the first order equation, Eq. 1, and the existence of an equilibrium in the land market, implies that the utility maximizing height is given by $h_i^* = h(\theta_i, \lambda_i, \eta_i)$, where θ_i is a parameter that represents the economic returns to building on a specific site; λ_i is a builder's taste for status; and η_i is the height of other buildings with whom a developer competes. To test the model, I estimate the following linear econometric model for building height:

$$\mathbf{h} = \alpha_0 + \mathbf{x}\boldsymbol{\alpha}_1 + \rho\mathbf{W}\mathbf{h} + \boldsymbol{\varepsilon},$$

where $\mathbf{x}$ is a matrix of variables that determine the returns to height, i.e., $\theta_i = \boldsymbol{\alpha}_1'\mathbf{x}_i$. Since λ is a builder's taste for status, it cannot be directly measured. Thus, in order to test for a preference for non-economic height, I estimate a spatial autoregressive model, which measures how the height choices of rivals affect the decision of a builder. Presumably, if status is important, then controlling for the other determinants of building height, there would be a positive relationship between the two. Spatial models have been used as a way to investigate spatial competition (See Brueckner 2003; Brueckner and Saavedra 2001). ρ is a parameter that measures the effect of rivals' height decisions on a builder. $\mathbf{W}$ is a square weight matrix that connects each building with its "neighbors."[13] As discussed below, different weighting schemes are used to explore how buildings might be related across space and time. Finally ε_i is the random, unmeasured, i.i.d. component of height, assumed to be normally distributed.

Data

Here I give a general description of the variables. Appendix B contains more information on the sources of the data. Table 1 provides descriptive statistics for the sample of 458 skyscrapers in Manhattan, completed between 1895 and 2004; all are located in Manhattan's densest area (south of 96th street).

To simplify the analysis, I limit the sample to buildings that are 328 ft (100 m) in height, as determined by the international real estate consulting firm Emporis. The height measured is structural height, and therefore excludes antennae or decorative elements.[14] The sample represents the tallest of the tall for New York City.

[13] As a matter of convention, 0's are assigned along the main diagonal, so that no building is connected to itself.

[14] On average, a 100 meter building has about 30 floors. In this sample, the average number of feet per floor is 12.62, with a standard deviation of 1.81. In general, the relationship between meters and floors is given by the OLS-derived equation: $\widehat{floors} = \underset{(5.9)}{5.3} + \underset{(39.2)}{0.227}$ m. $R^2 = 0.77$. 458 observations. t-stats. below estimates.

Table 1 Descriptive statistics for skyscrapers completed from 1895 to 2004

Variable	Mean	Std. dev.	Min.	Max.
Building information				
Height (ft)	490.24	141.22	328.08	1,368.11
Plot (000 ft^2)	44.67	63.66	4.00	681.60
Depth to bedrock (ft)	26.99	25.97	0.08	159.84
Distance to district core (mi)	0.612	0.448	0.016	2.55
Plot irregular dummy	0.570			
Downtown dummy	0.212			
Use dummy variables				
Residential condominum	0.081			
Residential rental	0.131			
Government	0.013			
Hospital	0.002			
Hotel	0.055			
Mixed-use	0.072			
Office	0.642			
Utility	0.004			
Corporate HQ dummy	0.164			
Zoning variables				
Built under 1916 zoning laws dummy	0.360			
1916 setback multiple[a]	1.927	0.374	1.25	2.5
Built under 1961 zoning laws dummy	0.590			
Plaza bonus dummy	0.362			
Max. floor area ratio[a]	12.71	2.58	3.44	15.0
Purchased air rights dummy	0.153			
Special zoning district dummy	0.037			
Economic variables (# obs. = 86, for each year with at least one observation)				
Real interest rate (%)	2.75	4.50	−13.86	23.92
Real construction cost index	1.34	0.266	0.872	1.67
NYC area population (millions)	9.16	2.45	3.21	11.90
National F.I.R.E./employment (%)	4.79	1.38	1.76	6.57
Δln(equalized land assessed value) (%)	4.88	7.98	−18.4	33.0

obs. = 458, unless otherwise noted. Sources: see Appendix B
[a] Stats. are for buildings completed during relevant zoning rules

Building Information The dependent variable is building height in feet. For each building, I include the log of plot size. The log form is used since the distribution of plot size is highly skewed to the right. Plot size is important since, presumably, a larger plot offers builders the chance to builder taller at lower marginal cost (see Barr 2010).

To take into consideration that sometimes plot sizes can be irregular, due to holdouts or odd-shaped blocks, and this irregularity may add an extra cost to construction, I have included a dummy variable that takes on the value of one if the plot is not perfectly rectangular or square, zero otherwise. Plot size is expected to be positively related to height, while an irregularly shaped plot should be negative.

In addition, I include dummy variables for the building's main use at the time of completion. Use is determined by both zoning, which can limit building types in specific neighborhoods, as well as land values and the relative rents available from office or residential space, which can depend, in part on taxes and subsidies. I assume that exogenously determined historical land use patterns and zoning rules are the primary driver of building uses. As can be seen from Table 1, offices comprise roughly 64% of building types, while 21% are residential. The remaining 15% are divided between hotels, mixed-use (which include office-residential, office-hotel, and residential-hotels), government-use buildings (e.g., courthouses), hospitals, and a final category, "utility," which comprises highrise buildings that house telephone and communications equipment. One would assume offices would be higher, cet. par., due to their greater income flows.

For each plot, I also have a measure of the approximate average depth to bedrock to investigate the degree to which this depth has affected building height. To account for the possibility that downtown and midtown may have differing subsoil conditions, I created two separate variables, one is the depth of the bedrock for downtown buildings and the other is the depth for midtown buildings (i.e., each variable is the depth to bedrock interacted with an area dummy variable). Presumably, the further down a builder needs to go the greater the costs and the lower the height.

To account for the fact that land values in the "center" are higher due to agglomeration economies and the concentration of public transportation, I include a measure of how close a building is to the central business core. In New York, there are two cores, one centered on Wall Street and the other centered in midtown at the Grand Central Station railway terminal. For downtown buildings, I measure each building's distance in miles to the corner of Wall Street and Broadway. For midtown buildings, I measure each building's distance in miles to Grand Central Station. I also include a dummy variable for downtown buildings, to control for systematic differences that may exist between downtown and midtown.

Lastly, I include a dummy variable to account for buildings that are corporate headquarters. These buildings were developed and owned by major corporations (this differs from speculative developers who build skyscrapers and then lease them to corporations). If a major corporation is also the developer then I would expect them to add extra height to signal economic strength and advertise their corporation.

Zoning For the 1916 zoning rules, I include a dummy variable for the buildings completed under this regime. In addition I include the setback multiple (interacted with the 1916 dummy variable) to account for its affect on height. I would expect a positive relationship with the multiple, but a negative one with the dummy variable.

For the 1961 zoning rules, I also include a dummy variable for buildings completed in this period (which is still in effect). I include the maximum allowable FAR that each building had; this should have a positive coefficient. I also include dummy variables for buildings that have provided a public amenity ("as of right") and for buildings that have purchased air rights. I would expect both of these dummy variables to have positive signs. Lastly I also include a dummy variable for two "special districts": Battery Park City (which includes the World Trade Center) and the Times Square district. In these cases, public agencies took the initiative in generating development in these neighborhoods; as such developers were not bound by the same rules in other districts. Because government agencies sought to promote business development, zoning and FAR restrictions were relaxed. I would expect this coefficient to be positive.

Economy-wide Costs and Benefits Because income and costs for specific buildings are generally not available, I have used economy-wide time series data to proxy for these variables (which are lagged one or two years to account for the time between when height decisions are made and when buildings are completed). To control for the demand for building space, I include a measure of the population of the New York City area (which, in this case, comprises the population of New York City and three surrounding counties). Because NYC employment data is not available back to 1893, I use national data to measure office employment, which in this case is given by the ratio of national employment in the Finance, Real Estate and Insurance (F.I.R.E.) industries to total employment. To measure the health of the New York City real estate market (and the growth in land values), I include the lagged growth of equalized assessed land values. Equalized assessed values are meant to adjust actual assessed values to close to market values. To measure costs I include the real interest rate on commercial paper and an index of real building material costs (both lagged two years). I would expect both of these coefficients to be negative.

Spatial Dependence and Weight Matrices In order to test for height competition due to the quest for status, I have run several regressions that include a spatial lag dependent variable. To do this requires that I generate several different weight matrices to account for the possible connections between builders. Because the sample varies across both space and time, it is necessary to generate weight matrices that reflect this. Table 2 gives the definitions for the different weighting procedures.

For spatial variation, I generate three types of weight matrices. The first type is the inverse of the distance of two buildings "as the crow flies." The second is more localized in nature; I assign a value of 1 for two buildings

Table 2 Definitions for weight matrices

Term	Definition
Over space	
Distance	$w_{ij} = 1/d\,(i,\,j)$, where $d\,(i,\,j)$ is Cartesian distance in miles for building i and j
Local	$w_{ij} = \{1 \text{ if } d\,(i,\,j) \leq \frac{1}{4};\ = \frac{1}{2} \text{ if } d\,(i,\,j) \leq \frac{1}{2};\ = \frac{1}{4} \text{if } d\,(i,\,j) \leq 1;\ = 0 \text{ otherwise}\}$
Binary	$w_{ij} = \{1 \text{ if } d\,(i,\,j) > 0; = 0 \text{ otherwise}\}$
Over time	
±2	Buildings completed within 2 years of each other
0–3	Buildings completed in same year and three years prior
Past	Buildings completed prior to completion of a particular building

that are within 1/4 mi of each other; a value of 1/2 for two buildings greater than a quarter mile but less than or equal to 1/2 mi; a value of 1/4 for two buildings greater than 1/2 mi but less than or equal to 1 mi; and a value of zero for a buildings greater than one mile apart. Note that because there is roughly a 1.5 mile gap between downtown and midtown, buildings in these regions are generally not connected to each other. The third weighting scheme is a binary one, assigning two buildings a value of 1 if they were completed within the given time dimension (described below); and a 0 otherwise. The third scheme does not take proximity into account, rather all buildings are potentially connectable.

To take into account the time dimension, I also look at three types of connection schemes based on time. The first one, labelled "±2," creates weight connections for buildings that have been completed within two years of each other. For example, let's say one building was completed in 1980 and another in 1982, then they would both potentially receive (the same) positive weight value (depending on the spatial weight definition). It's clear that a building completed in 1982 would be "connected" to a 1980 building, since the 1980 building preceded it. But one could argue that a 1980 building would potentially be influenced by a 1982 building since information about this building would, presumably, be available to the public several years before its completion. Building permits have to be filed, the site needs to be prepared ahead of construction and more importantly, in the insular world of New York real estate information can spread quickly (Samuels 1997).

To account for buildings constructed currently and in the recent past, another connection scheme, labelled "0–3," connects two buildings if they were completed in the same year or within three years prior to the construction of a particular building. For example, a building completed in 2000 would potentially be connected to buildings completed in 2000 as well as those completed between 1997 and 1999. Note that this weight matrix will not be symmetric. Finally, another weight matrix, labelled "*past*" connects a building only to ones completed in the years before the building was completed. For example, a building completed in 1980 would potentially be connected to all buildings completed prior to 1980. In sum a particular weight matrix is generated based on the intersection of both a spatial weight definition and a time connection definition.

Results

Spatial Dependence Tests

In order to assess whether the spatial lag model is appropriate, I have performed several diagnostic tests for the various weight matrices. Table 3 gives the results of these spatial dependence tests. For each weighting matrix, there are two types of tests. The first set of tests aims to explore if there is spatial dependence via the error term; that is, if there is some unmeasured spatial

Table 3 Error and lag dependence tests for different weight matrices

	$W^{local}_{\pm 2}$	W^{local}_{past}	W^{local}_{0-3}	W^{binary}_{0-3}	$W^{dist}_{2\ years}$	W^{dist}_{0-3}	W^{dist}_{past}
Spatial error							
Moran's I	1.35	–	1.39	2.20	0.75	0.94	0.69
	(0.18)	(–)	(0.16)	(0.03)*	(0.45)	(0.35)	(0.49)
Lagrange multiplier	1.34	0.64	0.01	3.13	0.97	0.10	1.50
	(0.25)	(0.42)	(0.93)	(0.08)	(0.33)	(0.75)	(0.22)
Robust Lagrange mult.	0.49	0.77	0.18	3.78	0.13	0.06	1.99
	(0.49)	(0.37)	(0.68)	(0.05)*	(0.72)	(0.81)	(0.16)
Spatial Lag							
Lagrange multiplier	6.68	0.77	9.03	1.06	6.37	7.13	1.31
	(0.01)**	(0.38)	(0.00)**	(0.30)	(0.01)**	(0.01)**	(0.25)
Robust Lagrange mult.	5.83	0.90	9.12	1.70	5.54	7.09	1.79
	(0.016)*	(0.34)	(0.00)**	(0.19)	(0.02)*	(0.01)**	(0.18)

See text for weight matrix definitions. P-values below estimates
*Stat. sig. at 95% level; **stat. sig. at 99% level

dependence.[15] The second set of tests aims to explore if spatial dependence occurs through the dependent variable (akin to moving average and autoregressive models in time series analysis, respectively). Here I briefly discuss the tests statistics; the reader is referred to Anselin and Bera (1998) and Anselin et al. (1996) for more information. The Moran's I, the Lagrange Multiplier Test and the Robust Lagrange Multiplier (robust to heteroskedasticity) statistics are generated to test for spatial correlation in the error terms, and, in general, they all produce very similar results. The Table also presents the Lagrange Multiplier Test and the Robust Lagrange Multiplier test for the spatial lag dependent variable model. Again, the results are qualitatively similar across test statistics.

In six out of seven cases, the tests reject the spatial error model. In four out of seven cases, the spatial lag model appears to be appropriate. Thus, in general, the tests support the spatial lag model over the spatial error model, especially for the matrices based on either distance or localized distance. In addition, across time, buildings completed close to each other appear to be the correct model (i.e., ±2 and 0–3 are favored over *past*).

Note that the weight matrices were not row-standardized (i.e., were not normalized so the sum of the weights adds to one). The diagnostic tests indicated that non-standardized matrices best captured the spatial interaction among buildings. This suggests then that builders respond to a weighted sum of the height of surrounding buildings rather than a weighted average. This would have the interpretation that builders respond to both the number of tall buildings and the height of these buildings, and not just the average height. More about this is discussed in the regression results below.

[15] A spatial error model would posit the following relationship: $\mathbf{h} = \mathbf{X}\boldsymbol{\alpha} + \boldsymbol{\varepsilon}$, where $\boldsymbol{\varepsilon} = \boldsymbol{\gamma}\mathbf{W}\boldsymbol{\varepsilon} + \boldsymbol{\epsilon}$, i.e., the error term has spatial autocorrelation.

Regression Results

Table 4 presents the results of the regressions. The first regression is a measure of "economic height," which excludes the spatial dependence term. In regard to plot size, there is the potential issue of endogeneity with respect to height. It could be that developers who would like to build tall seek out the largest available plot sizes; thus there might be an issue of plot size selection bias. To investigate this issue further, I collected three possible instruments related to the particular city blocks on which the buildings reside: (1) the size of the block in feet squared, (2) a dummy variable taking on the value of one if the block is a superblock, 0 otherwise, and (3) a dummy variable that takes on the value of one if the block is irregular in shape (i.e., not perfectly rectangular or square).

Block sizes (and shapes) appear to be a suitable instrument given that they were determined in 1811 with the implementation of the grid plan; thus they would be related to plot size but not skyscraper height. In a very few cases, block sizes were combined to be superblocks. These are generally rare (about 9% of the blocks). In the case of Battery Park City, new blocks were created from landfill. Superblocks tend to be clustered near the rivers and not in the center of the island, since port activity and manufacturing used to dominate these areas.

To consider using block size and related variables as an instruments, I first performed a test of the overidentifying restrictions, which produced a Sargan χ^2-statistic = 3.8 and Basmann χ^2-statistic = 3.6. With 2 degrees of freedom, I cannot reject the null hypothesis of strictly exogenous instruments with either statistic. In addition, the first-stage regression with instruments had an $R^2 = 0.37$, while the first-stage regression without the instruments had an $R^2 = 0.20$, indicating that these instruments had a substantial impact on lot size. Also, as an additional test, when the three potential instruments were included in equation (2), Table 2, an F-test did not reject the null hypothesis that they were jointly zero. Finally the Hausman test could not reject the null hypothesis of exogeneity for plot size. In sum, the instrumental variable tests show that the block size variables are valid instruments but that they are not needed since plot size appears to be exogenous.[16]

In regard to bedrock, across all specifications, the downtown bedrock coefficient is positive and statistically significant. The midtown bedrock coefficient is also positive, but statistically insignificant. The downtown bedrock coefficient is opposite what would be expected. One would presume that the further down a builder must go to anchor the building to bedrock, the greater the building cost and thus the lower the height. However, since the downtown dummy variable is negative, it might be that, in general, anchoring buildings downtown is more costly due to wet subsoil and the bedrock's greater

[16]Descriptive statistics for the instruments as well as IV test results are available upon request. Also note that the OLS regressions given in Table 4, Eq. 1 are very similar to results of the instrumental variables regression.

Table 4 Dependent variable: Skyscraper height (in feet)

Variable	(1) OLS	(2) $W^{local}_{\pm 2}$	(3) W^{local}_{past}	(4) W^{local}_{0-3}
ln(plot size)	73.3	74.9	74.4	74.5
	(7.18)***	(7.54)***	(7.46)***	(7.50)***
Irregular plot	−21.6	−22.5	−22.1	−24.2
	(1.83)*	(1.97)**	(1.90)**	(2.13)**
Rental apartment	−26.7	−22.6	−27.0	−22.9
	(1.66)*	(1.41)	(1.70)*	(1.42)
Office building	6.43	1.29	6.90	−0.432
	(41)	(0.08)	(0.46)	(0.03)
Corporate HQ	20.5	21.1	18.6	20.2
	(1.16)	(1.24)	(1.07)	(1.19)
Distance to core (mi)	−44.7	−29.4	−33.8	−25.2
	(3.20)***	(2.08)**	(1.74)*	(1.74)*
Depth to bedrock downtown (ft)	0.721	0.660	0.679	0.617
	(2.06)**	(1.89)**	(1.94)**	(1.75)*
Depth to bedrock midtown (ft)	0.335	0.360	0.374	0.411
	(0.65)	(0.72)	(0.75)	(0.82)
Downtown	−68.5	−44.6	−56.8	−36.8
	(2.32)**	(1.47)	(1.74)*	(1.18)
Zoning 1916	−242.4	−233.3	−216.5	−212.8
	(3.63)***	(3.63)***	(3.20)***	(3.37)***
Setback multiple	63.4	55.9	59.2	58.1
	(2.58)***	(2.34)**	(2.45)**	(2.48)**
Zoning 1961	−312.8	−303.4	−281.1	−267.1
	(4.46)***	(4.46)***	(3.92)***	(3.90)***
Max. FAR	12.4	11.3	11.2	11.1
	(3.85)***	(3.45)***	(3.33)***	(3.35)***
Plaza bonus	38.1	36.2	38.4	34.3
	(2.57)***	(2.46)**	(2.64)***	(2.30)**
Air rights	81.6	83.9	79.3	85.2
	(5.53)***	(5.78)***	(5.44)***	(5.79)***
Special district	137.4	139.0	137.4	146.2
	(3.02)***	(3.11)***	(3.11)***	(3.26)***
Pop. NYC Area$_{t-2}$ (millions)	20.1	17.6	19.0	12.1
	(2.33)**	(2.08)**	(2.30)**	(1.41)
% F.I.R.E./employment$_{t-2}$	42.2	37.3	34.8	30.7
	(2.77)***	(2.50)**	(2.08)**	(2.10)**
% Δ ln(Eq. assessed land value)$_{t-1}$	1.31	0.869	1.31	0.573
	(1.70)*	(1.18)	(1.74)*	(0.75)
% Real interest rate$_{t-2}$	−5.12	−5.37	−4.89	−5.36
	(2.14)**	(2.25)**	(2.05)**	(2.28)**
Real construction costs$_{t-2}$	−241.1	−203.4	−244.4	−164.7
	(5.21)***	(4.44)***	(5.41)**	(3.54)***
ρ		0.0065	0.00068	0.0098
		(2.82)***	(0.98)	(3.06)***
Constant	−203.9	−250.3	−200.5	−243.6
	(2.11)**	(2.64)***	(2.13)**	(2.47)**
R^2	0.41	0.42	0.41	0.42
$\bar{R}^2$	0.38			
Log likelihood		−2,793.0	−2,795.8	−2,791.8

Number of observation is 458. Absolute value of robust t- or z-statistics below coefficient estimates
*Stat. sig. at 10% level; **stat. sig. at 5% level; ***stat. sig. at 1% level

average depths. The positive coefficient on the downtown bedrock variable may be picking up some kind of agglomeration effect, where the benefits of skyscraper clustering are greater than the cost of digging to bedrock.

The negative sign on the downtown dummy variable may also be picking up something related the year of completion, since most of the early skyscrapers were built downtown. But another regression (not shown) that includes the year on the right hand side, shows the year variable to be statistically insignificant. In sum, the evidence does not support the hypothesis that the costs associated with anchoring a building to bedrock was strong enough to diminish building height.

In general, all of the zoning-related coefficients give the correct signs. Looking at equation (1), for example, the estimates show, for example, that under the 1916 zoning rules, a building in a “two times” district, would have reduced its height by $-242.4 + 63.4(2) = -115.6$ (about 9 floors) compared to the non-zoning era. Under the 1961 rules, assuming a building was in a FAR district of 15, took advantage of a plaza bonus, and purchased air rights from a neighboring building, the net effect of zoning on height would be a modest -7.1 ft or less than one floor as compared to the no-zoning regime before 1916.

All of the economic time series variables have the correct signs, and most are statistically significant across specifications. Over the course of the 20th century, I estimate that for each additional million people living in New York and surrounding counties, height has increased by about one to one and a half floors. Interestingly, the interest rate has a modest effect on height. For example, a doubling of interest rates from 5% to 10% is associated with only a two floor drop in height. Finally, being a corporate headquarters seems to add at most a relatively modest amount of height, adding, on average about two floors. Further it is not statistically significant across specifications.

Competition and Spatial Dependence Table 4 presents regression results for three “local” weight matrices. Results for other weight matrices are not given since they are broadly similar to those presented. Equation (2) uses the ± 2 weight matrix, equation (3) uses the *past* weight matrix and equation (4) uses the 0–3 matrix. The results suggest that spatial competition is an important component of building height, especially for buildings completed around the same time. That is to say, $\hat{\rho}$ is statistically significant in equations (2) and (4). They are economically significant as well. Figure 1 gives the estimated annual average additional height due to spatial competition. The results strongly suggest a positive reaction function.

Table 5 provides robustness checks, which gives the $\hat{\rho}$ parameter for different weight matrices. As can be seen from the table, for the ± 2 and the 0–3 connection schemes, both the local weights and the distance weights provide statistically significant results. There is no evidence that builders “compete” with the distant past.

Furthermore, it would appear that the positive and statistically significant coefficients for the spatial lags are not measuring some other latent, common factor for all connected skyscrapers. The regressions include variables that

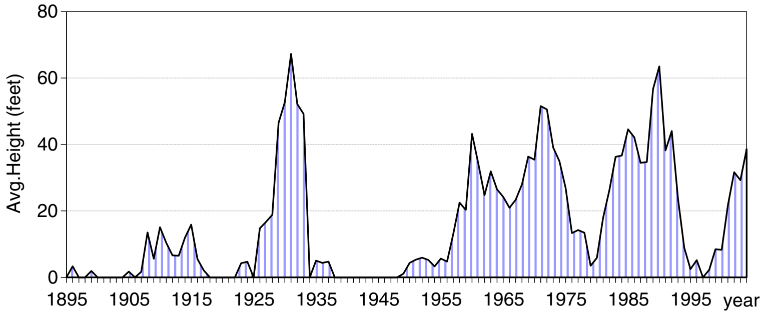

Fig. 1 Average additional height due to spatial competition, 1895–2004. Underlying data are from Table 4, eq. (4)

estimate land and rent values, which drive height. For example, the distance to the core variable remains relatively large and statistically significant in the spatial models. Furthermore, the other demand-related time series variables (growth in assessed land values, regional population and F.I.R.E. employment) would measure the city-wide rent levels for building space, and thus the income that can be earned from adding extra height. From a theoretical point of view, adding extra floors beyond the profit maximizing amount is risky. Not only does it lower the return to construction, ceteris paribus, but also introduces the possibility of lowering market rent values by generating an oversupply of space. Also, if unmeasured land values were driving the spatial height relationship, presumably, the tests would have indicated that the spatial error model was the appropriate one.

Furthermore, as a test of whether the spatial lag was estimating the "hotness" of the market rather than spatial competition, I ran regressions that also included measures of the number of completions (the results are not presented here, but are available upon request). The first regression included on the right hand side the total number of skyscraper completions in the year prior. The second regression included the total number of completions in the two years prior. The third regression included, for each building, the number that were completed within the last three years and were one mile or less from

Table 5 Estimated spatial lag parameter for different weight matrices

Connection type	$W_{\pm 2\text{ years}}$	W_{past}	$W_{0\text{–}3}$
Local	0.0065	0.00068	0.0098
	(2.82)**	(0.98)	(3.06)**
Distance	0.0008	0.0001	0.0011
	(2.70)**	(1.35)	(2.53)*
Binary	0.0001	0.0003	0.0011
	(0.18)	(0.94)	(1.03)

See text for weight matrix definitions. Robust z-scores below estimates
*Stat. sig. at 95% level; **stat. sig. at 99% level

the building. In all of these cases, for equations (2) and (4) in Table 4, the count measures were statistically insignificant, the estimate of ρ remained positive, statistically significant and was approximately the same value as in the regressions in the table. This suggests that the estimated spatial coefficient is not just picking up the degree of economic activity, but rather is measuring the effect of the heights of surrounding buildings.

Beyond Optimal Height

In this section, I use the coefficient estimates to compare the predicted economic heights to the actual heights, in order to get a measure of the degree to which some buildings are "too tall," in terms of profit maximization. This exercise can also provide evidence about who were the major "ego" developers in New York City, throughout the 20th century.

Table 6 shows the top "too tall" buildings in New York City, by using the predicted height values given by equation (1) in Table 4. The table also includes the actual number of floors and the predicted number of floors. Predicted floors were calculated via the formula $\widehat{floors}_i = \hat{h}_i^c(floors_i/height_i)$. As can be seen from the table, the number one building is the Empire State, with an estimated 54 floors more than economic height. Interestingly, "too tall" buildings are common throughout the century; and most of them were either world record holders and/or corporate headquarters.[17] Only the last two on the list were built as speculative projects.

Additional Height from Spatial Interaction

Figure 1 gives the annual average additional height due to spatial competition. The graph is generated by calculating the vector $\hat{\rho}\mathbf{Wh}$ (from regression equation (4)) and then taking averages for each year. As the graph shows, the additional height is highly cyclical and strongly suggests that the opportunity cost to height competition is reduced during boom times. Assuming that one floor is 12.5 ft, then during the boom of the late-1920s, on average, builders were adding roughly 4 to 6 more floors per project, just to stand out in the skyline.[18]

Barr (2010) finds that average heights have not been increasing over the 20th century, and further that manifestations of builders' egos do not appear in the aggregate at the market level. Figure 1 suggests the reason there is no time trend in average heights: ego manifestations only appear in a meaningful

[17] As documented in Willis (1992), the original developers of the Empire State Building site estimated that a 50 story building would profit maximizing. Furthermore, the original plans for the Word Trade Center called for a 72 story World Trade Mart building, as the center of the complex (Gillespie 1999).

[18] Across all buildings in the sample, the average spatial factor is 32.5 ft (about 2.5 floors), with a standard deviation of 27.7 ft.

Table 6 Rank of top 15 (out of 458) "too tall" buildings in New York City

Rank	Building	Year	h	$\hat{h}^c$	Diff.	Floors	$\widehat{Floors}^c$	Diff.
1	Empire State	1931	1,250	590	660	102	48	54
2	1 World Trade Ctr	1972	1,368	862	506	110	69	41
3	Chrysler	1930	1,047	547	499	77	40	37
4	2 World Trade Ctr.	1973	1,362	888	474	110	72	38
5	AIG/Cities Services	1932	951	526	425	66	36	30
6	40 Wall St	1930	928	555	374	70	42	28
7	JP Morgan Chase HQ	1960	705	369	336	52	27	25
8	Citigroup Center	1977	915	598	317	59	39	20
9	Woolworth	1913	791	514	277	57	37	20
10	GE/RCA	1933	850	574	276	69	47	22
11	One Chase Man Plz	1961	814	574	240	60	42	18
12	20 Exchange Pl	1931	741	514	228	57	39	18
13	Singer	1908	614	388	226	47	30	17
14	1 Worldwide Plz	1989	778	559	219	50	36	14
15	CitySpire Center	1987	814	596	218	75	55	20

Predicted values come from Eq. 1, Table 4. h is the actual height; $\hat{h}^c$ is the predicted optimal economic height

way during boom periods and this additional height is locally derived, that is, is a function of the particular neighborhood.

Conclusion

This paper has investigated the determinants of skyscraper height. First I provide a simple model of builders who must consider the profits from construction in addition to their relative status ranking when deciding how tall to build. Empirical estimates of this model for New York City show that economic factors, land use regulation and the quest for social status are important determinants of building height over the 20th century. Height increases with regional population and office job growth, and falls with interest rates and building costs. The estimated "height gradient" shows that height drops at a rate of about between 3.6 and 2.0 floors per mile vis a vis the business core. Zoning regulations, while not limiting height per se, have negatively impacted height by placing restrictions on the shape of the building or the total building volume. But amenity bonuses and air rights purchases, which have been common over the last 30 years, have allowed builders to go taller than otherwise. I find no evidence that the depth of the bedrock below the building has affected skyscraper height.

Using a spatial econometric model, I find evidence that builders are engaging in height competition. In particular, I find that builders positively respond to the height of buildings in close vicinity. The results support that builders look to the contemporary buildings and ones completed in the recent past. There is no evidence that builders look to the long term past. Furthermore, the evidence suggests that height competition is greatest during boom times, when, presumably, the opportunity cost of achieving social status is lower, since height competition requires that builders build taller than the profit maximizing amount.

As discussed above, surprisingly little work has been done on the economics of skyscrapers. Despite the continued fascination by the public, journalists and scholars within other disciplines, the field of "skynomics" remains relatively unexplored. Future work might consider measuring the rate at which technological improvements in skyscrapers have occurred since the 1880s. Also one could measure the degree to which skylines, as goods unto themselves, improve the well-being of urban residents. For example, the social value of the Empire State Building would appear to be far greater than any direct monetary benefits that have accrued to its owners.

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Appendix A: Proofs

Lemma 1 *For* $\lambda \in \left[0, \overline{\lambda}\right]$, *there is a unique value of* h, h^*, *such that* $h^* = \arg\max_{h \in R_+} u_i(h)$.

Proof For $\lambda = 0$, $h^* = \arg\max_{h \in R_+} \pi(h^*)$, which is unique by definition. For $\lambda > 0$, at $h = 0$, $\pi(0) + \lambda F(0) = 0$. Recall $F(h)$ bounded by one. Further, since profit is single-peaked and strictly concave, there exits and $\tilde{h}$, such that, $\pi\left(\tilde{h}\right) + \bar{\lambda} = 0$. Thus for $h \in \left[0, \tilde{h}\right]$, there must be a global maximum, since the contribution of $\lambda F(h)$ to utility is bounded and adding $\lambda F(h)$ to $\pi(h)$ preserves the single peaked nature of the utility function when $h \in \left[0, \tilde{h}\right]$. □

Lemma 2 $h^* > h^c$ *for* $\lambda \in \left(0, \overline{\lambda}\right]$; $h^* = h^c$ *for* $\lambda = 0$.

Proof If $\lambda = 0$, then $h^* = h^c$ will be equal since the "status" developer is maximizing the same function as the "competitive" developer. If $0 < \lambda \leq \overline{\lambda}$, then given Lemma (1), there exists a unique h^*,such that $u'(h^*) = \pi'(h^*) + \lambda f(h^*) = 0$, or $\pi'(h^*) = -\lambda f(h^*)$, where $f(h^*) > 0$. Given that $\pi(h)$ is single-peaked, and $F(h)$ is increasing, the optimal building height is therefore taller than a building where $\pi'(h) = 0$; that is, h^* will be chosen along the negatively sloped portion of the profit function beyond the peak of $\pi(h)$. □

Lemma 3 *$h^*$is strictly increasing with λ.*

Proof For a given h^*, the utility function is at a global maximum and therefore $u'(h^*) = 0$, and $u''(h^*) = \pi''(h^*) + f'(h^*) < 0$. The first order condition gives $\pi'(h^*) + \lambda f(h^*) = 0$. Taking derivatives via the Implicit Function Theorem gives $dh^*/d\lambda = -f(h^*)/\left[\pi''(h^*) + f'(h^*)\right] > 0$. □

Lemma 4 $dh^*/d\theta > 0$.

Proof As above, $u'(h^*, \theta) = 0$, and $u''(h^*, \theta) = \pi''(h^*) + f'(h^*) < 0$. Via the Implicit Function Theorem $dh^*/d\theta = -\left(\partial^2\pi/\partial h\partial\theta\right)/\left[\pi''(h^*) + \lambda f'(h^*)\right] > 0$, since $\partial^2\pi/\partial h\partial\theta > 0$, by assumption. □

Lemma 5 $dh^*/d\eta > 0$.

Proof $u'(h^*, \eta) = \pi'(h^*) + \lambda f(h^*, \eta) = 0$, and $u''(h^*, \eta) = \pi''(h^*) + f'(h^*, \eta) < 0$. Via the Implicit Function Theorem, $dh^*/d\eta = -\lambda f'(h^*, \eta)/\pi''(h^*) + f'(h^*, \eta) > 0$, since $f'(h^*, \eta) = \partial^2 F/\partial h\partial\eta > 0$, by assumption. □

Lemma 6 *l^* is monotonically increasing in λ; $l^* = l^c$, when $\lambda = 0$.*

Proof Given the optimal height for a plot, h^*, land value is given by $l^* = \pi(h^*(\lambda)) + \lambda_i F(h^*(\lambda_i)) - r$. By the Implicit Function Theorem, $dl^*/d\lambda = F(h^*) > 0$. If $\lambda = 0$, land value is simply given by $l^*(\lambda_i) = \pi(h^c) - r$, since h^c maximizes profit. □

Lemma 7 *Given the monotonicity of l^*, the minimum and maximum land values for a plot of land is l^c and $\bar{l}^* = \pi(h^*) + \bar{\lambda} F(h^*) - r$, respectively.*

Proof If $\lambda = 0$, $l^* = l^c = l(h^c) = \pi(h^c) - r$, where $l'(h^c) = \pi'(h^c) = 0$. As discussed in lemma (4), for $\lambda > 0$, since l^* is strictly increasing in λ, and λ has a maximum of $\bar{\lambda}$, no developer would be willing to pay more than $\bar{l}^*$ □

Lemma 8 *Given that $\lambda \sim U\left[0, \bar{\lambda}\right]$, the pdf for land valuations is given by* $k(l^*) = \left\{\begin{array}{c} \frac{1}{\bar{\lambda}F(h^*)}, l \in \left[l^c, \bar{l}^*\right] \\ 0,\ otherwise \end{array}\right\}$*;with a cdf of* $K(l^*) = \frac{l^* - l^c}{\bar{\lambda}F(h^*)},\ l \in \left[l^c, \bar{l}^*\right]$.

Proof Recall that $l^*(\lambda) = \left[\pi(h^*) - r\right] + \lambda F(h^*)$. Since $\lambda \sim U\left[0, \bar{\lambda}\right]$, $g(\lambda) = \frac{1}{\bar{\lambda}}$. The pdf of $l^*(\lambda)$ follows from the formula for a change of distribution for a function of a random variable that has a uniform distribution: $k(l^*) = \frac{d\lambda}{dl^*} g(\lambda) = \frac{1}{F(h^*)} \frac{1}{\bar{\lambda}}$. Note that $l^c = \pi(h^*) - r$. The cdf follows from $K(l^*) = \frac{1}{\bar{\lambda} F(h^*)} \int_{l^c}^{l^*} dx = \frac{l^* - l^c}{\bar{\lambda} F(h^*)}$. □

Proposition 1 *Given each agent's land valuation function, and that the status parameter has a* $U[0, \bar{\lambda}]$ *distribution, there exists a unique, symmetric equilibrium of the land auction game such that each agent's bid is given by* $\beta(l^*) = \frac{(N-1)l^* + l^c}{N}$.

Proof Note that this proof is adapted and condensed from Krishna (2002), to which the reader is referred for more information. Let's say there are N bidders, each with private valuation of $l_i^*(\lambda_i)$, where l_i^* is strictly increasing in λ. Suppose there exists a symmetric, increasing equilibrium strategy, $\beta(l_i^*)$. First, it would never be optimal to bid $b > \beta(\bar{l}^*)$, since the agent would win the auction and could have done better by slightly reducing his bid, as he could win and pay less. Second, a bidder with $\lambda = 0$, would never submit a bid greater than l^c, since he would have negative utility if he were to win, thus $\beta(0) = l^c$. Bidder i wins the auction when he submits the highest bid; that is when $max_{j \neq i} \beta(l_j^*) < b$. Define λ^{N-1} as the value of λ for the second highest bidder out of N bidders. Since $\beta(l^*)$ is increasing, bidder i wins if he has the highest value of l_i^* (i.e., if $\lambda_i > \lambda^{N-1}$) or if $\beta(l^{*N-1}) < b$, or equivalently if $l^{*N-1} < \beta^{-1}(b)$. Agent $i's$ expected payoff is therefore $K(\beta^{-1}(b))^{N-1}(l^* - b)$, where $K(l^*)^{N-1}$ is the distribution of the second highest order statistic for land values. Taking the first order condition, replacing $b = \beta(l^*)$ (at the symmetric equilibrium), and solving for the differential equation given by the FOC, yields the equilibrium function $\beta(l^*) = \left[1/K(l^*)^{N-1}\right](N-1)\int_{l^c}^{l^*} y dK(y)^{N-2} dy$. Given that land values are distributed $U\left[l^c, \bar{l}^*\right]$, this bid function is $\beta(l^*) = \frac{(N-1)l^* + l^c}{N}$.

This result is a necessary condition for the optimal strategy, I now turn to showing the sufficient condition: that if the $N-1$ bidders follow $\beta(l^*)$, then it is optimal for agent i to do so as well. Suppose that all agents but bidder i follow the strategy $\beta(l^*)$. Given that the winner has the highest bid, it is never optimal for agent i to bid more than $\beta(\bar{l}^*)$. Denote $z = \beta^{-1}(b)$ as the value for which b is the equilibrium bid for agent i, that is $\beta(z) = b$. The expected payoff to agent i from bidding $\beta(z)$ is $\Pi(\beta(z), l^*) = K(z)^{N-1}(l^* - \beta(z)) = K(z)^{N-1}(l^* - \beta(z)) + \int_{l^*}^{z} K(y)^{N-1} dy$, where this equality is obtained via integration by parts. This leads to the conclusion that $\Pi(\beta(l^*), l^*) - \Pi(\beta(z), l^*) \geq 0$, regardless of whether $z \geq l^*$ or $z \leq l^*$. Thus for agent i, not using $\beta(l^*)$ will make the agent no better off, which implies that $\beta(l^*)$ is a symmetric equilibrium strategy. □

Appendix B: Data Sources and Preparation

Skyscraper Height, Number of Floors and Year of Completions: Emporis.com.[19]
Plot size: NYC Map Portal (http://gis.nyc.gov/doitt/mp/Portal.do); Ballard (1978); http://www.mrofficespace.com/; NYC Dept. of Buildings Building Information System, (http://a810-bisweb.nyc.gov/bisweb/bsqpm01.jsp).
Plot Regularity: Various editions of the *Manhattan Land Book* (1927, 1955, 2002; see references) and the NYC Map Portal.
Use and Corporate HQ: For each building, one or more articles were obtained from the *New York Times* at the time of the building's construction or just after its completion. From this, I ascertained its primary use and the developer. If the developer was a major corporation and the corporation had an equity stake in the building, it was listed as a Corporate Headquarters.
Distance from Core: For each building I obtained the latitude and longitude from http://www.zonums.com/gmaps/digipoint.html. I calculated the distance for each building $i = 1, \ldots, 458$, from its respective core using the formula $d_i = \sqrt{[69.1691\,(\text{latitude}_i - \text{latitude}_{\text{core}})]^2 + [52.5179\,(\text{longitude}_i - \text{longitude}_{\text{core}})]^2}$, where latitude and longitude were initially measured in degrees. The degrees to miles conversion is from http://jan.ucc.nau.edu/~cvm/latlongdist.html. In NYC, there are two cores: the intersection of Wall Street and Broadway (downtown) and Grand Central Station (42nd Street and Park Ave.). All buildings south of 14th street belong to the downtown core; all buildings on 14th street or above belong to the midtown core.
Depth to Bedrock: For each building, elevation from sea level (in feet) comes from http://www.zonums.com/gmaps/digipoint.html. Depth to bedrock from sea level (in feet) comes from maps provided by Dr. Klaus Jacob, Columbia University. The maps are based on hundreds of borings throughout Manhattan. The depth to bedrock was calculated by subtracting the depth of bedrock from sea level from the elevation from sea level.
Zoning 1916 and 1961: The *New York Times* was consulted to determine the first buildings completed under the respective regimes.
1916 Height Multiples: Original zoning maps in effect at the time of completion for each building.
The maps were provided by the New York City Department of City Planning.
1961 Maximum Allowable FAR: Original zoning maps in effect at the time of completion for each building. The maps were provided by the New York City Department of City Planning.
Special Districts: Zoning maps from NYC Dept. of City Planning, and articles from the *New York Times.*
Air Rights: Data about which buildings purchased air rights comes the *New York Times, Real Estate Weekly* and http://beta.therealdeal.com/front.

[19] Note that Emporis.com does not contain the entire population of 100 meter or taller buildings. Based on a comparison of the website with http://skyscraperpage.com, it appears the Emporis.com under represents residential buildings,

Plaza Bonus: Kayden (2000); www.nyc.gov/html/dcp/html/priv/priv.shtml
Real Construction Cost Index (1893–2004): Index of construction material costs: 1947–2004: Bureau of Labor Statistics Series Id: WPUSOP2200 "Materials and Components for Construction" (1982=100). 1893–1947: Table E46 "Building Materials." *Historical Statistics* (1926=100) (1976). To join the two series, the earlier series was multiplied by 0.12521, which is the ratio of the new series index to the old index in 1947. The real index was create by dividing the construction cost index by the GDP Deflator for each year.
GDP Deflator (1893–2004): Johnston and Williamson (2007). (2000=100).
Finance, Insurance and Real Estate Employment (F.I.R.E)/Total Employment (1893–2004): 1900–1970: F.I.R.E. data from Table D137, Historical Statistics. Total (non farm) Employment: Table D127, Historical Statistics. 1971–2004: F.I.R.E. data from BLS.gov Series Id: CEU5500000001 "Financial Activities." Total nonfarm employment 1971–2004 from BLS.gov Series Id: CEU0000000001. The earlier and later employment tables were joined by regressing overlapping years that were available from both sources of the new employment numbers on the old employment numbers and then correcting the new number using the OLS equation; this process was also done with the F.I.R.E. data as well. 1893–1899: For both the F.I.R.E. and total employment, values were extrapolated backwards using the growth rates from the decade 1900 to 1909, which was 4.1% for F.I.R.E. and 3.1% for employment.
Real Interest Rate (nominal rate minus inflation) (1893–2004): Nominal interest rate: 1893–1970: Table X445 "Prime Commercial Paper 4–6 months." *Historical Statistics.* 1971–1997 http://www.federalreserve.gov, 1998–2004: 6 month CD rate. 6 month CD rate was adjusted to a CP rate by regressing 34 years of overlapping data of the CP rate on the CD rate and then using the predicted values for the CP rate for 1997–2004. Inflation comes from the percentage change in the GDP deflator.
Population NYC, Nassau, Suffolk, and Westchester Counties (1893–2004): 1890–2004: Decennial Census on U.S. Population volumes. Annual data is generated by estimating the annual population via the formula $pop_{i,t} = pop_{i,t-1}e^{\beta_i}$, where i is the census year, i.e., $i \in \{1890, 1900, ..., 2000\}$, t is the year, and β_i is solved from the formula, $pop_i = pop_{i-1}e^{10*\beta_i}$. For the years 2001 - 2004, the same growth rate from the 1990's is used.
Equalized Assessed Land Value Manhattan (1893–2004): Assessed Land Values: 1893–1975: Various volumes of *NYC Tax Commission Reports.* 1975–2003 Real Estate Board of NY. Equalization Rates: 1893–1955: Various volumes of *NYC Tax Commission Reports.* 1955–2004: NY State Office of Real Property Services. Equalization Rate: 1893–1955: Various reports *NYC Tax Commission Reports.* 1955–2004: NY State Office of Real Property Services.

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