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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 status, as measured by their rank in the height hierarchy. The optimal height in equilibrium is a function of the cost and benefits of building as well as the height of surrounding buildings. Using data from New York City, I empirically estimate skyscraper height over the 20th century. The results show that the quest for status has increased building height by about 15 floors above the non-status profit maximizing height. In addition, I provide estimates of which buildings are "too tall" and by how many floors.

JEL Classification: D24, D44, N62, R33

Key words: Skyscrapers, building height, status, New York City

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1 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.

Despite the initial fears that the attacks of September 11, 2001 would curtail construction, skyscrapers continue to be built in large numbers around the globe (Economist, 2006). The current cycle of the"race to the sky" is in full swing (Ramstack, 2007). The Burj Dubai, still under construction as of February 2008, may top out at nearly half a mile tall. This building will replace the Taipei 101 as the world record holder. With increased globalization and international development, cities world over seek to develop skyscrapers as a way to announce their newly created economic strength and to put their cities "on the map" (Gluckman, 2003).

Skyscrapers are used to advertise and signal economic strength for their builders, be they speculative developers, major international corporations or government entities. As such, they not only provide profits but also "status." For this reason, height has a strategic component. If a developer prefers to have his building stand out in the skyline or to be taller than others, then he must consider the height of surrounding buildings.

Despite their importance for both local and national economies, skyscrapers have drawn little attention from economists. Beyond the many journalistic and popular accounts, the last time economists discussed skyscrapers in any detail was during the building boom of the late 1920s. During that time, especially in New York City, the debate centered around whether these buildings were somehow "freak" buildings, built not on sound economic principles, but rather as expressions of personal ego or for their ability to advertise (Clark and Kingston, 1930).

Buildings such as the Bank of Manhattan (now 40 Wall Street) (1929), the Chrysler (1929) and the Empire State (1930) illustrate the symbolic and strategic importance of skyscrapers. At the time of their completions each was the world's tallest building, and the developers were explicit about their intention to be the world record holder, despite each being taller than the profit maximizing height (Tauranac, 1995).

Skyscraper height can be thought of as a good that brings value to both builders and height "consumers," who desire dramatic views, and, as such, there are gains to trade in the height market. The developer must make both an economic and strategic decision about how tall to build; this height is de-

Figure 1: New York City Skyline, lower Manhttan.

termined both by the builder's desire for profits and status and consumers' utility derived from height, which also provides status (such as executives placing their offices on top floors, and the wealthy living in penthouse apartments) as well as the enjoyment of the fantastic views (of the skyline itself).

Figure 1 presents a photograph of part of the New York City skyline. As can be seen from the picture, collectively, the skyline is an entity unto itself due to the density and height of the buildings. Within this skyline there is a great deal of variation in building height. Not every building can be the tallest and not every builder cares to build the tallest. Rather we can infer that building height is a function of economics, land use regulations and also the desire for status.

One also notices that within the skyline there are distinct "waves" of building heights, with height rising toward the "center." These waves reflect the endogenous relationship between strategic height, land values and agglomeration economies. Corporations need to be near each other to lower their business costs and increase demand, yet they also desire to stand out in the skyline. Being close is valuable, which is reflected in property values in the center; large land costs, in turn, drives developers to build even higher if they are to get a return on their investment, as well as have their buildings stand out.

This paper is an investigation into the determinants of skyscraper height. To the best of my knowledge, it is the first work that investigates the theoretical and empirical determinants of height for any city skyline over such a long time period. Here, I use the example of New York City, since it is one of the most important and active skyscraper cities in the world. I investigate the relative effects of status, economics and regulation using a data set of 458 skyscrapers completed in Manhattan from 1895 to 2004, which includes a mix of residential, office and other building types.

First, I provide a simple model of building height. The model has two parts. First developers bid for the right to develop a plot of land. Next 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. That is, the developer also includes his desire for "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 is based on, in part, 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.

Here skyscraper "status" is meant to encompass a few different factors. First, major corporations seek status to advertize their corporations. Also speculative developers desire status because, presumably, this status will increase rents or just bring more respect to the developers themselves, who often have enormous egos (Helsley and Strange, 2007; Betsky, 2002).

In dense real estate markets, developers are forced to act in secrecy, since any information about their intentions can lead to hold outs (see Strange (1995), for example) 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 (see Samuels (1997) for example). 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."

Next, I use the optimal height equation as a guide to estimate the effects of economics, land use regulations and status on skyscraper height in

New York City. Since it is virtually impossible to collect data on actual construction costs and income flows, I use several economic variables that can measure the costs and benefits of construction. On the costs side, I show that building materials costs and interests rates negatively impact building height. On the benefits side, I show that population, office employment and land value growth are positively related to height. In addition, I am able to quantify the effects of zoning regulations on height by showing how they alter the incentives to build taller. Furthermore, some skyscraper historians have argued that Manhattan's bedrock formation has helped to contribute to New York City's skyline. I find mixed support for this theory; specifically I find a small negative relationship between the depth to bedrock and a building's height in midtown and no direct effect for buildings downtown (though a larger indirect negative effect for all buildings downtown).

Lastly, I am able to measure the desire for status for building height. Corporations who build their own headquarters add only a modest amount of height; on average adding about two additional floors. Using the lagged average height of all completed skyscrapers, I am able to measure the importance of "standing out" in the skyline. I estimate that builders responded by adding about one foot to their own buildings for each one foot growth in the skyline itself. By the end of the 20th century, the effect of this was that builders were adding about 15 extra floors, on average, above the profit maximizing level so their buildings can be seen.

The rest of this papers is as follows. The next section gives a review of the relevant literature. Then, section 3 presents the land allocation game and the optimal height decision. Next, section 4 discusses the functional form for skyscraper construction; this function is used as a guide for empirical estimation. Then section 5 discusses the relevant issues for New York City. Discussion of the data and the empirical results follow in section 6. Section 7 uses the estimates to make some predictions about which buildings are "too tall" as compared to the estimated optimal "economic height"; as well, time series for the optimal "economic height" and "status height" are given for the 20th century. Section 8 offers some concluding remarks. Finally two appendices provide additional information.

2 Related Literature

Despite the attention given to skyscrapers by the popular media, there have been only very few recent studies directly addressing their economics. The last time that economists have looked at skyscrapers in any detail was during the great building boom of late 1920s. Then the debate focused on whether tall buildings like the Chrysler and Empire State were built to be monuments rather than money makers.

Perhaps the most cited work from that time is that of Clark and Kingston (1930), who estimate the costs and income flows from a hypothetical 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.[1] Their aim was to demonstrate that skyscrapers, at their heart, were economically rational investments.[2] In fact, they also estimated that a 100 story building would provide a net return of 7.08%.

More recently, two papers deal directly with the economics of skyscrapers.[3] Barr (2007) 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 though the costs and benefits that have determined the decision about whether to build and how tall to build have varied over the course the twentieth century, there has been no fundamental change in skyscraper building patterns over the 20th century. Though the 1920s represented an

[1] Their fictional plot size of 81,000 square feet is in the 87th percentile for plot size in my data set; it's in the 91st percentile for plot size for buildings completed before 1950. To give a sense of comparison, the Empire State Building has a plot area of 91,351 square feet (with 102 floors), and the Chrysler Building's plot area is 37,525 square feet (with 77 floors).

[2] Their building's estimated return on investment was "rational" given 1929 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 soon become known as the "Empty State" Building because of the Great Depression (Tauranac, 1995).

[3] There are also two related strands of real estate literature that I do not address here: real estate cycles (such as Wheaton (1999) and Case and Shiller (1989)), and the decision about when to build (such as Titman (1985) and Bar-Ilan and Strange (1996)).

aberration in terms of the number of skyscraper completions at its peak, the forces driving the average heights of buildings, however, have not changed significantly over the 20th century. Rather the average height is based on the supply and demand for this height, which is determined by factors related to both the New York City and national economies, regulations on land usage, and taxation. The work here is different in that I look directly at the determinants of building height, at the building level, asking what fraction of building height can be accounted for by economics, land use regulation and the quest for status.

Another paper is by Helsley and Strange (2007). They investigate a two-person game, where each player aims to building the world's tallest building. They demonstrate that when players value being the tallest for its own sake (as a desire for status), the contest can dissipate profits from tall buildings. 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 a city and over time.

The paper here also draws from recent work on the economics of status. Most notable 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 (cdf), 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 at the mean heights of completed buildings when deciding how tall to build; as the means rise so does the extra height.

3 The Model

Here I provide a simple model for the optimal height decision. 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 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 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.[4] The equilibrium is symmetric, with each bidder using the same bid function.

3.1 The Height Decision

First, we 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

$$u_i(h) = \pi(h) + \lambda_i F(h) - l_i, \tag{1}$$

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 (we relax this assumption below). 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 value of the building less the construction costs. l_i is the cost of the plot of land. Assume that all potential developers know the profit function and that it is the same for all developers.[5] The value of the building can be determined in part from site-specific factors, such as its access to public transportation, zoning regulations, and proximity to the business district "core" as well as economy-wide or regional factors such as interest rates and building costs.

λ_i is the developer's private value that is placed on status or his 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

[4] Though not addressed here, both the number of bidders as well as the number of auctions could be made endogenous.

[5] 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.

have utility at or above his reservation level. In addition, all agents know $G(\lambda)$.

$F(h)$ is a continuous, strictly monotonic ranking function (or cumulative distribution function) such that there are values $\underline{h}$, $\overline{h}$, with $0 \leq \underline{h} < \overline{h}$, with $F(h) = 0$ for $0 \leq h \leq \underline{h}$, and $F(\overline{h}) = 1$ for $h \geq \overline{h}$. That is, if $F(h)$ is the rank of a developer's building in terms of its height, $\underline{h}$ is the minimum size necessary to achieve any status all. $\overline{h}$ is the current record-holder for the tallest building in the city or region. These minimum and maximum values can change over time, but builders take then as given when deciding on a possible height for their building. In short $\lambda_i F(h)$ is the contribution of status to a builder's utility; $F(h)$ is his possible rank, given the current skyline, when deciding how tall to build. Building a skyscraper is no small feat, and not all builders have the skills, knowledge or access to capital; as such, status is only conferred upon those can succeed in constructing a building of certain height.

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 $h^* = \arg\max_{h \in R_+} u_i(h)$:

$$u_i'(h^*) = \pi'(h^*) + \lambda_i f(h^*) = 0,$$

where $f(h) = F'(h) > 0$ for $h \in [\underline{h}, \overline{h}]$. (For the remainder of this section the subscripts are dropped to simplify notation.)

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

Lemma 1 *For $\lambda \in [0, \overline{\lambda}]$, 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* $\lambda \in (0, \overline{\lambda}]$; $h^* = h^c$ *for* $\lambda = 0$.

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

In summary, this section 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 status.

3.2 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. Let l_i^* be developer $i's$ land valuation from choosing an optimal 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, we could simply assume that 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 we assume $r = 0$). 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 4 *l^* is monotonically increasing in λ; $l^* = l^c$ when $\lambda = 0$.*

Lemma 5 *Given the monotonicity of l^*, the minimum and maximum land values for a plot is l^c and $\bar{l}^* = \pi(h^*) + \overline{\lambda} F(h^*)$, respectively.*

Lemma 6 *Given that $\lambda \sim U\left[0, \overline{\lambda}\right]$, the probability distribution function for land valuations is given by*

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

with a cdf of

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

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

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 $\beta(l^*) = \frac{(N-1)l^* + l^c}{N}$.*

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 $N \to \infty$, $\beta(l^*) \to l^*$.

4 Functional Form and Optimal Height

For the developer with the highest valuation, utility is given by

$$u(h) = V(a, h; \theta) - C(h, a; \gamma) + \lambda F(h) - l,$$

where h is the building height (in feet), a is the land area of the plot (in square feet). V is the expected present discounted value of the net rent flows from a newly constructed building. θ is the contribution to the value from city-wide and site-specific factors. City-wide factors might include city employment and population; while site-specific factors might include zoning regulations, which might limit use or height, and neighborhood effects (such as localization economies).

Again, $F(h)$ is the ranking function. V is a function of height since there is demand for height from height "consumers" who enjoy the great views from up above, as well as those to whom being on the top floors is a demonstration of conspicuous consumption and/or status. $C(h, a; \gamma)$ is the cost function, which is determined by the plot area, the height, and γ, which measures the factors that can affect the costs of construction, such as the depth to bedrock, the regularity or shape of the plot, input costs and interest rates.

To make matters more concrete let's assume that total building value, V, is per floor value times the height of the building, that is $V = vh$, where $v = \left(\theta a + \frac{1}{2}h\right)$. θa is the per floor value for the site (assuming that a builder builds on the whole plot) and $\frac{1}{2}h$ (whose coefficient is normalized to one-half) is the additional per floor value that comes from the increased height due to the extra value for height by consumers.[6]

In terms of building costs, assume that height has increasing marginal costs due to the fact that as buildings go taller there are additional expenses, including increased foundation preparation, wind bracing materials, more elevator shafts, and larger heating and cooling systems (Clark and Kingston, 1930; Shabbagh, 1989). For simplicity, assume a cost per floor of $c = \left(\gamma a + \frac{\varphi}{2}h\right)$, where γa is the cost per floor and $\varphi/2$ is the marginal height cost for each additional floor. Total construction cost is given by $C = ch$.

Further assume that the ranking function is a uniform cumulative distribution function, $F(h) = \frac{h-\underline{h}}{\overline{h}-\underline{h}}$, where $\overline{h}$ is the record, $\underline{h}$ is the minimum building height to have any status. Putting the value and the cost functions together, and rearranging terms gives

$$u(h) = \left((\theta - \gamma)a + \frac{\lambda}{\overline{h} - \underline{h}}\right)h - \frac{1}{2}(1 - \varphi)h^2 - \lambda\frac{\underline{h}}{\overline{h} - \underline{h}} - l. \qquad (2)$$

Assume that $(1 - \varphi) > 0$ and $\left((\theta - \gamma)a + \frac{\lambda}{\overline{h}-\underline{h}}\right)$ is large relative to $\frac{1}{2}(\gamma - 1)$. The optimal height with status is derived from the first order condition for

[6] Note that h could be converted to the number of floors, where, for example $floors = 12h$, if we assume that floors are 12 feet high.

equation (2). Denote $\rho \equiv 1/(1-\varphi)$, and note that for a uniform distribution, the mean ranking is $\mu = (\overline{h} - \underline{h})/2$. The optimal height is given by

$$h^* = \rho \left((\theta - \gamma) a + \frac{\lambda}{2} \mu \right). \tag{3}$$

In summary, optimal height is given by the profit from development plus the interaction of the average building height and desire for status. Further note that $h^c = \rho (\theta - \gamma) a$, which means that $h^* = h^c + \frac{\lambda}{2}\mu$, where $\frac{\lambda}{2}\mu$ is the status component of height.

5 New York City

Given the discussion of skyscraper height above, we now turn to 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 status factors. In this section, I first present a brief history of New York and discuss the relevant issues for estimating skyscraper height. Then I discuss the empirical model, the data and the results.

After the completion of the Erie Canal in 1825, New York City became the nation's most important city, and the center of finance and commerce.[7] The city's economic and population growth created a great demand for land on which to house both residents and businesses. At its widest point, Manhattan island is about three miles wide, and about thirteen miles long, comprising a total of about 23 square miles. The city's initial development was on the lower, southern tip of the island; over the 19th century development generally proceeded up the island, northward.

In 1811, in an effort to rationalize its street pattern, the city implemented its now-famous gridplan. The plan standardized street patterns and lot sizes. Standard blocks measured 200 feet wide (north-south) and ranged from 400 to 920 feet long (east-west). Lots were generally 25 feet wide and 100 feet 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

[7] Up until 1874, New York City was just the island of Manhattan, when it annexed parts of the Bronx. In 1898, New York City merged with the city of Brooklyn and other surrounding towns to become what is today the five boroughs of the city.

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 Up until the mid part of the 19th century, building height was limited primarily by technological considerations. A building's load bearing was done by masonry walls. To build taller required ever thicker walls, which then cut into the usable space of the plot. Secondly, without elevators, people were forced to ascend to the upper floors via the stairwells, which they were reluctant to climb beyond five or six stories. As a result, the top floors generally housed the least valuable economic activities (Shultz and Simmons, 1959).

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 skeleton cage could be constructed, with a thin brick or stone facade.

In addition, new methods of transporting people upwards had to be developed. The original elevators were powered by steam, and they were soon replaced by hydraulic lifts. But it was the invention of electric elevators in the 1880s that eliminated passenger height constraints altogether. Perhaps most important was the creation by Elisha Otis in 1853 of the safety break, which eliminated the fear that the elevator might violently plummet to the ground (Landau and Condit, 1996).

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). In sum, by around 1890, technological issues were no longer the major determinant of building height; rather skyscraper height was primarily one of economics and status.

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, 208 feet below street level (with a standard deviation of 104 feet), 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 56 feet, with a standard deviation of 34 feet). 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 to a height of two times the width of the street before it had to set back.[8] 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.

[8] "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)).

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.[9] 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 square feet of usable space for every 100 square feet 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 (Chandler, 1977). Because New York was the center of much of this economic

[9]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 (Bennet, 1960). In 2006, the population of New York City was 8.21 million (http://www.census.gov).

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 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).[10]

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).

6 Empirical Analysis

The optimal height equation (3) demonstrates that the building height on a specific site will be a function of the income that can be generated, the cost

[10] 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).

of building, and the utility value of status. To estimate the model, however, requires the collection of unobservable data, such as on the value of λ, and on building-specific costs and income flows. Unfortunately, this type of specific building data do not readily exist.

Rather I use a combination of site-specific and economy-wide variables to measure the costs and benefits of skyscraper construction. For this reason, I estimate the following linear econometric model for the optimal building height:

$$h_i^* = \alpha_0 + \alpha_1 a_i + \boldsymbol{\alpha}_2'\mathbf{x}_i + \boldsymbol{\alpha}_3'\mathbf{z}_i + \boldsymbol{\alpha}_3'\mathbf{w}_i + \varepsilon_i,$$

where $\theta_i = \boldsymbol{\alpha}_2'\mathbf{x}_i, \gamma_i = \boldsymbol{\alpha}_3'\mathbf{z}_i$,and $\lambda_i\mu = \boldsymbol{\alpha}_5'\mathbf{w}_i$.[11]

That is, θ_i can be decomposed into a weighted sum of factors that affect the net income from the site. γ_i is a weighted sum of factors that contribute to construction costs, $\lambda_i\mu$ is decomposed into a weighted sum of status factors. a_i is the plot area. ε_i is the random, unmeasured, i.i.d. component of height, assumed to be normally distributed. We now turn to the specific variables.

6.1 Data

Here I give a general description of the variables. Appendix B contains more information on the sources of the data. As the model above illustrates, height is a function of the costs of building, the building's expected revenues, the plot size and the degree to which a building will provide relative status. 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 322 feet (100 meters) 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. Limiting a skyscraper to 100 meters or taller means that I only include buildings that have about 30 or more floors.[12] As discussed above, since the late 1880s, the problem of *engineering height* was essentially solved, and thus the issue of how tall

[11] Note that I assume that ρ is constant over time, and thus θ and γ are the important parameters with respect to the costs and benefits of height.

[12] Note that there is not a one-to-one relationship between the number of floors and height. In this sample, the average number of feet per floor 12.62, with a standard deviation of 1.81, with a min. of 8.98, and a max. of 19.96.

to build was one of economics. Clearly, what makes a building a skyscraper is relative, especially in the early period of their construction. But since 100-meter buildings have regularly been built since 1895, I use this value as the minimum height to be considered a skyscraper (see Barr (2007) for more information on skyscraper time series).

Building Information The dependent variable, as mentioned above, 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. A few plots like those of the World Trade Center and United Nations are extremely large. In these instances, the respective government agencies created a master plan of superblocks. 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 is one if the block is not perfectly rectangular or square, zero otherwise.

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 soil 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.

Variable	Mean	Std. Dev.	Min.	Max.
Building Information				
Height (feet)	490.24	141.22	328.08	1368.11
Plot (000 sq. feet)	44.67	63.66	4.00	681.60
Plot Irregular Dummy	0.570			
Depth to Bedrock (feet)	88.56	85.20	0.26	524.43
Distance to District Core (Miles)	0.612	0.448	0.016	2.55
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			
Status Variables				
Avg. Height of All Completions$_{t-1}$	465.23	25.93	311.70	490.66
Corporate HQ Dummy	0.164			
World Record Dummy	0.022			
NYC Record within Use Category Dummy	0.083			
Zoning Variables				
Built Under 1916 Zoning Laws Dummy	0.360			
1916 Setback Multiple*	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*	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 only)				
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

Table 1: Descriptive Statistics for skyscrapers completed from 1895 to 2004. # obs.= 458, unless otherwise noted. Sources: See Appendix B. *Stats. are for buildings completed during relevant zoning rules.

To account for the fact that land values in the "center" are higher due to agglomeration economies and the concentration of public transportation, I use 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. Lastly, I include a dummy variable for downtown buildings, to control for systematic differences that may exist between downtown and midtown. Most notably, downtown has bedrock quite far down and quicksand below the surface, while midtown has bedrock quite near to the surface and relatively dry soil.

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 which height decisions are made and when buildings are completed). For income, 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. Finally to measure the health of the New York City real estate market (and 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.[13]

Status and Ego To measure the degree to which status affects height, I include four status-related variables. First, I have 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 building. Second, I include the average building height of all buildings completed in the year prior to the completion of each building. As equation (3) demonstrates, average height of completions measures the relative ranking of a building. Thus if status was important I would expect the coefficient to be positive.

In addition, occasionally, a builder has the right economic conditions and plot size to aim specifically for the world's tallest building (see Tauranac (1995) for the case of the Empire State Building). To control for this fact, I include a dummy variable for world record buildings. Lastly, I also include a dummy variable to measure the additional height added by a developer who aims to have the tallest building within its use class. Presumably status is conferred upon the builder who, say, builds the city's largest residential building (as did Donald Trump in 1998) or the city's tallest hotel.

[13]Note that I don't not have any direct measures of technological change in building materials and methods over the 20th century. However, the cost index used here implicitly captures this change. For example, the 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.

6.2 Results

Table 2 presents the results of the regressions. The first regression is a measure of "economic height," without any of the status measures. Equation (2) includes the measures of status and ego. The status measures increase the explanatory power by about 15 percentage points. Three out of four of the status measures are statistically significant at the 90% level and all four have signs consistent with the theory.

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 was planned by a government agency according to some master plan.

Block sizes appear to be a suitable instrument given that they were determined in 1811 with the implementation of the grid plan; thus they would appear to 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 used to dominate these areas. Finally, a few blocks, generally near the rivers, were the product of master plans, such as the United Nations, and the World Trade Center. The master plans are generally produced in areas that were formally related to port activities and as a result emerged due to exogenous historical conditions.

To consider using block size and related variables as an instruments, I first performed a test of the overidentifying restrictions, which produced a χ^2-statistic=2.58. With 2 degrees of freedom, I can not reject the null hypothesis of strictly exogenous instruments. In addition, the first-stage regression with instruments had an $R^2 = 0.39$, while the first-stage regression without the instruments had an $R^2 = 0.22$, 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.[14]

In regard to bedrock, the downtown depth to bedrock coefficient is positive and statistically significant in equation (1) and statistically insignificant for equation (2). The positive effect in equation (1) might have been due to an omitted variable bias eliminated in equation (2). However, this positive effect comes because of the inclusion of the *downtown* dummy variable, which appears to measure (at least in part) the differing subsoil conditions between lower Manhattan and midtown. The downtown subsoil is often composed of quicksand, which necessitates the use of caissons and expensive retaining walls to ensure that surrounding buildings don't cave in during construction. In midtown, the bedrock is relatively close to the surface and the soil is dryer. In many cases, the main issue with foundation preparation is blasting away the bedrock that is close to the surface. For midtown, the depth to bedrock coefficient shows a small negative effect; for example, for every extra 10 feet a builder has to dig, I estimate a reduction in height of about 1.6 feet. Note that when equation (2) was run without the downtown dummy variable (results not shown), the depth to bedrock coefficients for both midtown and downtown were negative but statistically insignificant.

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 strongly support that the depth to bedrock is a key factor in skyscraper height. However, a more direct analysis of the depth to bedrock and the placement of early skyscrapers is needed; this is left for future research.[15]

In general, all of the zoning-related coefficients give the correct signs. The estimates show, for example, that under the 1916 zoning rules, a building in a "two times" district, would have reduced its height by $-190.6+58.8(2) = -73$ feet (about 6 floors) compared to the non-zoning era. Under the 1961 rules,

[14] Descriptive statistics for the instruments as well as IV test results are available upon request.

[15] The failure to find statistical significance for the bedrock coefficient may also be due to measurement error, given the estimated averages from the maps, or possibly due to the fact that several foundations may have been prepared for buildings that preceded the skyscrapers in the data set.

Variable	(1)	(2)
ln(Plot Size)	74.4	59.1
	(7.57)***	(8.67)****
Irregular Plot	−22.3	−18.2
	(1.89)*	(1.80)*
Rental Apartment	−25.1	−19.7
	(1.56)	(1.32)
Office Building	13.1	26.2
	(0.87)	(1.84)*
Distance to Core (miles)	−45.0	−41.4
	(3.25)***	(3.27)***
Depth to Bedrock Downtown (feet)	0.234	0.116
	(2.21)**	(1.14)
Depth to Bedrock Midtown (feet)	−0.100	−0.160
	(0.81)	(1.64)*
Downtown	−79.8	−61.6
	(2.72)***	(2.22)**
Zoning 1916	−251.8	−190.6
	(3.75)***	(3.00)***
Setback Multiple	66.4	58.8
	(2.67)***	(2.49)**
Zoning 1961	−312.6	−268.0
	(4.44)***	(4.01)***
Max. FAR	12.1	10.6
	(3.77)***	(3.68)***
Plaza Bonus	38.8	51.08
	(2.65)***	(4.12)***
Air Rights	82.6	65.0
	(5.65)***	(4.83)***
Special District	132.2	95.8
	(2.93)***	(3.24)***
Pop. NYC Area_{t-2} (millions)	19.8	20.8
	(2.30)**	(2.40)**
% F.I.R.E./Employment_{t-2}	41.6	39.3
	(2.75)***	(2.61)***
% Δ ln(Eq. Assessed Land $\text{Value})_{t-1}$	1.25	1.14
	(1.62)	(1.71)*
% Real Interest Rate_{t-2}	−4.52	−4.99
	(2.00)**	(2.22)**
Real Construction Costs_{t-2}	−241.3	−255.1
	(5.20)***	(5.76)***
Corporate HQ		24.50
		(1.53)
World Record		337.0
		(5.40)***
Category Record		77.9
		(3.19)***
Avg. Height_{t-1} (feet)		1.10
		(1.68)*
Constant	−198.2	−589.6
	(2.12)**	(2.42)**
R^2	0.41	0.57
$\bar{R}^2$	0.38	0.54

Table 2: Dependent Variable: Skyscraper Height (in feet). Number of observation is 458. Absolute value of robust t-statistics below coefficient estimates. *Stat. sig. at 10% level, **Stat. sig. at 5% level. ***Stat. sig. at 1% level.

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 -7.4 feet or less than one floor as compared to the no-zoning regime before 1916.

All of the economic time series variables all have correct signs and are statistically significant. 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 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 heights.

The role of status, as measured in the regression has had both a statistically and economically significant impact on the skyline. Most interesting is perhaps the coefficient for the average height of buildings. The coefficient shows that, on average, building height increases with the total completions average a little more than equally (i.e., a one foot increase in the average of all buildings increases building height by 1.1 feet). Over the twentieth century the total completed average increased by about 177 feet, which means that, on average, building height is now increased by about 15 floors so that developers can "keep up with the Trumps."

Being a corporate headquarters seems to add a relatively modest amount of height, adding, on average about two floors. Those who aim for the world record appear to shoot for the moon. Perhaps, on average, the record-breaking developers aim to hold onto their world record for as long as time as possible, since all else equal, a world record breaking developer adds over 400 feet (32 floors) to his building (the sum of the record break dummy and the category record dummy). The developer aiming for a category record appears to be more modest in his aims, adding only about six floors to achieve that record. This makes sense given that the categories include apartments, hotels and hospitals, where income flows are not as great as office buildings, which have, to date, been the world record buildings.

7 Optimal Height and Beyond

In this section, I use the coefficient estimates to perform two exercises. First, by comparing the predicted economic height to the actual height, we can get a measure of the degree to which a building is "too tall" in terms of the competitive profit maximization sense. Second, we can look at how the optimal height has changed over time, since this optimal height is a function of the costs and benefits of building, which generally vary from year to year.

Table 3 investigates the top "too tall" buildings in New York City, by using the predicted height values given by equation (1) in table 2. 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. Only the second to last buildings on the list was built as a pure speculative office project; the last building on the list is a hotel.

Rank	Building	Year	h	$\hat{h}^c$	Diff.	Floors	$\widehat{\text{Fls.}}^c$	Diff.
1	Empire State	1931	1250	589	661	102	48	54
2	One World Trade Ctr.	1972	1368	865	503	110	70	40
3	Chrysler	1930	1047	547	500	77	40	37
4	Two World Trade Ctr.	1973	1362	890	472	110	72	38
5	AIG/Cities Services	1932	951	537	414	66	37	29
6	40 Wall St	1930	928	544	384	70	41	29
7	Citigroup Center	1977	915	574	342	59	37	22
8	JP Morgan Chase HQ	1960	705	371	335	52	27	25
9	Woolworth	1913	791	511	280	57	37	20
10	GE/RCA	1933	850	589	260	69	48	21
11	One Chase Man. Plz.	1961	814	563	251	60	42	18
12	20 Exchange Pl.	1931	741	503	239	57	39	18
13	Singer Building	1908	614	381	233	47	29	18
14	CitySpire Center	1987	814	593	221	75	55	20
15	Ritz Hotel Tower	1926	541	332	209	41	25	16

Table 3: Rank of top 15 (out of 458) "too tall" buildings in New York City. Predicted values come from equation (1), table 2. h is the actual height; $\hat{h}^c$ is the predicted optimal economic height.

Figure 2 presents the predicted economic height and "status" height over time for the same hypothetical plot discussed in Clark and Kingston (1930) (here in CK). As did CK, I assume that a speculative office would be constructed on the 81,000 square foot, regular-shaped plot, with a distance to Grand Central Station of 0.1 miles, and a depth to bedrock of 55 feet. Next

I assumed that no zoning regulations were in effect till 1918 (assuming a two year lag between ground breaking and completion). 1916 zoning rules were in effect till 1963, and 1961 rules thereafter. For each year, I generated a predicted value using annual time series data for the New York City area population, office employment, land value growth, real interest rates and construction costs. Economic height was calculated by holding the lagged average height of completed buildings constant at the initial value in 1894 of 311.7 feet (95 meters). The predicted height in feet was then converted to the number of floors by dividing height by 12, the number of feet per floor in the CK building.

Note that the predicted values are generated from a regression run on office buildings only (results available upon request). Also note that the graph includes predicted values for years in which no skyscrapers were completed, including during the depression and World War II. (See Barr 2007 for actual time series of average heights and number of completions over the same time period.)

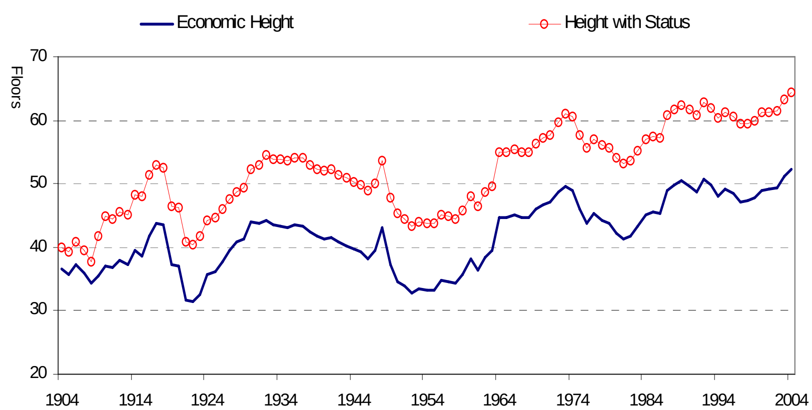

Figure 2: Predicted economic height and status height from 1904 to 2004 for the Clark and Kington (1930) plot.

The graph shows a few things. First, on average, both economic and status height are increasing over the century. Economic height starts at about 37 floors, and by 2004 is approximately 52 floors; similarly status height goes from about 40 floors to 64 floors. This would be expected given the increasing economic activity in New York. However, optimal height moves in waves, with approximately four cycles over the twentieth century. Second, there is a substantial difference between economic and status height; by the century's end, the "status differential" on this plot is about 12 floors by the century's end. Lastly, the regressions under-predict CK's optimal height of 63 floors in 1929. For that year, the regressions give an optimal height of 41 and 49 for economic and status height, respectively. As discussed above, CK used actual rent and cost numbers for a specific plot, whereas here the estimates come from proxy variables and include coefficients estimated from data for 110 years.

8 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 economics, land use regulation and status are important determinants of building height over the 20th century. In general, as would be expected, as the costs and benefits to construction have changed, so has the optimal height. Height has responds positively to population and office job growth, and negatively to interest rates and building costs. As expected, I also find evidence that height is positively related to land values. The estimated "height gradient" shows that height drops at a rate of about 3.3 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 amount of 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 strong evidence that the depth to bedrock has affected skyscraper height, though differing subsoil conditions and bedrock depths in lower Manhattan and midtown appear to have affected height in this two different urban cores.

In addition, I include four variables to account for builders' desire to obtain status and recognition. I find that corporations who build headquarters add only a modest amount of height, as compared to speculative office developers (about two extra floors). I also find that builders who aim for world records strive for the moon by adding, on average, about 32 extra floors beyond the profit maximizing amount. While those developers aiming for a record within their own use group (such as apartments or hotels) add a modest six floors. Finally, by looking at the lagged average height of completions, I estimate that the desire to "stand out" in the skyline has increased building height by about 15 floors by the end of the 20th century.

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 1890s. More work is needed to directly measure of the supply and demand for height. Lastly, one could measure the degree to which skylines, as goods unto themselves, improve the well-being of urban residents.

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 $h = 0$, $\pi(0) + \lambda F(0) = 0$. Since $F(h)$ is a cdf, its maximum value is 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 $u_i'(h^*) = \pi'(h^*) + \lambda f(h^*) = 0$, or $\pi'(h^*) = -\lambda f(h^*)$, where $f(h^*) > 0$. Given that $\pi(h)$ is single-peaked, 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. ■

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 $\pi'(h^*) + \lambda f(h^*) = 0$. Via the envelope theorem: $[\pi''(h^*) + f'(h^*)]\,\partial h^*/\partial\lambda + f(h^*) = 0$, which gives $\partial h^*/\partial\lambda = -f(h^*)/[\pi''(h^*) + f'(h^*)] > 0$. ■

Lemma 4 *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 $l^*(\lambda_i) = \pi(h^*(\lambda)) + \lambda_i F(h^*(\lambda_i)) - r$. By the envelope theorem, $dl^*/d\lambda = [\pi'(h^*(\lambda)) + \lambda f(h^*(\lambda))]\,\partial h^*/\partial\lambda + F(h^*) = F(h^*) > 0$ for all $\lambda > 0$ since $\pi'(h^*) + \lambda f(h^*) = 0$. If $\lambda = 0$, land value is simply given by $l^*(\lambda_i) = \pi(h^c) - r$, since h^c maximizes profit. ■

Lemma 5 *Given the monotonicity of l^*, the minimum and maximum land values for a plot of land is l^c and $\bar{l}^* = \pi(h^*) + \overline{\lambda} F(h^*) - r$, 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 6 Given that $\lambda \sim U\left[0, \overline{\lambda}\right]$, the pdf for land valuations is given by $k(l^*) = \left\{ \begin{array}{c} \frac{1}{\overline{\lambda} F(h^*)}, l \in \left[l^c, \bar{l}^*\right] \\ 0, \text{ otherwise} \end{array} \right\}$;with a cdf of $K(l^*) = \frac{l^* - l^c}{\overline{\lambda} F(h^*)}$, $l \in \left[l^c, \bar{l}^*\right]$.

Proof. First note that land valuations are linear functions of $\lambda : l^*(\lambda) = [\pi(h^*) - r] + \lambda F(h^*)$. Since $\lambda \sim U\left[0, \overline{\lambda}\right]$, $g(\lambda) = \frac{1}{\overline{\lambda}}$. The pdf of $l^*(\lambda)$ follows simply from the formula for the distribution of a random variable that is a linear function of a uniformly distributed variable (DeGroot, 1989). Note that $l^c = \pi(h^*) - r$. The cdf follows from $K(l^*) = \frac{1}{\overline{\lambda}F(h^*)}\int_{l^c}^{l^*} dx = \frac{l^*-l^c}{\overline{\lambda}F(h^*)}$. ■

Proposition 1 *Given each agent's land valuation function, and that the status parameter has a Uniform* $\left[0, \overline{\lambda}\right]$ *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 $b > \beta\left(\bar{l}^*\right)$, 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 $max_{j\neq i}\beta\left(l_j^*\right) < b$. 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 $\beta\left(l^{*N-1}\right) < b$, or equivalently if $l^{*N-1} < \beta^{-1}(b)$. Agent $i's$ expected payoff is therefore $K\left(\beta^{-1}(b)\right)^{N-1}(l^* - b)$, 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 $\beta(l^*) = \left[1/K(l^*)^{N-1}\right](N-1)\int_{l^c}^{l^*} ydK(y)^{N-2}dy$. 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, we 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 $\beta\left(\bar{l}^*\right)$. 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. ■

B Data Sources and Preparation

-Skyscraper Height, Number of Floors and Year of Completions: Emporis.com.

-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* (see references) and the NYC Map Portal.

-Use and Corporate HQ: For each building, one or more articles about the building 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. Then I calculate the distance for each building $i = 1, ..., 458$, from its respective core using the formula $d_i = \sqrt{[69.1691\,(latitude_i - latitude_{core})]^2 + [52.5179\,(longitude_i - longitude_{core})]^2}$, where latitude and longitude were initially measured in degrees. The degrees to miles conversion is from http://jan.ucc.nau.edu/~cvm/latlongdist.html. Given New York's location on the earth, 1° latitude is about 69.1691 miles and 1° longitude is about 52.5179 miles. 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 of bedrock from sea level (in feet) comes from maps provided by Dr. Klaus Jacob, Lamont-Doherty Earth Observatory of 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 Department of City Panning, 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.

-*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). 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.

-*World Records:* Helsely and Strange (2007) and Emporis.com.

-*Use category records:* From the building height data, based on year of completion.

- *Average Height:* Taken from building height data, with demolitions removed in year of demolition, except for the World Trade Center Buildings, which were left in the averages. The first value for this variable is 311.7 feet (95 meters).

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