Skyscrapers and the Skyline: Manhattan, 1895-2004*

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Abstract

This paper investigates the determinants of skyscraper building cycles in Manhattan from 1895 to 2004. We first provide a simple model of the market for tall buildings. Then we empirically estimate the determinants of the time series of the number of skyscraper completions and their average heights over the 110 year period. We estimate the model under the assumption of rational expectations and myopic expectations, and find that the myopic model provides a better fit of the data. Furthermore, we find that several local and national variables determine both the number of completions and the average height of skyscrapers, including New York City area population; national employment in finance, insurance and real estate; building costs; access to financing; property tax rates and zoning regulations.

JEL Classification: D84, N61, N62, R11, R33

Key words: Skyscrapers, building cycles, building height, Manhattan, myopic expectations, rational expectations

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1 Introduction

Skyscrapers have captured the public imagination since the first one was completed in Chicago in 1885. Manhattan soon took the lead in the race to build the world's tallest buildings; and ever since the late nineteenth century, the Manhattan skyline has become, arguably, the key symbol of New York's economic might. As such, the existence and development of skyscrapers and the skyline are inherently economic phenomena, and yet, surprisingly, little work has been done to investigate the economic factors that have determined this skyline.

This paper studies skyscraper building cycles in Manhattan from 1895 to 2004, focusing on two related variables: the number of completions, and the average height of these completions. The factors that have determined the decision about whether to build, and how tall to build, have varied over the course the twentieth century. Skyscraper heights do not simply increase, on average, each year. Rather the "optimal" height is determined by a host of factors related to both the New York City and national economies, as well as regulations on land usage and taxation.

To investigate these cycles, we first provide a simple model of the market for skyscrapers. Then we empirically estimate the determinants of the number of skyscraper completions and their average heights over the 110 year period. Two versions of the model are estimated. The first is done under the assumption of myopic expectations on the part of the builders; the second is done on the assumption of rational expectations.

Most popular and academic accounts of skyscrapers (with the exception of Willis, 1995) fail to make the important distinction between *engineering height* and *economic height*. The technological capability and know-how to construct very large buildings (engineering height) were essentially in place by the 1880's; however, the costs and benefits of skyscraper development (economic height) have varied dramatically over the years. In Manhattan, for example, since 1895, there have been five major skyscraper building cycles. Based on the data set (discussed below), the average duration of the first four cycles has been about 26 years (we are still in the 5th cycle), with the average heights of completed skyscrapers varying accordingly.[1] Table 1 lists

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[1] While skyscraper cycles appear to have some similarities to overall building cycles in Manhattan, they do appear to have distinct characteristics them make worthy of study in their own right. This conclusion is based on a comparison of all new building permits issues in Manhattan each year to the skyscraper completions (adjusted for building lags).

the periods of these cycles.

Major Skyscraper Building Cycles in Manhattan			
Cycle	**Period***	**# of Years**	**Year of Peak**
1	1894-1919	26	1915
2	1920-1945	26	1931
3	1946-1978	33	1971
4	1979-1997	19	1987
5	1998-	-	-
Avg. cycle length		26.0	

Table 1: *Trough to trough. Source: Author's calculatons based on data aquired from emporis.com. See section 5 for the time series graph of completions and average heights.

For the purposes of this paper, we define a "skyscraper" as a building that is 100 meters or taller, as determined by the international real estate consulting firm Emporis.[2] Clearly, over time, the definition of what constitutes a "skyscraper" has changed, but since our motivation is understanding the economic determinants of these buildings, and since they have been regularly built since 1895, we choose 100 meters as the cut-off point.[3] Using some relative measure to determine a skyscraper, such as the a building's deviation from the mean building height is too difficult to measure over such a long time span.

Skyscrapers are important buildings to study in their own right since they are qualitatively different than most type of structures. Skyscraper construction requires vast amounts of capital, both equity and loans; and to amass this capital often requires that builder assemble a consortium of different types of investors, including banks, insurance companies and equity partners, both

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Building permit data is available upon request.

[2] The measure of building height used here is structural height, and does not include any additional antennae or decorative elements.

[3] The average number of floors for a 100 meter building is 30. In fact, we can predict the number of floors from the height by the OLS-derived equation:

$$\widehat{floors} = \underset{(5.36)^{***}}{5.82} + \underset{(29.9)^{***}}{0.224}\, meters$$

$$R^2 = 0.76,\ \#\, obs:\ 473$$

***Stat. sig. at greater than 99%. Robust t-stats. below estimates.

local and foreign. The knowledge and skills needed to construct skyscrapers are very specific and complex. Approval from many city government agencies is needed, including (but not limited to) the Department of Buildings, the Department of Finance, and the Department of City Planning. Only a handful of builders (and their lawyers) have the arcane knowledge to negotiate the city bureaucracy (See Jonnes (1981) and Salmans (1984), for example). The engineering and architectural complexities involved with skyscraper construction also requires the hiring and management of very specific building talent (Sabbagh, 1989). The process of land assembly in Manhattan also requires a very detailed set of skills, from both a legal and real estate point of view. It because of these complexities and the large costs that skyscraper construction in Manhattan is dominated by a small group of locally-based, family-run companies (See, Samuels (1997) for example). Lastly, skyscrapers are different simply because they take so long from conception to completion; this requires builders to be forward-looking and develop expectations about market conditions at a minimum three to five years down the road.

In addition to completions, height is also an important variable to study.[4] The construction of tall buildings reflects the demand for dense office and housing space, in a market where land costs are very expensive, and where agglomeration economies are great. Relative land scarcity in Manhattan is particularly severe since it is a long, but narrow island, and the 1811 gridplan (discussed below) inadvertently put limits on the size of large building plots. As a result, building height is relatively more important in the contribution to total rental space than is the horizontal area. Adding extra height is a way for developers to reap extra profits and satisfy the demands of height "consumers," who demand height for the value and utility it brings.

Height provides highly prized views which provide greater utility (Benson *et al.*, 1998), and it is also an important symbol of status and power. Executives place their offices on the top floors; penthouse apartments generally have the most value, not only because of the views, but also because they are a form of "conspicuous consumption": only the very wealthiest can afford to pay for these great views and are therefore a grand demonstration of this wealth (Veblen, 1899/1992).

Tall buildings confer status upon the builders themselves. And it is the stories of these builders that have garnered much of the attention in the

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[4] Barr (2007) looks at the determinants of height at the building level, the study here focuses on completion and height cycles.

skyscraper literature. Tall buildings are a form of "conspicuous production" for the developers. In the early part of the twentieth century, for example, there is the Woolworth building (1913), the Candler Building (1912), the Chrysler Building (1930), and the Empire State building (1931). In later part of the twentieth century, there is, for example, the Twin Towers (1973), and Trump Tower (1983) and Trump World Tower (2001).

In addition, major corporations use skyscrapers as a location for their headquarters, as a form of advertising, and as a means to signal economic strength. Such buildings include the Metropolitan Life Insurance Company Tower (1909), the Banker's Trust Building Company Building (1912), the RCA Victor Building at Rockefeller Center (1933) and more recently the Time Warner Center (2004). These buildings often have the company's logo or name on the very top of the building. In addition, many buildings add dramatic architectural elements to the top of buildings to heighten their recognizability in the skyline, such as the "Chippendale" pediment for the AT&T (now Sony) building (1984), and, the Chrysler Building, with its famous stainless steel spire.

This paper is novel in several respects. To the best of my knowledge, there has been no systematic economic study of the determinants of building heights or completions over such a long period. Here, we take a long run view, investigating buildings completed over the range of the entire 20th century. Though there exists a fairly large literature on building cycles, these studies generally look at the determinants of office or housing completions within relatively short time period (at most over the course of 25 years); and they do not focus on the determinants of building height. Furthermore, we present a very detailed econometric account of the variables that affect Manhattan's skyline in particular. Most real estate cycle models study an amalgam of metropolitan regions or the national level, and thus, assume that many local determinants of real estate construction are random and unrelated to the included set of independent variables.

Here we include several variables that directly affect the decisions of New York City developers, such as a measure of Manhattan land values, the real estate tax rate, and the presence or absence of zoning regulations or building subsidies. Thus this paper contributes not only to the literature on real estate cycles but also to the study of New York City directly. The Manhattan skyline is perhaps *the* signature symbol New York City and, even the United States, in general; the skyline is primarily an economic phenomenon, and, as such, requires economic investigations.[5]

The data set allows us to test several hypothesis about the nature of skyscraper building. In the empirical section of the paper we compare so-called myopic models to rational expectations models. The evidence in this paper suggests a myopic model is a better fit of the data, in terms of both the number of completions and the average height of these completions. This finding is consistent with several studies on real estate cycles (Case and Shiller, 1989; Clayton, 1996; Wheaton, 1999), since skyscrapers are very expensive, complex, semi-irreversible projects that take several years from the time of conception to the time that the first tenants move in. Furthermore, we compare equations before World War II to after, to see if there are structural differences across the two periods. Lastly, we investigate the role that land values play in skyscraper heights and completions.

Findings Here we give a preview of the major findings. The first is that the regressions based on the myopic model provide a very good fit with the number of completions each year. It is shown that national employment in the Finance, Insurance, and Real Estate industries (F.I.R.E.), construction costs, the net cumulative number of completed skyscrapers, average annual NY Stock exchange volume, NYC area population, the growth in real estate loans, and zoning laws are some of the major determinants of completions– and all of these have the expected signs, as given by the model. We find some mild support that environmental "volatility" reduces completions, and that the growth in the stock market is positively related to height. Real interest rates appear, at best, to have a weak relationship to the number of completions. There is also evidence that the presence of zoning laws has reduced the number of completions. In general, these economic variables can account for the major cyclical swings in New York skyscraper construction over the course of the twentieth century.

In terms of the time series for the average heights, the estimated regressions can account for much of the variation in year to year. Here we find mild evidence that F.I.R.E. employment is positively related to height. The presence of zoning height regulations, as would be predicted, has reduced height. In fact, we estimate that presence of zoning laws has reduced the average building height by about 18%, on average.

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[5] The attacks of September 11, 2001 clearly demonstrate the symbolic importance of New York City's skyline for both the city and the U.S.

The ease with which developers can get real estate loans is positively and significantly related to height; while the real interest rate, however, does not appear to affect height. In addition, we use the equalized assessed value of Manhattan land as a proxy for the market value for land in Manhattan. We show that the growth in land values is an important determinant of building height. This is something that we would expect, since conventional wisdom says that there are often height "arms races" in certain districts of Manhattan, in the sense that a tall building will increase property values and will therefore increase the incentive to build taller to recoup the cost of building on more expensive land.

In addition, via some trial and error, we can determine the lag lengths for the important variables that determine completions and height. For the two equations, we find different lag lengths, with relatively longer lengths for the number of completions and shorter ones for the average heights. A Chow test for a structural break after World War II indicates that for both the number of completions and the heights, there was no major change after the war, this is so, despite the various building subsidies have been offered in the post-War decades.

The rest of the paper proceeds as follows. In the next section, we provide a very brief review of the major economic and institutional factors that allowed New York City to rise from a small, middling trading city to one of the most important financial and economic centers in the world. In addition, we review the city's major developments in the 20th century. Then section 3 reviews the relevant literature on the economics of building cycles and building heights. In section 4, we give a simple model for the market for height. Then in section 5, we present the results of the time series regressions. Section 6 is devoted to concluding remarks.

2 A Brief Economic History of New York

While a detailed treatment of New York's economic history is beyond the scope of this paper, it is because of the economic incentives that were created by this history that skyscrapers rose in such numbers and with such heights. We therefore briefly lay out some of the major developments that affected its growth and the evolution of its skyline.

New York City began as a small trading outpost of the Dutch West India

Company (WIC) in 1624 (and received its first corporate charter in 1625). Inspired by Henry Hudson's exploration of New York harbor and the Hudson River in 1609, the Dutch West India Company, which in 1621 received a monopoly on all Dutch trade in the Americas and West Africa, sought to exploit the region's natural resources by shipping furs, timber and surplus farm produce back to the Netherlands.

In terms of Manhattan's location and geography, it was centrally located between Amsterdam, the headquarters of the WIC, and its ventures in the Caribbean. The Hudson and the East rivers, which lead to the Long Island Sound, allowed for easy access to the interior and other colonies to the north. As Albion (1939) writes, "[A]t no other spot on the North Atlantic coast was there such a splendid harbor so favorably situated for a combination of transatlantic, coastal and inland trade" (p. 17).

Ironically, the Dutch West India company found its New York investment was a disappointment–unable to secure enough fur skins or timber to make the venture profitable. Over time the WIC eventually loosened restrictions on private trading and on self-governance, and after 1647 "insisted that economic freedom was the *sine qua non* of economic growth" (Kammen, 1975, p. 57). Under the stewardship of Peter Stuyvesant, and until the English took control of New Amsterdam in 1664, the city developed into a small, but thriving merchant city, whose businessmen were able to exploit its central location and great harbor. Under the English, New York City's economy evolved into a central location for flour processing, and as a trading entrepot between the Old World and the new one (Albion, 1939).

In the early part of the 19th century, New York City adopted three key innovations that transformed it into the leading port and center of trade, as well as the center of financial capital. First was the introduction of regularly scheduled packet service to Liverpool and Le Havre in 1818. With the inauguration of the Black Ball Line in New York City, a small shipping revolution began. Ships were now pledged to sail at regularly scheduled times whether full or not eliminating uncertainty for merchants, and therefore, lowering their shipping costs and increasing the demand for their goods. As Albion (1939) "[M]ore than anything else, the ocean packets contributed to the rise of the port of New York" (p. 54).

Second was the insertion of New York City merchants into the lucrative cotton trade between the south and Europe (i.e., the "Cotton Triangle"). As the port of New York became the nation's busiest port, New York's merchant economy grew accordingly. As such, New York merchants became a natural source of financial credit for farmers and businessmen in the interior and the south. Most importantly, was the ability of New York City merchants in the 1820's to insert themselves into the lucrative cotton trade between the southern states and Europe. Using its leverage, New York merchants provided Southern plantation owners with needed capital, but only on the condition that ships filled with cotton sailing to Europe stopped at the port of New York. Even as late as 1860, cotton was New York's number one export (Albion, 1939).

Lastly, the building of the Erie Canal, completed in 1821 revolutionized New York's economy. Once hailed as simply DeWitt Clinton's "big ditch," the canal connected the Hudson river to Buffalo. It was an instant success, dramatically reducing the time to ship goods and people between the newly developing west and New York. The canal cemented New York's central role in U.S. commerce.

By the turn of the 19th century, it was clear to the city leaders that a more rational city plan was needed to aid future growth. The small, curvy street and lot patterns that developed from the Dutch days were inefficient and impractical. In 1807 a commission was formed to develop a street plan, and in 1811, New York City implemented its now-famous gridplan, which laid out wide avenues in a north-south direction and the narrower streets in an east-west direction. In addition, lot sizes were standardized at 25 feet wide by 100 feet deep, a size seen as adequate for early 19th century homes and businesses (Spann, 1988).

The effect of this grid plan was to dramatically aid economic development by reducing uncertainty in real estate ownership, and by providing standardization of lot sizes. However, the commissioners did not realize at the time that they inadvertently created artificial land restrictions, because, by the late nineteenth century, when tall buildings become more economically feasible, large lot assemblages has become relatively difficult, thus placing more incentive on builders to build even taller (Willis, 1995).

After the Civil War, the United States economy began to change dramatically. Technological innovation allowed for the rise of national industries, which relied heavily on economies of scale (Chandler, 1977). Most famous were the great railroad networks, the steel and oil industries. The rise of big business generated the need for corporate offices. Since New York City had become the center of finance and commerce (a position further strengthened by the Civil War), it naturally become the center of corporate headquarters, including those of J. P. Morgan, Cornelius Vanderbilt, John Rockefeller, and

Andrew Carnegie (Kessner, 2003). World War I, in addition, had the effect of removing London as the word's center for finance and shifting it to New York (Chernow, 2001). The rise of the office economy made Manhattan real estate more valuable, which in turn, increased the incentives for developers to build as tall as possible (Willis, 1995).[6]

With the rise of the office economy and the tremendous population growth of New York City, there was a great demand for building space to house offices and residences. By the late 19th century, the technological capabilities existed to supply this space, which needed to be in the form of highrise buildings, given expensive land values and small lot sizes. Perhaps the two most important innovations where the elevator (and safety break) and the use of steel for building frames, which replace heavy, load-bearing masonry (Landau and Condit, 1992).[7]

2.1 The Twentieth Century

By the early part of the twentieth century, the economic realities that created the Manhattan skyline had also generated concerns that these buildings were blocking valuable sun light of nearby buildings and casting shadows on the streets (and generating too much traffic congestion), and therefore depressing property values. The first generation of skyscrapers were not subject to any height or bulk regulations; and developers felt free to build very tall buildings that maximized the total rentable space by using as much of the plot area as possible (Willis, 1996). As a result of the emergence of skyscrapers, starting in 1916, New York City implemented the first comprehensive zoning legislation that stated height and use regulations for all lots in the city. (See Revell (1992) for more details about the zoning plan.)

The zoning code did not regulate height *per se*, but rather generated setback requirements. Buildings, after reaching certain height, had to set the building back on higher floors. The very top floors could be built as high as the developer wanted, as long as the area of those floors were not more than 25% of the area of the lot. The regulations generated the so-called wedding cake style buildings, of the 1920's and 1930's.

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[6] Another, oft-cited, reason for the popularity of skyscrapers in Manhattan is the ideal bedrock formations that lie at or just-below the surface in downtown and midtown Manhattan (Landau and Condit, 1996). Barr (2007) explores this is hypothesis in more detail.

[7] New York permitted steel frame construction in 1887.

After World War II, New York's economy began to change. Decentralization of the American population and business, as spurred by the automobile, took its toll on New York City. In 1950, New York's population was 7.89 million and had a murder rate of 3.73 murders per hundred thousand people. By 1980, the New York City population was down to 7.07 million, and its murder rate was up to 25.65 per hundred thousand people (U. S. Census, 1950; 1980; Monkkonen, 2001).[8]

With the flight of population and manufacturing jobs and the decline of the port of New York, New York City's tax base was severely eroded. In the face of these changing economic realities, New York City responded by increasing welfare programs for the poor, middle class housing subsidies, and the municipal payroll. To finance its operations, mayors resorted to bonds to finance day-to-day operations. In 1975, with a national recession as a catalyst, New York was ready to default on its bond payments (Adams, 1976). This financial crises forced New York City to be subjected the New York State Financial Control Board, which required balanced budgets from then on.

In terms of zoning, by the late-1940's, government officials and city planners felt that the 1916 zoning resolution needed a major overhaul to better reflect the realities of post-War New York. In addition, it was felt by many that the 1916 zoning resolution did little to curb excess density and congestion. As a result, in 1961, New York City implemented a new zoning law.[9] Like the 1916 resolution, building height was not restricted *per se*, rather the new zoning resolution established limits on the so-called floor area ratio (FAR). The FAR is a number that dictated the maximum amount of constructible building area for each square foot of lot size. A FAR of 10, for example, means that for each additional square foot of lot size, a builder can add an additional ten square feet to the building. The builder has the prerogative about how to distribute this space between larger floor area or building height. In addition, the code permitted FAR bonuses if a developer provided a public plaza.

By the mid-1960s, however, highrise builders began to negotiate with the

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[8] New York City's population initially peaked in 1967 with 8.1 million people. The murder rate peaked in 1990 at a rate of 30.66 per hundred thousand people (NYC Dept. of Health Reports; Monkkonen, 2001).

[9] 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).

New York City Planning Commission to provide additional floors in exchange for urban amenities, such as renovated subway stations. This led the City Planning Commission to frequently amend the zoning codes. By the early, 1980's, New York Times architecture critic Paul Goldberger wrote, "As far as Manhattan skyscrapers are concerned, the 1961 ordinance has so frequently been amended and altered–and even in special cases–put aside–that it has almost ceased to exit" (Goldberger, 1981, p. B1).

One revision, for example, included, in 1982, the creation a special "Midtown" zoning district to encourage development on the west side of midtown, which expired in 1988; this provision allowed FAR bonuses of up to 20%. The provision, however, was also accompanied by restrictions on how much sun light could be blocked by the top floors of the building, requiring that 75% of the sky surrounding a new building remain open. In addition, since the early 1970's builders have been allowed to purchase the "air rights" of adjacent or nearby buildings. The purchase entitles the builder to add more floors, and the seller is then prevented from constructing a taller building on the property.

As a result of the city's economic problems, starting in the 1970's, a series of building-related subsidies were introduced to stimulate both business and residential construction. In 1977, the Industrial and Commercial Incentive Board (ICIB) was authorized to grant tax abatements to businesses if they constructed offices in New York City. The Board granted abatements to such companies as Philip Morris and AT&T. Starting in 1984, the Board was disbanded and the program became the Industrial and Commercial Program (ICIP) which provided business subsidies "as of right," if the business satisfied a certain set of criteria. In the mid-1990s, the ICIP program was curtailed in Manhattan, but mayors since then have negotiated tax abatements directly with several companies, such as Bear Sterns and Conde Nast, to build office space in Manhattan.

In terms of housing subsidies, in 1977, the "421-a" program was introduced to provide tax abatements to building developers for constructing apartments. For builders of rental units, the builder would qualify for the subsidies if they agreed to charge rents within New York City's rent stabilization program. Developers of condominiums could also qualify for the abatements, and the savings could then be passed to the purchasers. The program was curtailed for most of Manhattan in 1985.

Over the years, despite the city's problems, the demand for Manhattan highrise buildings, both commercial and residential, has been great because agglomeration and New York's central role in finance, marketing and communications. These "pull" factors, have apparently been greater than the "push" factors as New York has retained its place as the preeminent city in the United States.[10] In the last 15 years, New York's economy has seen a renaissance. Population has returned and surpassed its earlier heights; crime levels are back to where they were in the 1950's; city budget surpluses are the norm; and new building construction has been brisk.

3 Related Literature

3.1 Early Work on Skyscrapers and Building Cycles

The last time that economists have studied skyscrapers in any significant detail was during the building boom of the late-1920s. At the time, the focus of the discussion appears to have been centered around the debate about whether the incredibly tall buildings being erected at the time (e.g., 40 Wall Street, The Empire State Building, and the Chrysler Building) were some how "freak" buildings, built, not based on sound economic principles, but rather based set on non-profit maximizing motives (Clark and Kingston, 1930). The work of Clark and Kingston (1930) showed, for example, that the height of buildings at the time were, in fact, consistent with profit maximization, given the rent levels, the value of land, and the cost of building in the late-1920's. They did not consider, however, any expectations about future rent, when making their calculations on the optimal building height.

Work by Long (1936) investigated building cycles in Manhattan from 1865 to 1935. He computed the "major" cycles as defined by Burns (1934) and Kuznets (1930), as well as the "minor" fluctuations. He found that the median minor building cycle length was between four and six years, while the two major cycles in his data set lasted, on average, 37 and 20 years, respectively. Further he investigated the statistical relationship between building construction and stock prices, the interest rate, industrial profits, and "general speculative psychology" (p. 190). Interestingly, he finds no relationship between the interest rate on new mortgages and changes in construction. Further, he concludes that building cycles and stock prices are "apparently not very close" (p. 190). He writes, "All things considered, it is difficult to

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[10] See Carmody (1972) for a discussion of the costs and benefits that firms faced when deciding to remain in the Manhattan or move to the suburbs.

escape the conclusions that the common causal factor affect both building and stock market prices is, in all likelihood, the element of speculative psychology. Building projects in Manhattan are large unit affairs, and therefore are probably stimulated as much by the prospects of promotional gains as by the possibilities of operating profits" (p. 190).

Perhaps the classic work in the field on land values and long building cycles is Hoyt (1933/2000), who detailed the value of Chicago land over 100 years. Hoyt documented roughly 18 year cycles, based primarily on the ebb and flow of population and business in Chicago. While he did not directly address the nature of expectations, Hoyt demonstrated the repeated boom and bust behavior of urban real estate cycles.

The work here focuses on the long building cycles in Manhattan. Because we have annual data and we are dealing with only the largest building projects, we cannot focus on the minor cycles, though clearly there is much year-to-year variation of completions within the major cycles. We also account for the "optimal height" of these buildings over the years, by looking at the relative costs and benefits of height. Unlike any previous studies, we specifically employ econometric models that are able to account for the major completions and height cycles. Since New York has been and continues to be an integral part of the U.S. economy, we can measure the degree to which the large cycles are affected by both important local and national factors such as population growth, supply of building and stock market activity.

3.2 Recent Work on Real Estate Cycles

In the last twenty years, there has been much work exploring the nature of real estate cycles using standard supply and demand models. Much of the literature focuses on the debate whether the real estate market is best captured by models of myopic or rational expectations. Another, more statistical approach has used vector autoregressions to understand these cycles. In regard to office construction, as well as residential construction, the empirical evidence indicates that construction cycles appear to behave in a way that is not compatible with builders having rational expectations, in the sense defined by Muth (1961).

Wheaton (1987), for example, investigates national office market cycles from 1960 to 1986. He finds a cycle length of roughly 10 years, "a length too long to be accounted for by realistic construction lags" (p. 282). Further he finds the office market must remain soft or tight for several years before rents change, and supply or demand react. Further, he finds the supply side factors are more responsive to rents than the demand side, helping to generate some of the market instability.

Wheaton (1999) provides a model of supply and demand for building construction to demonstrate how expectations about future prices can drive price cycles. He compares two versions of the model: one with myopic expectations and the other with rational expectations. His model demonstrates that when market agents are rational and are able to forecast the results (but not the timing) of market shocks, the rational model with building lags can behave like the myopic model, but that the parameter values necessary to generate the type of oscillations are "extreme enough to be considered unrealistic. Thus clearly, the effect of the induced historical 'momentum' in a rational model is nowhere near as extreme as that generated by the inefficient pricing of the myopic model" (p. 227).

The work here also investigates the nature of expectations in the skyscraper market by testing the models implied by both myopic and rational expectations. We specify a supply and demand model to generate equations for the supply of both new buildings and the height of the buildings. Based on the econometric models, skyscraper construction and height appear to be consistent with a more myopic account of expectations.

McGough and Tsolacos (1999), for example, investigate office market cycles from 1980-1997 in Great Britain using an unrestricted vector autoregression (VAR). Their VAR includes office construction (as measured by the value of new office building expenditures), service sector output, employment in the banking-finance-insurance industry, office rents and short-term interest rates. Tests for Granger causality show that rents and service sector output both Granger cause office construction, while banking and finance employment and real interest rates do not Granger cause office construction. Their findings contrasts with the findings here. Office employment is found to be an important determinant of office construction, though, we do not have measures for office rents. The focus of VAR models, however, is generally on forecasting, rather than investigating the specific economic factors that determine the market for real estate.

In recent years, there has been a series of papers that discusses the role of options pricing theory in the decision to build office space (Titman, 1985, Grenadier, 1995; Schwartz and Torous, 2004; Holland, *et al.*, 2002.) One common theme of this work is that the value of the option to build depends on the level of building value uncertainty. An increase in uncertainty means that the value of vacant land will go up, and, therefore builders are less likely to commit to development. However, Bar-Ilan and Strange (1996) demonstrate that with investment lags (long delays to completions) and the option to abandon the project before full completion (as is somewhat possible with skyscrapers) will, in fact, reduce the incentives to delay the project, since the opportunity cost of waiting increases with long lag times. Thus the net effect of uncertainty on skyscraper development is uncertain given the lag time between project formation and completion.

In the vein of Holland, *et al.* (2002), a measure of "total uncertainty" (or uncertainty with respect to rent values) is generated to test its effect on completions and height. As will be discussed below, since we don't have rent values, we use a proxy measure of economic activity that affects rents and look at how the standard deviation of this measure effects completions and height. For completions, uncertainty does appear to be negative, but uncertainty does not appear to affect height.

None of these works has discussed the determinants of building height, and to the best of my knowledge there has been no recent work looking at the economic determinants of building height or height cycles.

4 The Market for Skyscrapers

Here we present a simple model of the market for skyscrapers in order to provide structure to the empirical analysis. A potential developer of a skyscraper faces the following profit function:[11]

$$\pi_t = V_t A_{t-n} M_{t-n} - C_{t-n} A_{t-n} \left(\frac{M_{t-n}}{A_{t-n}} \right)^2 - A_{t-n} L_{t-n}, \qquad (1)$$

where $V_t = \sum \left(\frac{1}{1+r}\right)^{\tau} P_\tau$ is per square foot value of the building at time t. P_τ is the net rental price, per square foot. For the time being, take V_t as given.[12] Below we discuss two possible assumptions about how expectations for V_t are set at time $t-n$, the time when the decision to build is made. A_{t-n} is the area of the plot, M_{t-n} is the height of the building (in meters).

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[11] The data set below contains several types of buildings, including offices and apartment buildings. In this model, without loss of generality, we do not distinguish among the type of the building.

[12] For the sake of simplicity we assume that each floor as the same value. In truth rents are higher in higher floors, but here we can consider V_t to be the average rent per floor.

C_{t-n} measures the cost of construction. Finally L_{t-n} is the square foot cost of acquiring the land.[13]

A developer will start reaping returns at time t for decisions made at time $t-n$, since there is a lag between the decision to build and when the building can start collecting rent. We assume, in accordance with Clark and Kingston (1930), Picken and Ilozor (2003) and Sabbagh (1989), that building costs are quadratic with respect to height per square foot. This profit function represents that fact that for a given plot size, the costs to building higher have increasing marginal costs, due to increased cost of elevators, HVAC systems, wind bracing and foundation preparation. The function also reflects that fact that a flat, bulky building is generally cheaper to build than a tall, narrow building of the same volume.

Given equation (1), the first order condition with respect to M_{t-n} yields a decision about the optimal height, which is a function of the value of the building and the building costs:

$$M^*_{t-n} = \frac{1}{2}\left(\frac{V_t A^2_{t-n}}{C_{t-n}}\right), \tag{2}$$

assuming that profits are greater than or equal to zero.

Next, we assume the standard zero profit condition for the value of land: the landowner will charge the developer a price for land such that there are no economic profits. If we set the profit equation (eq. 1) equal to zero, plug in equation (2) and solve for L_{t-n} we get the per-square-foot value of land, which is based on the value of the building and the costs of building, as well as the size of the plot:

$$L^*_{t-n} = \frac{1}{4}\left(\frac{V^2_t A^2_{t-n}}{C_{t-n}}\right).$$

Furthermore, we assume that the supply of plots that are available to developers to build on is a function of the value of the land at each period:

$$N_{t-n} = \gamma_0 \left(L_{t-n}\right)^{\gamma_1}. \tag{3}$$

We can then plug this equation into equation (3) get an equation for the number of skyscraper starts as a function of the costs and benefits of

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[13] In this paper we assume A is exogenous. We discuss this empirical implications of this assumption in more detail in section 5 below. In addition, we assume the developer builds on the entire plot.

building:

$$N^*_{t-n} = \gamma_0 \left(\frac{V_t^2 A_{t-n}^2}{4C_{t-n}} \right)^{\gamma_1} \tag{4}$$

In terms of the market for building space, we assume, as in Wheaton (1999), that the demand for building space is given by a the following demand function:[14]

$$P_t = \alpha_0 D_t^{-\alpha_1} E_t^{\alpha_2},$$

where D_t is the quantity of space demanded, and E_t is the exogenously determined level of office employment.

Next we assume, similar to Wheaton (1999), that the short run supply (i.e., the current building stock at time t), S_t is fixed so that the price is set to clear the market. This gives:

$$P_t = \alpha_0 S_t^{-\alpha_1} E_t^{\alpha_2}. \tag{5}$$

Since we do not have data for rent, equation (5) plays an important part in the analysis, since we will use building stock, employment and other demand variables to proxy for building rents. We do not directly incorporate vacancy into the model. In the empirical models below, however, we do include vacancy rates for several years, and find that, controlling for the other variables that determine skyscraper completions and height, vacancy is relatively unimportant.

In summary, equation (3) assumes that the supply of lots on the market is determined by the price of land, and the price of land is determined by the value of the building. This model generates two equations: the optimal number of completions and the optimal height, as a function of building value and costs. Building value is determined by the demand for office space and the nature of expectations about future demand.

4.1 Myopic Expectations

Following the literature on the calculation of building values, we can assume that expectations of the building value are based on myopic or rational expectations (Wheaton, 1999). Under myopic expectations we have future prices

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[14] Without loss of generality, we simplify the model by having one variables that determines the quantity demanded and one that shifts demand. To reflect the particular characteristics of New York City, we expand upon this list in the empirical sections below.

determined simply by the discounted value of the net rental price at time $t-n$:

$$V_t = P_{t-n}/r_{t-n}, \tag{6}$$

where r_{t-n} is the current real discount rate. Plugging in equation (6) into the rent equation yields:

$$V_t = \frac{\alpha_0 S_{t-n}^{-\alpha_1} E_{t-n}^{\alpha_2}}{r_{t-n}},$$

and the plugging equation (6) into equations (2) and (4) gives:

$$\begin{aligned} M_{t-n}^* &= \frac{\alpha_0}{2}\left(\frac{S_{t-n}^{-\alpha_1} E_{t-n}^{\alpha_2} A_{t-n}^2}{r_{t-n} C_{t-n}}\right) \\ N_{t-n}^* &= \gamma_0 \left(\frac{\alpha_0}{4}\right)^{\gamma_1} \left(\frac{\left(S_{t-n}^{-\alpha_1} E_{t-n}^{\alpha_2}\right)^2 A_{t-n}^2}{r_{t-n} C_{t-n}}\right)^{\gamma_1}. \end{aligned}$$

Since we have data on the number of completions, we assume that the number of completions is equal to the number of starts $N_t = N_{t-n}$, and $M_t = M_{t-n}$.[15] These two equations are linear in log-log form.[16]

4.2 Rational Expectations

In this section we explore the dynamics of skyscrapers under the assumption of rational expectations. For simplicity we now deal with the log versions of variables, which gives us linear equations to work with (where logged variables are in lower case):

$$\begin{aligned} m_t &= \ln(1/2) + v_t - c_{t-n} + 2a_{t_{-n}} \\ l_{t-n} &= \ln(1/4) + 2v_t - c_{t-n} + 2a_{t-n} \\ n_t &= \gamma_0 + \gamma_1 l_{t-n} \\ p_t &= \alpha_0 - \alpha_1 s_t + \alpha_2 e_t \end{aligned}$$

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[15] Clearly, the number of completions can be less than the number of starts, but given the large costs of development, the irreversible nature of many construction-related decisions, and based on the fact that many building completions occur well into an economic downturn, this assumption appears to be valid.

[16] Since the real interest rate can be negative, we leave it in levels in the regressions below.

Rational Expectations models have the developers making forecasts about the value of an office building such that $E_{t-n}\left[v_t\right] = v_t$, where $E_{t-n}\left[v_t\right] = \sum E_{t-n}\left(\frac{1}{1+r_t}\right) p_t$ and $E_{t-n}\left[\cdot\right]$ is the conditional expectations operator given all available information at time $t-n$. Under the assumption of rational expectations: (1) agents do not make systematic mistakes in estimating future returns, (2) they use available knowledge of the relevant stochastic processes to make unbiased forecasts, and (3) the economic model and the forecasting model used by the developer are the same (Clayton, 1996).

Given the discount rate, $\lambda \equiv \left(\frac{1}{1+r}\right)$, if we assume no bubbles (i.e., $\lim_{t\to\infty} \lambda^t p_t = 0$) and, for now, set $r_t = r$, then we have

$$v_t = \sum_{i=0}^{\infty} \lambda^{n+i} E_{t-n} p_{t+i}, \tag{7}$$

where $E_{t-n}p_{t+i}$ is the expected net rental price at time $t+i$ given all available information at time $t-n$.

Rents, however, are generally assumed to have a unit root, therefore the first differences of the rent is best described via an $AR\left(q\right)$:

$$\begin{aligned} \phi\left(L\right)\Delta p_t &= \mu_t, \\ \phi\left(L\right) &= 1 - \phi_1 L - \phi_2 L^2 - \ldots - \phi_q L^q, \end{aligned}$$

where μ_t white noise.

As Clayton (1996) discusses, the Hansen-Sargent (1982) formula allows equation (7) to be expressed as a function of the $AR(q)$ process, since the autoregression function can be used to forecast future rents. However, since $E_{t-n}\Delta p_t \neq \Delta E_{t-n} p_t$, we must make some modifications to the Hansen-Sargent formula, which are discussed in Clayton (1996), and are based on a derivation given in Finn (1986). In short, we can write the expected change in building value as a function of past values of rent:

$$\begin{aligned} \Delta v_t &= \sum_{i=0}^{\infty} \lambda^{n+i} E_{t-n} \Delta p_{t+i} \qquad (8) \\ &= \frac{\lambda^n}{\phi\left(\lambda\right)}\left[1 + \sum_{j=1}^{q-1}\left(\sum_{k=j+1}^{q} \lambda^{k-j}\phi_k\right) L^j\right]\Delta p_{t-n} + \frac{\lambda^n \phi\left(L\right)}{\left(1-\lambda\right)\phi\left(\lambda\right)}\Delta p_{t-n}, \end{aligned}$$

4.3 Time Varying Discount Rate

Equation (8) above gives a functional form for the change in the value of the building. However, this functional form emerges based on the assumption of a constant discount rate. Given the data, though, we have reason to believe the real interest rate varies over time (as will be demonstrated in the descriptive statistics section below). If this is the case then

$$v_t = \sum_{i=0}^{\infty} \lambda^{n+i} E_{t-n} \left[p_{t+i} \prod_{j=1}^{i} \lambda^j \right],$$

where $\lambda^j \equiv \frac{1}{1+r_j}$. As discussed in Clayton (1996) an approximately linear version, based on a first-order Taylor approximation is given by

$$\Delta v_t = \rho_1 \sum_{i=0}^{\infty} \rho_3^{n+i} \Delta E_{t-n} p_{t+i} - \rho_2 \sum_{i=0}^{\infty} \rho_3^{n+i} \Delta E_{t-n} r_{t+i},$$

where ρ_j, $j = 1, 2, 3$ are model parameters, and $\rho_3^i < 1$. If Δr_t follows an autoregressive process of order q' such that $\theta(L)\Delta r_t = \mu_t^r$, then we can write this model as

$$\begin{aligned} \Delta v_t &= \frac{\rho_1 \rho_3^n}{\phi(\rho_3)} \left[1 + \sum_{j=1}^{q-1} \left(\sum_{k=j+1}^{q} \rho_3^{k-j} \phi_k \right) L^j \right] \Delta p_{t-n} + \frac{\rho_3^n \rho_1 \phi(L)}{(1-\rho_3)\phi(\rho_3)} \Delta p_{t-n} \qquad (9) \\ &\quad - \frac{\rho_2 \rho_3^n}{\theta(\rho_3)} \left[1 + \sum_{j=1}^{q'-1} \left(\sum_{k=j+1}^{q'} \left(\rho_3^{k-j} \theta_k \right) \right) L^j \right] \Delta r_{t-n} + \frac{\rho_3^n \rho_2 \theta(L)}{(1-\rho_3)\phi(\rho_3)} \Delta r_{t-n}, \end{aligned}$$

Since we do not have rent data, but rather the variables that determine rent, we have

$$\Delta p_t = -\alpha_1 \Delta s_t + \alpha_2 \Delta e_t.$$

The proper lag lengths for the building stock, demand variables and interest rates are discussed in the empirical section below. Given the equation for rents, we can then plug this into the completions and height equations. In short, we can now estimate now estimate the following model given by the assumption of rational expectations:

$$\begin{aligned} \Delta n_t &= 2\gamma_1 \left[-\psi_1(L)\Delta s_{t-n} + \psi_2(L)\Delta e_{t-n} - \psi_3(L)\Delta r_{t-n} \right] - \gamma_1 \Delta c_{t-n} + \varepsilon_t^n \qquad (10) \\ \Delta m_t &= \psi_1(L)\Delta s_{t-n} + \psi_2(L)\Delta e_{t-n} - \psi_3(L)\Delta r_{t-n} - \Delta c_{t-n} + \varepsilon_t^m, \qquad (11) \end{aligned}$$

where $\psi_i(L)$ are the reduced-form autoregression functions for the demand and interest rate variables..

5 Empirical Results

In this section we empirically investigate the determinants of the number of completions and the average height of these completions from 1895 to 2004. Figure 1 shows the time series graphs over the period. The graph shows the cyclical nature of both the number of completions and the heights themselves, with average heights rising over the cycle.

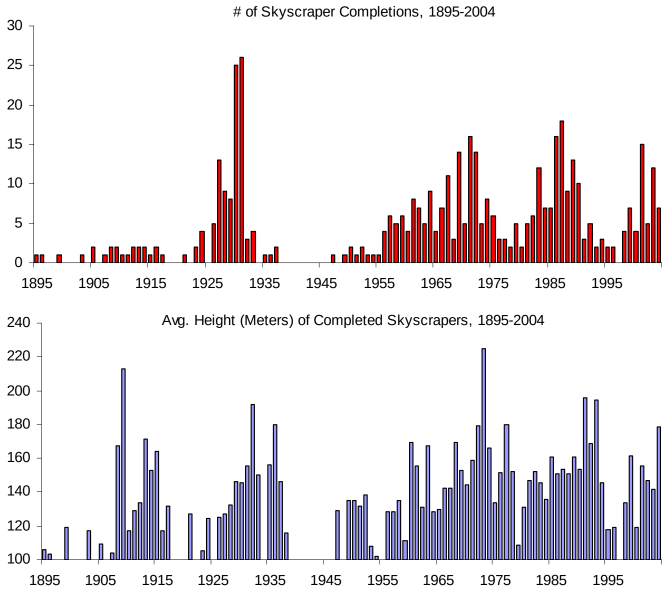

Figure 1: Time Series of number of skyscraper completions and their average heights, 1895-2004. Source: Emporis.com.

The regressions below present results of more detailed equations than the ones presented above. The aim of section 4 was to generate a framework for the regressions. Because we use proxy variable for rents, and some of these variables are national rather than local, and because some of the data is not precisely the same as the model would specify, we do not attempt to test restrictions imposed by the structural equations, since this does not appear to be a valid exercise. Rather, we shall compare the validity of the myopic model to the rational expectations model based on the relationship of the coefficient estimates to their theoretical predictions, as well as the goodness-of-fit of the regressions themselves.

5.1 The Data

The models in section 4 above generate equations for both the number of completions and the (average) height of completed buildings as a function of the lags of several demand and supply variables. As discussed above in the literature review, the number of completions has been shown in past works to be strongly related to office employment variables, and other economic variables such as GNP growth (see Wheaton (1999) and Kling and McCue (1987), for example). This paper includes variables that relate directly to the New York City economy, and which have not been explored elsewhere.

In many cases, time series variables that relate directly to New York City do not exist annually for the entire sample period of 1895 to 2004; in these cases, national variables are used; interestingly, as will be discussed below, these variables are important determinants of skyscraper development in New York City. This is true for several reasons. One is that while some variables, like interest rates and inflation, may show regional differences, the variation across regions tends to be less than their co-movements with the national average; using national measures is a good proxy for the local variables. In addition, since New York City is arguably the most important city in the national economy, it clearly affects and is affected by the national trends, and, therefore, national variables can be important variables for New York City.

In addition, some variables that exist at the New York City level are not the ideal. For example, the population of the New York City metropolitan area is clearly an important determinant of the demand for building space. The New York City regional population has become more decentralized over the course of the 20th century and thus looking at the NYC area population is important. While annual data exists for the NYC population, annual data for surrounding jurisdictions do not appear to exist (or is not accessible), as a result, decennial census data are used for the population of New York City and three counties in New York that supply a large fraction of workers and visitors: Nassau, Suffolk and Westchester.[17] 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 to 2004, the same growth rate from the 1990's is used.

Ideally, we would like to get a true measure of the market value of the land in Manhattan. Since this is not feasible, this paper uses a proxy variable: the equalized assessed value of land in Manhattan. The advantages of this variable are that every block and lot in Manhattan has been assessed and reassessed every year since the late 18th century; and this is a comprehensive and systematic measure. Every year, New York State issues "equalization values" for each jurisdiction in New York State as a way to equalize the assessment values across the state. In other words, New York State derives the equalization factor to convert all assessed values to market values, so that land values then are comparable across that state.[18]

In addition, clearly there has been technological innovation and improvements in building materials and methods over the 20th century. However, we do not have a direct measure of technological change. Rather we use an index of real construction costs, which, at least implicitly, measures the effect of technological change, since there have been extended periods over the sample period where real building costs have fallen.[19]

The Variables Table 2 presents the descriptive statistics for the data used in the time series regressions. In general, we have data for 115 years, 1890 to 2004. The dependent variables are observed from 1895 to 2004; additional years of data were acquired for the lags of the independent variables. For data about the buildings, we have the number of completions each year

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[17] New York City population data is used in one of the regressions presented and is discussed below. Note that New York City before 1898 was just Manhattan and Staten Island, but the population of the other boroughs are included in 1890.

[18] "An equalization rate is a ratio of the locally determined assessed value of taxable real property to the Office of Real Property Office's estimate of market value. Equalization rates are New York State's independent measure of each municipality's level of assessment. For example, an equalization rate of 50 indicates that a town's total assessed value of all real property is 50% of the town's full (market) value determined for a specified date." (http://www.nysegov.com/citGuide.cfm, 2006)

[19] For example, the index of real construction costs used here 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.

and the average of height of the completions.[20] The appendix gives details on how these variables were constructed. As a measure of the total building stock we use the net cumulative number of completed skyscrapers for each year. That is to say, the measure of total stock is the cumulative number of completions, with the number of destructions or demolitions removed in the year of the demolition or destruction. We also include the average area of the plots for the completed buildings.

For office employment we use the proportion of total national employment that is in the Finance, Insurance and Real Estate industries (F.I.R.E./Emp.) (New York City level employment data has not been collected over the sample period). To measure the cost of building we have an index of real construction material costs (nominal building material cost index divided by the GDP deflator). In addition, we also have the annual growth rate of real estate loans provided by commercial banks. This variable is designed to measure the access that developers have to capital for building. To measure the discount rate we use the real interest rate on commercial paper, which is the commercial paper rate minus the current inflation rate, as determined by the GDP deflator. Also, as mentioned above, the New York city metropolitan area population is measured from census data.

To measure the health of the New York economy, as well as the demand for building space, we use variables that relate to stock markets in New York: the average daily volume of stock trades on the New York Stock Exchange (NYSE), and the year-to-year change in the log of Dow Jones Industrial Index, as a measure of the stock market returns. NYSE volume is a measure of the income available from stock trading.

For taxes, subsidies and zoning policy, we include four variables. First we include the real estate tax rate (per $100 assessed value). Next, in terms of zoning, we include a dummy variable that takes on a value of one in years 1916 to 2004 to account for the presence of zoning regulations. In addition, we include a “Westside zoning” dummy variable that takes on the value of one in the years 1982 to 1988. In these years, builders were given FAR bonuses to give builder the incentive to construct office space on the Westside of Manhattan’s midtown business district. In terms of building subsidies, we include a dummy variable that takes on the value of one in the years 1977 to

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[20] Note that, without loss of generality, we do not distinguish among uses for the buildings. Roughly 63% of the buildings are offices, the remaining 37% are residential, hotels or mixed use. Barr (2007) investigates how use affects height.

1992, to measure the effect of the business subsidies offered in those years. Lastly, we include a "421-a" dummy variable that takes on a value of one in years 1971 to 1985 to reflect the relative generous residential subsidies offered in this period.

Finally, the variable "economic volatility" was a derived variable designed to measure the volatility of building values. The variable is derived from eight variables that measure the health of the New York City Economy.[21] Each of the variables was normalized by subtracting its mean and dividing by the standard deviation (i.e., turned into a z-score). The four "bad" variables were then made negative, and all the z-scores were added together to create an economic activity index. The mean of this index is 0.0015 and the standard deviation is 3.11. Thus any value above zero indicates a robust New York City economy; anything below is a weak one. The volatility measure was derived by taking the standard deviation of the economic index for each year and the prior two years. Thus the volatility variable is a type of moving average, designed to measure the average variation in economic activity and hence building values for a three-year period.

In this study we assume that plot size is a randomly determined, exogenous variable. Builders, however, may seek out large plot sizes so they can build tall buildings since it is more efficient to build on larger plots. The problem of endogeneity, however, cannot be investigated further here due to the lack of instruments that are related to plot size but not height or completions.

Investigation of the statistical properties of the average plot size time series and the effect of plot size on the other coefficients indicates that the assumption of exogeneity may not cause severe problems. First, the distribution of the log of average plot sizes appears to be log normal (the Jarque-Bera statistic is 3.89, with a p-value of 0.14), second the time series does not show autocorrelation across the whole sample, which would indicate that, in general, there is not a strong cyclical component to plot size; there does appear to be first order autocorrelation for subsamples, but this finding is not robust across subsamples of various years and year lengths. In addition, when

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[21] These variables are: (1) Nominal commercial paper rate, (2) the GDP Deflator Inflation rate, (3) the percent change in the Dow Jones Industrial Index, (4) the percent change in the New York Stock Exchange trading volume, (5) the New York City property tax rate, (6) the ratio of national F.I.R.E. employment to total employment, (7) the national unemployment rate, and (8) the growth in the equalized assessed values of land in Manhattan. The descriptive statistics of these variables are given below.

the plot size variable is omitted, there is no systematic change in the other coefficient estimates.

{Table 2 here}

5.2 Regression Results of The Myopic Model

As the models above demonstrate, the lags of many variables are important determinants of skyscrapers completions and heights. However, discovering the correct lag structure for each equation requires a bit of experimentation. As prior studies have discussed (e.g., Wheaton, 1999) and as the data for this project indicate, building a skyscraper can take several years. Starting with lag lengths of five years prior to completion, regression results were compared to other regressions with different lag lengths to see which equations had the best overall fit, in terms of adjusted-R^2. In the end, lag lengths for the equations varied between one and four years. In general, those variables that related to the demand for building space had shorter lag lengths than those that related to financing, which makes sense given that builders must first secure financing before beginning construction.

Hypotheses To Test The model presented in section 4 generates a few hypotheses to test. The model was simplified for ease of exposition, but the empirical model includes several other variables that relate to the supply or demand of the height and completions equations. First, we would expect office employment to be positively related to building height and completions. As additional measures of demand we include a measure of the New York City metropolitan area population, the average daily trading volume on the New York stock exchange and the return on the Dow Jones Industrial average; we would also expect these to have positive coefficients. In terms of the supply side, we have interest rates, a measure of the total building supply, the presences of zoning rules, and a measure of the access to building capital. We would expect all but the last one to be negative, while access to capital should be positive. The tax rate should be negative, as it increases the cost of a maintaining a building.

In terms of what might be thought of as direct government actions, we have a dummy variable for the years Westside zoning plan was in effect, which was to encourage development on the Western part of midtown Manhattan, but also put sunlight regulations in place; we would expect a positive coefficient on this plan for the number of completions since it provided FAR bonuses, but we cannot determine the effect on height *per se*. On one hand the FAR bonus may be used for additional height, but if the sunlight regulations place additional costs on that height, the FAR bonus may be use for bulkier but relatively shorter buildings. In addition we include dummy variables for the years that the 421-a and ICIP programs were the most generous (the benefits of these were later curtailed). We would expect these three variables to also be positive since they lowered the cost of building, by providing tax abatements.

Finally, we include the volatility measure to see if it affects the option value of holding land. Given the theory discussed in section 3.2, we hypothesize a negative effect of uncertainty for completions, but perhaps no effect on height, since once a builder begins the project, the option to build has been exercised.

5.2.1 Number of Completions

Table 3 presents the regressions for the number of completions. The dependant variable is the log of one plus the number of completions.[22] In general these regressions show a good fit to the data, and, the coefficients show the expected signs. Table 3 presents three different models. Equation (1) looks at the determinants of completions with only the basic supply and demand variables (and the zoning dummy variable) to explore the role that just market factors play in skyscraper cycles; equation (2) expands this equation to include the average plot size; and equation (3) is the "full" equation that also includes the effects of volatility, post-War policy changes and property tax rates. The regressions had positive first-order serial correlation and heteroskedasticity; Newey-West standard errors were calculated.

We can see that the two-year lag of national F.I.R.E employment is an important determinant of the number of completions; the proxy for total building stock also shows a strong negative relationship with completions. Real construction costs are also statistically significant and negative. The effect of the metropolitan area population is also positive and large. These all concord with the theory provided by the model. Notice, too, that the variables that relate to project financing and the decision to build give the best fit when they are lagged three or four years before completion; those

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[22] For simplicity, we show the results of OLS regressions rather than Poisson regressions. The results are quite similar.

variables that relate to demand and construction costs have the best fit two years prior to completion.

Since the regressions are in log-log form, we can interpret the coefficients as elasticities. For example, we see that both demand and supply variables are relatively elastic. Most notably office employment, and population on the demand side, and construction costs and access to loans on the supply side.

The coefficient on the *zoning* variable (= 1 if after 1915, 0 otherwise) is negative, as would be predicted, but, interestingly, it is not statistically significant across specifications. The effect of zoning would be to presumably make buildings less tall, on average, and would therefore lower completions of very tall buildings. The coefficients show, however this effect appears to be relatively large, decreasing completions by 18%. An F-test comparing separate zoning dummy variables for the 1916 and 1961 zoning regulations, respectively, did not show statically significant differences and thus only one dummy variable was included.

The real interest rate appears to be a relatively unimportant determinant of the number of completions; the coefficient is quite small in magnitude; and generally not statistically significant. This result concords with the early work of Long (1936) and more recently with McGough and Tsolacos (1999). The real interest rate maybe relatively unimportant, in part, because New York builders often have access to foreign sources of capital, from such places as Japan, for example (See Quint, 1990). As a result, a high interest rate may cause builders to seek relatively less costly capital sources abroad. In addition, as the coefficient on the change in real estate loans indicates, access to capital appears to be relatively more important than the cost of this capital, all else equal.[23] Finally, total volatility does appear to be a negative determinant of completions, as would accord with the findings in the options literature, and Holland, *et al.* (2002).

{Table 3 here}

5.2.2 Height

Table 4 presents the height equation results. Because for some years there were no completions of skyscrapers, we do not have observations for the aver-

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[23] Note that the inclusion or exclusion of $\Delta \ln(R.E.$ Loans) from the equation does not materially affect the other coefficients, including the interest rate.

age height for those years. Equation (1) and (2) are the results of regressions where each observation was weighted by multiplying it by the square root of the proportion of completions in that year, which can be appropriate when dealing with variables are that are averages (and this also has the effect of removing the years for which no observations exist). Equations (3) and (4) are produced by ordinary least squares, but with the inclusion of a dummy variable for the years in which their were no completions. Note that the presence of the dummy variable inflates the value of R^2.[24]

In terms of lag lengths we see that the demand variables have the best fit with lags of one or two; while the "decision to supply" variables have optimal lags of two or three years. That the lag structure is a bit different for the height equation as compared to the completions equation is most likely due to the fact that height adjustments can be made during the course of the project, though not without some costs to the builders. As a result if costs are relatively high, then the coefficient for that variable indicates, the decision to shorten the building can be made, on average, one year before completion.

Across equations we see that F.I.R.E. employment does not appear to be strongly related to height. Total stock appears to be a slight negative determinant of total height. The presences of zoning laws, appears to have reduced building heights by a large percentage, around 18%. Construction costs determine height, with a negative effect as predicted, but the coefficient is relatively inelastic. Though stock exchange volume is positive and significant, the return on the Dow Jones Index does not appear to affect height. Both the New York City area population and the NY stock exchange volume positively affect building height.

Similar to the completions equations, interest rates do not strongly determine height, and as expected the average plot size is an important determinant of average height across years. The tax rate is also a negative determinant of height. Unlike the completions equations, however, volatility does not appear to affect the building height. Lastly, the government policy variables do appear to have modestly affected building height over the years. The Westside zoning coefficient is negative, which appears to be because of the sunlight provisions in the zoning code amendment (though it is

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[24] In addition, a Heckman selection model was run, but the coefficient for the Mills ratio was found to be statistically insignificant, and the coefficient estimates were generally close to the results of the OLS model with the dummy variable; as a result the Heckman regression results are not presented.

not statistically significant). The ICIP program appears to have provided an incentive for corporations to build taller; while the 421-a program appears to have, at most, a modest effect on building height.

{Table 4 here}

5.2.3 Additional Models

Here we present the results of additional econometric models.[25] Table 5 presents regressions for the number of completions. Equation (1) and (2) are for pre-WWII (1895-1945 and post-WWII (1946-2004), respectively. Interestingly, a Chow test for differences in the coefficients shows does not reject the null hypothesis of no differences across the two periods ($F - stat = 0.66$, $p - val = 0.82$). This would indicate that, fundamentally, the causes of the building cycles have not changed over the course of the 20th century. Equation (3) presents regressions that includes the vacancy rate, which was not obtainable for the full sample period. Interestingly, vacancy does not appear to affect the number of completions.

{Table 5 here}

Table 6 presents the results for the height equations. As with the regressions in Table 5, a Chow test does not show any structural break after World War II; though the F-stat is close to rejecting the null ($F - stat = 1.28$, $p - val. = 0.13$) In equation (3), the vacancy rate is statistically significant and has a negative coefficient, though the effect of vacancy is quite small, all else equal. Equation (2), shows that in the post-war period, F.I.R.E employment, building costs and interest rates appear to have become relatively more important in determining height.

{Table 6 here}

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[25] In addition to regressions presented in this section, a seemingly unrelated regression (SUR) was performed using a completions equation (Table 3 equation (4)), and a height equation (Table 4, equation (3)). The correlation of residuals was 0.114; a Breusch-Pagan test on the correlation of the residuals did not reject the null of uncorrelated errors. Therefore we don't present the SUR results. Furthermore, the coefficient estimates were quite similar to the results shown above.

5.2.4 Land Values

Every year since late 18th century, New York City has given assessed valuations for every lot and block in the city for both the land and the improvements. Here we investigate the role that land values play in building height and completions. Given our assumption about the relationship between the number of completions and the value of land, we can test a version of this equation. To do this, we perform two-stage least squares. The first stage regresses the growth of equalized land value on the variables that affect both the demand and supply of building space. The right hand side of this equation is very similar to the ones presented above, with the following differences. First, we estimate land values based on the differences and levels of contemporaneous values of the right hand side variables on the assumptions that land is assessed based on current market values, which are based on current economic conditions. Secondly we include the population growth of both New York city in addition to the population of the Metropolitan area. We look at the growth of land values, rather than the levels, because of the presences of unit roots in the dependent variable and as some of the independent ones. The results are presented in table 7.

{Table 7 here}

First we can see that the growth in the land value measure is an important determinant of both building completions and height (controlling for plot size). However, we can see that this variable alone cannot account for as much of the variation in the dependent variables as the disaggregated equations above. Second, the growth equalized land value equation has most of the signs we would expect. Total stock is positively related to assessed values which is presumably due to increased economic activity that these buildings house. Land value has a negative relationship with building costs. The presence of zoning laws does not appear to have affected land value growth. The Westside Zoning and ICIP dummies are positive and significant, while the 421-a dummy is negative and significant. The incentives for businesses apparently have provided increased land value growth, while the incentives for apartment buildings have apparently decreased land value growth. Interestingly Relative F.I.R.E growth and population growth seem unimportant determinants of land value growth.

5.3 Regression Results of the Rational Expectations Model

As discussed above, rational expectations models assume that agents use all available information about the stochastic processes driving the future rents. Furthermore, it is assumed that agents know and use the economic model to forecast the value of buildings (Sheffrin, 1996). In order to do time-series forecasting, the variables must be made covariance-stationary, which is generally done by differencing. Next, the proper lags lengths of the variables must be discovered, by Box-Jenkins methods, for example. In the data set here, we do not have observations on rents, but rather we use economic variables that determine rents, such as employment and total building stock.

When implementing the rational expectations model here two caveats are in order. First, the data used is often national (macro) in scope or imperfectly measured, but, nonetheless, we use this data to infer the nature of micro-level, Manhattan-specific expectations formation. Second, despite the potential limitations of the data, a test of the rational expectations model here is a test of both model itself as well as the nature of expectations. Rejection of the model does not necessarily mean that agents are not following rational expectations, but rather may not be using the same model or data presented in this paper. To compare the models, we look at their predictive power and the statistical significance of the coefficients.

5.3.1 Unit Root Tests

Table 8 presents the results of the unit root tests. As can be seen from the table, several of the variables have unit roots in their levels.

{Table 8 here}

Next the appropriate lag lengths of the differences of the variable were determined in the following manner. First the graphs of the partial autocorrelation functions (PAC) were used to determine the approximate lag lengths.[26] Next autoregressive function regressions were run based on the PACs; the residuals were tested serial correlation using the Breusch-Godfrey Serial Correlation LM Test. In all cases, but one, there was no serial correlation.

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[26] We assume that the number of completions and the average heights do not Granger cause the independent variables.

The one variable that exhibited serial correlation was $\Delta \ln(F.I.R.E./Emp.)$. Adding additional lags beyond that suggested by the PAC, severely reduced the Akaike Information Criterion (AIC) and did not remove the serial correlation. Tests were also run to check for heteroskedasticity. Robust standard errors were used in the time series because of the presence of heteroskedasticity. As the Durbin-Watson statistics indicate first-order serial correlation is generally not a problem. Table 9 presents the lag lengths for the demand-related variables.

{Table 9 here}

Generally the variables have lag lengths of one to three, except, interestingly $\Delta(\Delta\text{lnDJI})$ has a relatively long lag length of six. Notice that instead of using the differences in the cumulative number we use the log of number of completions in a given year.

5.3.2 Regression Results for Completions

Here run a regression based on equation (10). Table 10 presents three different equations. Equation (1) includes all of the demand variables and their lags, the supply variables and real interest rate and its lags; also included is a measure of the average plot size in the following way. The change in plot size is multiplied by a dummy variable, that takes on a zero if there was no completion in the year prior and one if there was. Thus the plot size variable is interacted with a dummy variable that accounts for the whether there is an observation or not. Equation (2) includes only the years in which changes in plot size variable was obtainable. Finally equation (3) represents a parsimonious version of the model. That is to say, the non-statistically significant lags were omitted, and then optimal lag lengths were selected based on adjusted-R^2.[27]

In general, looking at the statistical significance of the demand coefficients, we see that many of the lags of the demand variables are statistically insignificant, which would suggest they are not used to forecast building value. For example, of the four lags for the office employment measure, none is statistically significant. In general the coefficients have the expected signs, especially the cost side of the equation.

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[27] Note that the dummy variables for $zoning$, $Westside\,zoning$, $ICIP$ and $421-a$ were omitted, as they were not statistically significant.

If we compare equation (3) to equations (1), for example, we see that equation (3) provides generally the same fit, as measured by $\bar{R}^2$. This would suggest that the rational expectations model is not consistent with the actual behavior of agents. In addition, in section below we see that the rational expectations has far larger prediction errors as compared to the myopic model.

{Table 10 here}

The Average Height Table 11 presents regression results of the reduced form equation (11). Here we present the results of two regressions. Equation (1) presents the regression for all the years for which we can calculate the growth in height. Equation (2) is the parsimonious version of equation (1). In general, a similar over-all conclusion for the height equation can be made as for the completions equations: the rational expectations model does not appear to be a very good fit of the data. The overwhelming majority of the coefficients are statistically insignificant, and the parsimonious model provides roughly the same fit (in terms of $\bar{R}^2$).

In terms of the coefficients, we see only one statistically significant effect from the office employment measure, and none for the population. We do see a positive effect from interest rates cost growth. This further suggests this is the wrong model. In the next we section we look at the predictions of the econometric models.

{Table 11 here}

5.4 Model Predictions

In assessing the validity of the two models, we need to look at how well they predict the completions and height cycles. In Figure 2, we present the predictions made by the myopic model (Table 3, equation (3)) and the rational expectations model for completions (Table 10, equation (1)).[28] As can be seen from the graph, the myopic model does a good job of tracking the major skyscraper building cycles. The rational expectations model does a poor job, significantly over-predicting the number of completions. Also note that we present the variables in their log form. If we looked at the actual

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[28] The predicted values from the rational expectations model are generate by $\widehat{\ln y_t} = \widehat{\ln y_{t-1}} + \Delta\widehat{\ln y_t}$, $\widehat{\ln y_0} = 0$

number of completions versus the predictions, there would be a much greater difference between the rational expectations and myopic models.

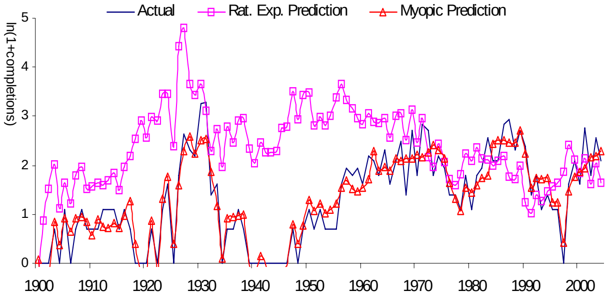

Figure 2: Actual completions and predicted completions, 1900-2004.

In Figure 3, we look at the height predictions for the years 1949 to 1996, because in this period there was at least one completion in every year. Again, we see the rational expectations model does not track the actual heights. The myopic model, on the other hand appears to have a very good fit with the actual completions.

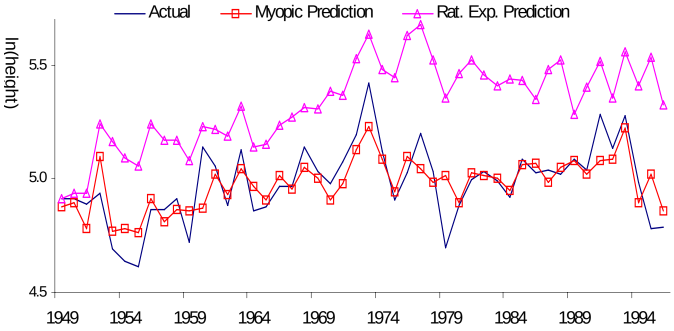

Figure 3: Prediction of height versus actual heights (in logs), 1949-1996.

6 Conclusion

This paper has presented an econometric analysis of the determinants of skyscraper construction and height cycles in Manhattan from 1895-2004. We presented a simple model for the market for tall buildings under the assumptions of both myopic and rational expectations. These models provide a framework for the regressions. We then estimate completions and the average height using several local and national variables that determine the demand and supply for space and height. Regressions for the two models indicate that the myopic model provides a better fit of the data as compared to the rational expectations model. This finding is consistent with other work on commercial and residential construction, due to the long lag time between conception and completions, as well as the semi-irreversibility of these projects. Rejection of the rational expectations model, however, is does mean builders don't follow rational expectations, but rather we don't find rational expectation here based on the model or the included variables.

An investigation of the optimal lag structure shows that for completions variables that relate to building financing such as interest rates and access to capital have three or four year lags, while those variables that relate to the demand for building space and the construction of the building have optimal lags of two years prior to completion. For height, all variables have optimal lags of one or two years prior to completion.

Furthermore, we measure the elasticity of the variables with respect to completions and height. We find that the elasticity of completions with respect to the national employment in the Finance, Insurance and Real Estate (F.I.R.E.) sector is relatively elastic, as is building costs. In addition, we look at the effect of three specific government programs that offered building incentives (via dummy variables for those periods): the "Westside zoning" rules, the Industrial and Commercial Incentive Program (ICIP), and the "421-a" housing tax abatement program. We find that they generally have increased the number of completions, but have had mixed-effects on height. The sunlight provision of the Westside zoning rules was negative, while the ICIP apparently gave builders the incentive to go taller. The 421-a program does not to appear to have an effect on height.

Interest rates appear to play a relatively minor role in determining completions, while the effects of zoning on completions is negative and large, but is not statistically significant. The coefficient measures a decline in tall building completions by around 18%, which is roughly the same magnitude for the reduction of average height (i.e., average height has decreased by about 18% because of zoning regulations). Property tax rates also negatively determine completions and heights.

Comparing regressions for the pre-World War II period to the post-War period show that they capture roughly the same amount of variation across years; however, in the post-War period, completions have become more sensitive to costs, total stock, and the effect of the NYC area population growth. While height has become more affected by relative F.I.R.E employment, as well as building costs and access to capital. Additional regressions demonstrate the importance of Manhattan land value growth for skyscraper development.

As would be expected, there are periods where the predictions for both height and completions do not perfectly match the actual numbers. This is especially true at the peaks of the cycles, where the regressions under-predict the number of completions. Perhaps the unaccounted for portion of the peaks is due to the emergence of an "irrational exuberance" or the development of conspicuous production competitions that have developed among builders (especially in the 1920s). We leave these non-economic factors for future study.

A Appendix: Data Sources and Preparation

The data in the paper comes from several different sources. Here we describe the mains sources and features of the data. The first source of data comes from the website of Emporis (emporis.com), an international real estate consulting firm. Their website lists 473 the buildings in New York City that are 100 meters or taller and the years of their completion.[29] These buildings could be of any type, including for office, apartment, and other uses.

This data was then used to generate the number of completions and the average height of the completions for each year from 1895 to 2005. Emporis.com also lists if the building was destroyed or demolished. The year of destruction or demolition was located by searching the historical volumes of the New York Times.

For the national economic variables such as building material construction costs and interest rates, the main sources were generally from the volume, *Historical Statistics of the United States: Colonial Times to 1970* (1976) and several U.S. government websites such as BEA.gov and BLS.gov. In short, variables from the *Historical Statistics* were combined with the more recent downloaded data. Methods for combing the same variable from different sources are described below for each particular variable.

The New York City and building variables came from several different sources. For each of the 473 buildings in the database, the square footage of the plot was obtained from one of three different sources. For the vast majority of these cases, plot size was obtained from either the *Directory of Manhattan Office Buildings* (Ballard, 1977), its web-based offspring, *mrofficespace.com,* or the New York City's web-based G.I.S database called the New York City Map Portal (http://gis.nyc.gov/doitt/mp/Portal.do). In some rare cases, information on the lot size has to be obtained by viewing the original certificates of occupancy for the buildings, which listed the frontage and depth of plot. PDF versions of the certificates can be viewed via the NYC Dept. of Buildings' web-based Building Information System.

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[29] A few caveats are in order. I have every reason to believe the list is very close to complete. Since this is the only list of its kind there is no ability to cross check it. However, given the data collection for this paper and for Barr (2007), and due to the apparent thoroughness of Emporis' data collection process, the list appears to be quite close to complete, if not 100% so.

Secondly, clearly there can be some debate about what constitute the year of completion; and in this regard there is some discrepancies with other sources, such as New York City's web-based G.I.S. database. However, it was felt best to use the Emporis' year for the sake of consistency and because Emporis is a for-profit firm and, presumably, has a vested interest in culling the most accurate data possible.

New York Stock Exchange volume data and Dow Jones Industrial Index data were obtained from New York Stock Exchange and a Dow Jones company publication (Pierce, 1996) and www.yahoo.com. The total assessed valuation of land for Manhattan was obtained from historical volumes on property taxes in Manhattan and the NYC Department of Finance website.

In terms of population data, New York City's Health Department has tabulated population counts for New York City annually back into the early part of the 19th century. However, data for the surrounding counties could not be obtained on annual basis, therefore decennial census data was used, and annual population figures were estimated based on the population change in each 10-year period. Next we give specific details for each of the variables.

-*Skyscraper Height, Year of Completions and Current Status (extant or not), and Net Total Stock*. The primary source is Emporis.com, which provides information on the height, year of completion and status (demolished or not). From this set of 473 buildings in Manhattan, I aggregated the data to generate the number of completions per year, the average height of those completions for each year and the total net cumulative number of completions. The year of demolition or destruction was found from articles from the historical New York Times (proquest)

-*Average plot size:* Data on each building's plot size comes from the 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.

-*Real Construction Cost Index.* For index of construction material costs: 1947-2004: Bureau of Labor Statistics Series Id: WPUSOP2200 "Materials and Components for Construction" (1982=100). 1890-1947: 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.

-*Annual NYC Population*: 1890-1959: Various annual reports of the NYC Health Department. 1960-2004: NYC Department of Health website:

http://home2.nyc.gov/html/doh/downloads/pdf/vs/2005sum.pdf

-*Inflation*, 1890-2004: GDP Deflator, EH.net (2000=100)

-*Value of Real Estate Loans*: 1896-1970: Table X591, "Real Estate Loans for Commercial Banks." 1972-2004: FDIC.gov Table CB12, "Real Estate Loans FDIC-Insured Commercial Banks." The two series were combined without any adjustments. For 1890-1895: Values are generated by forecasting backwards based on an $AR(3)$ regression of the percent change in real estate loans from one year to the next.

-*Finance, Insurance and Real Estate Employment (F.I.R.E)/Total Employment:* 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 number 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. 1890-1899: 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):* Nominal interest rate: 1890-1970: Table X445 "Prime Commercial Paper 4-6 months." *Historical Stats.* 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.

-*Average Daily NYSE Traded Stock Volume:* http://www.nyse.com/

-*Dow Jones Industrial Index (closing value on last day of year):* 1896-1932: Pierce (1996); 1933 - 2004 from Yahoo.com, 1890-1895: Generated "backwards"from predicted values based on a regression of the DJI on NYSE Volume, the year, and total nonfarm employment, from 1896-1925.

-*NYC Property Tax Rates (per $100 total assessed value):* 1890-1975: Various volumes of the NYC Tax Commission Reports. 1976-2004: NYC Dept. of Finance website. Note that in 1983 tax rates became different for different types of property usages. The rates used here are the ones for commercial property.

-*Population NYC, Nassau, Suffolk, Westchester:* 1890-2004: Decennial Census on U.S. Population volumes. Annual data based on extrapolations, outlined in text above.

-*Assessed Land Value Manhattan:* Assessed Land Values: 1890-1975: Various reports of NYC Tax Commission. 1975-2004 Real Estate Board of NY.

-*Equalization Rate:* 1890-1955: Various reports NYC Tax Commission. 1955-2004: NY State Office of Real Property Services.

-*Office Vacancy* (1925-2005): 1925-1940: Armstrong and Hoyt (1941). 1941-1959: Real Estate Board of New York Report (1968) 1960:-2002: Kelly (2002). 2002-2004: Real Estate Board of New York.

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Descriptive Statististics					
Variable	Mean	Std. Dev.	Min.	Max.	Obs.
Manhattan Skyscraper Variables					
Manhattan Skyscraper Completions	4.31	5.18	0.00	26.00	110
Avg. Height of Completions (meters)	143.36	25.29	100.0	224.60	87
Avg. Plot Size (sq. feet)	49,005	47,352	5,198	342,937	87
Net Total Cumulative # of Skyscrapers	169.99	142.94	1.00	464.00	110
National Economic Variables					
Real Construction Costs Index	1.28	0.267	0.862	1.70	115
% Inflation, GDP Deflator	2.46	4.47	-17.30	18.93	114
Δ ln(Value of Real Estate Loans)	0.08	0.073	-0.165	0.352	114
F.I.R.E /Total Employment	0.044	0.015	0.018	0.066	115
Economic Volatility	2.47	1.35	0.437	6.52	111
Real Interest Rate (%)	2.29	4.73	-13.86	23.92	114
NYC Economic Variables					
Avg. daily NYSE Traded Stock Volume (M)	103.3	290.6	0.11	1456.7	115
Δ ln(Dow Jones Industrial Index)	0.04	0.214	-0.740	0.623	114
NYC Property Tax Rate (per $100 AV)	4.70	3.16	1.41	11.43	115
Population NYC (M)	6.49	1.83	1.61	8.13	115
Pop.: NYC, Nassau, Suffolk, Westchester (M)	8.43	2.79	2.74	11.90	115
Equalized Assessed Land Values, Manhattan (B)	12.50	19.08	1.01	74.07	115
Δ ln(Equalized Assd. Land Val., Mnhttn.)	0.038	0.075	-0.184	0.330	114
Equalization rate of AV	0.820	0.211	0.314	1.05	115
% Office Vacancy (1925-2004)	8.07	6.81	0.20	25.20	80
NYC Dummy Variables					
Zoning Law Dummy (1916-2004)	0.774				115
"Westside" Zoning (1982-1988)	0.061				115
Indstl. & Comm. Incentive Prgrm. (1977-1992)	0.139				115
"421-a" (1971-1985)	0.130				115

Table 2: Time Series Descriptive Statistics. See Appendix for Sources.

Dep. Var.: $ln(1 + Number\, Completions)$			
	(1)	(2)	(3)
$ln(F.I.R.E/Emp)_{t-2}$	4.10 $(5.24)^{***}$	2.39 $(3.58)^{***}$	2.71 $(4.92)^{***}$
$ln(total\, stock)_{t-2}$	-2.15 $(7.4)^{***}$	-1.53 $(5.65)^{***}$	-2.05 $(8.25)^{***}$
$ln(construction\ costs)_{t-2}$	-1.78 $(2.34)^{**}$	-1.69 $(2.41)^{**}$	-1.90 $(3.34)^{***}$
$ln(NYSE\ volume)_{t-2}$	0.106 $(1.83)^{*}$	0.125 $(3.14)^{***}$	0.238 $(3.1)^{***}$
$ln(NYC\ area\, pop.)_{t-2}$	8.35 $(6.2)^{***}$	5.82 $(4.62)^{***}$	7.32 $(6.83)^{***}$
$zoning_{t-2}$	-1.61 $(3.92)^{***}$	-0.495 (1.5)	-0.244 (1.02)
$\Delta \ln{(R.E.\, Loans)}_{t-3}$	1.91 $(2.72)^{***}$	1.68 $(2.3)^{**}$	1.04 $(2.3)^{**}$
$\Delta \ln(DJI)_{t-3}$	0.729 $(2.41)^{**}$	0.532 $(2.28)^{**}$	0.443 $(2.29)^{**}$
$Real\ interest\ rate_{t-4}$	-0.01 (0.45)	0.001 (0.07)	-0.016 $(1.8)^{*}$
$volatility\ index_{t-2}$			-0.152 $(3.9)^{***}$
$Westside\ zoning_{t-2}$			0.559 $(2.51)^{**}$
$ICIP_{t-2}$			0.493 $(2.85)^{**}$
$421a_{t-2}$			0.193 (1.2)
$ln(property\ tax\ rate)_{t-2}$			-0.129 $(1.8)^{*}$
$ln\,(avg.\, plot\ size)_t$		0.089 $(7.37)^{***}$	0.077 $(6.19)^{***}$
$Constant$	-109.1 $(5.24)^{***}$	-79.1 $(4.17)^{***}$	-106.91 $(6.85)^{***}$
$Observations$	110	110	107
R^2	0.66	0.77	0.85
$\bar{R}^2$	0.63	0.75	0.83
$Durbin - Watson$	1.6	1.3	2.0

Table 3: Absolute value of Newey-West t-statistics in parentheses. *significant at 10%; **significant at 5%; ***significant at 1%.

$Dep.Var: ln(avg.\ height)$	$(1)^{\%}$	(2)%	(3)	(4)
$ln(F.I.R.E/Emp.)_{t-2}$	0.234	-0.259	0.187	0.069
	(.89)	(0.86)	(1.19)	(0.43)
$ln(total\ stock)_{t-2}$	0.049	-0.022	-0.002	-0.069
	(0.63)	(0.27)	(0.03)	(1.15)
$ln(construction\ costs)_{t-1}$	-0.519	-0.731	-0.446	-0.553
	$(3.99)^{***}$	$(4.14)^{**}$	$(3.37)^{***}$	$(3.71)^{***}$
$ln(NYSE\ vol.)_{t-2}$	0.000	0.08	0.019	0.069
	(0.01)	$(2.83)^{***}$	(1.6)	$(2.87)^{***}$
$ln(NYC\ area\ pop.)_{t-1}$	0.225	0.832	0.166	0.561
	(0.8)	$(2.54)^{**}$	(0.67)	$(2.07)^{**}$
$zoning_{t-2}$	-0.339	-0.215	-0.199	-0.183
	$(1.97)^{*}$	(1.31)	$(2.25)^{**}$	$(1.94)^{*}$
$\Delta \ln(R.E.\ Loans)_{t-3}$	0.299	0.272	0.310	0.215
	(1.45)	(1.32)	(1.64)	(1.14)
$\Delta ln\,(DJI)_{t-2}$	0.057	0.10	-0.01	-0.004
	(0.95)	$(1.77)^{*}$	(0.19)	(0.06)
$Real\ interest\ rate_{t-2}$	0.001	0.001	-0.005	-0.005
	(0.28)	(0.18)	(1.78)	$(1.88)^{*}$
$ln(tax\ rate)_{t-2}$		-0.051		-0.043
		$(2.56)^{**}$		$(2.26)^{**}$
$volatility\,index_{t-2}$		0.007		0.001
		(0.58)		(0.12)
$Westside\,zoning_{t-2}$		-0.086		-0.076
		$(1.88)^{*}$		(1.35)
$ICIP_{t-1}$		0.283		0.241
		$(4.29)^{***}$		$(3.31)^{***}$
$421a_{t-1}$		0.032		0.041
		(1.14)		(0.95)
$ln\,(avg.\ plot\ size)_t$	0.122	0.167	0.12	0.141
	$(3.98)^{***}$	$(5.26)^{***}$	$(5.65)^{***}$	$(6.45)^{***}$
$At\ Least\ One\ Completion_t$			3.65	3.41
			$(16.4)^{***}$	$(14.67)^{***}$
$Constant$	0.987	-11.5	-2.038	-9.0
	(0.26)	$(2.33)^{**}$	(0.5)	$(2.25)^{**}$
$Observations$	87	86	110	109
R^2	0.46	0.59	0.997	0.997
$\bar{R}^2$	0.39	0.51	0.996	0.997
$Durbin-Watson$	1.4	1.8	1.5	1.8

Table 4: Absolute value of Newey-West t-statistics in parentheses.*significant at 10%; **significant at 5%; ***significant at 1%. $^{\%}$ Variables in each year weighted by square root of number of completions; year with no completions for dep. var. were dropped.

$ln(1+number)$			
	Before 1946	After 1945	
	(1)	(2)	(3)
$ln(F.I.R.E./Emp)_{t-2}$	2.04	2.09	2.74
	$(3.17)^{***}$	(1.03)	$(3.29)^{***}$
$ln(vacancy\ rate)_{t-4}$			−0.009
			(0.14)
$ln(total\ stock)_{t-2}$	−1.34	−4.29	−2.34
	$(3.58)^{**}$	$(3.53)^{***}$	$(6.02)^{***}$
$ln(construction\ costs)_{t-2}$	−1.52	−2.81	−2.36
	(1.55)	$(2.31)^{**}$	$(3.05)^{***}$
$ln(NYSE\ vol.)_{t-2}$	0.307	0.434	0.299
	(1.65)	$(3.07)^{***}$	$(3.09)^{***}$
$ln(NYC\ area\ pop)_{t-2}$	4.33	12.07	8.60
	$(2.71)^{*}$	$(5.21)^{***}$	$(7.06)^{***}$
$zoning_{t-2}$	−0.249		
	(0.97)		
$\Delta ln(R.E.\ loans)_{t-3}$	2.43	1.81	1.36
	$(2.56)^{**}$	$(2.36)^{**}$	$(2.51)^{**}$
$\Delta ln(DJI)_{t-3}$	0.428	0.607	0.534
	$(1.71)^{*}$	$(1.7)^{*}$	$(2.18)^{**}$
$real\ interest\ rate_{t-4}$	−0.016	−0.009	−0.009
	$(2.4)^{**}$	(0.47)	(0.56)
$volatility\ index_{t-4}$	−0.152	−0.104	−0.127
	$(3.29)^{***}$	(1.57)	$(2.84)^{***}$
$Westside\ zoning_{t-2}$		0.521	0.540
		(1.52)	$(2.17)^{**}$
$ICIP_{t-2}$		0.734	0.60
		$(4.36)^{***}$	$(3.18)^{***}$
$421a_{t-2}$		0.292	0.252
		(1.29)	(1.37)
$ln(tax\ rate)_{t-2}$	0.281	0.010	−0.156
	(1.03)	(0.1)	$(1.93)^{*}$
$ln(Avg.plot\ size)_{t}$	0.091	0.084	0.061
	$(5.69)^{***}$	$(4.01)^{***}$	$(3.94)^{***}$
$Constant$	−60.3	−171.21	−120.32
	$(2.5)^{**}$	$(4.13)^{**}$	$(6.38)^{***}$
$Observations$	48	59	77
R^2	0.87	0.78	0.84
$\bar{R}^2$	0.82	0.71	0.80
$Durbin-Watson$	1.9	2.5	2.3

Table 5: Absolute value of robust t-statistics in parentheses. * significant at10%; ** significant at 5%; *** significant at 1%.

ln(Avg. Height)			
	(1) Before 1946	(2) After 1945	(3)
$\ln(\text{F.I.R.E./Emp})_{t-2}$	0.074	1.24	0.872
	(0.32)	(1.97)**	(3.11)***
$\ln(\text{vacancy})_{t-2}$			-0.007
			(1.98)*
$\ln(\text{total stock})_{t-2}$	0.012	-0.318	0.074
	(0.11)	(1.06)	(0.84)
$\ln(\text{construction costs})_{t-1}$	-0.070	-1.469	-1.15
	(0.22)	(4.81)***	(7.63)***
$\ln(\text{NYSE vol})_{t-2}$	0.068	0.078	0.023
	(1.78)*	(2.33)$_{**}$	(0.75)
$\ln(\text{NYC area pop})_{t-1}$	0.0201	0.646	0.772
	(0.03)	(0.95)	(2.07)**
zoning_{t-2}	-0.219		
	(2.1)**		
$\Delta\ln(\text{R.E. loans})_{t-3}$	0.362	0.699	0.452
	(0.72)	(3.52)***	(2.21)**
$\Delta\ln(\text{DJI})_{t-2}$	-0.114	0.261	0.137
	(1.28)	(2.33)**	(1.58)
$\text{real interest rate}_{t-2}$	-0.006	-0.014	-0.013
	(1.7)*	(3.03)***	(3.09)***
$\text{volatility index}_{t-2}$	0.001	-0.002	0.004
	(0.06)	(0.12)	(0.23)
$\text{Westside zoning}_{t-2}$		-0.164	-0.139
		(3.8)***	(2.71)***
ICIP_{t-1}		0.263	0.239
		(3.68)***	(3.04)***
421a_{t-1}		0.103	0.033
		(3.03)***	(0.98)
$\ln(\text{tax rate})_{t-1}$	0.034	-0.068	-0.055
	(0.58)	(2.6)**	(2.51)**
$\ln(\text{Avg. plot size})_{t}$	0.132	0.129	0.138
	(4.67)***	(4.92)***	(5.7)***
$\text{At Least One Completion}_{t}$	3.59	3.48	3.42
	(12.0)***	(12.3)***	(12.67)***
Constant	-0.956	-5.32	-9.84
	(0.11)	(0.44)	(1.69)*
Observations	50	59	78
R^2	0.998	0.994	0.998
$\bar{R}^2$	0.998	0.992	0.997
$Durbin-Watson$	2.0	2.3	2.2

Table 6: Absolute value of robust t-statistics in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

	$ln(1+num.)$	$ln(height)$	$\Delta ln(Eq.\,LandValue_{t-2})$
	(1)	(2)	$(3)^{\%}$
Δln(Equalized Land Value$_{t-2}$)	4.09 $(3.63)^{***}$	0.808 $(3.34)^{***}$	
Δln(F.I.R.E./Emp)$_{t-2}$			0.070 (0.45)
Δln(total stock)$_{t-2}$			0.176 $(2.68)^{***}$
Δln(construction costs)$_{t-2}$			-0.338 $(2.52)^{**}$
Δln(NYSE vol)$_{t-2}$			0.001 (0.03)
Δln(NYC pop.)$_{t-2}$			0.131 (1.06)
Δln(NYC area pop.)$_{t-2}$			-0.333 (0.32)
zoning$_{t-3}$			0.005 (0.24)
Δ ln(R.E. loans)$_{t-2}$			0.331 $(3.37)^{***}$
Δln(DJI)$_{t-2}$			-0.034 (0.11)
real interest rate$_{t-3}$			0.002 $(1.7)^{*}$
Westside zoning$_{t-3}$			0.057 $(1.92)^{*}$
ICIP$_{t-3}$			0.107 $(4.14)^{***}$
421a$_{t-3}$			-0.060 $(2.53)^{**}$
ln(tax rate)$_{t-3}$			-0.002 $(53)^{***}$
ln(Avg. plot size)$_t$	0.136 $(17.31)^{***}$	0.133 $(5.1)^{***}$	0.002 (1.2)
At Least One Completion$_t$		3.52 $(12.6)^{***}$	
Constant	-0.027 $(0.77)^{***}$	-0.002 (0.36)	-0.002 (0.39)
Observations	110	110	110
R^2	0.56	0.997	0.51
$\bar{R}^2$	0.55	0.996	0.43
Durbin-Watson			1.5

Table 7: Absolute value of robust t-statistics in parentheses. *significant at 10%; **significant at 5%; ***significant at 1%. $^{\%}$First-stage regression for the number of completions equation.

Augmented Dickey-Fuller* (null hyp. is unit root)			
Var	**|t-stat.|**	**p-va.l**	**Unit Root**
ln(F.I.R.E/Emp.)	1.56	0.50	Yes
Δln(Eq. Land Val.)	5.07	0.00	
NYC Area Pop.	.2.62	0.27	Yes
Ln(1+Num)	3.34	0.06	
ln(NYSE Vol.)	1.18	0.91	Yes
ln(tax rate)	2.53	0.38	Yes
Δln(dow)	9.29	0.00	
ln(Height | num>0)	4.63	0.00	

Table 8: *with constant and time trend, 1890-2004.

	Time Series Variables						
	Δln(FIRE /Emp)	Δ(ΔlnDJI)	Δln(Tax rate)	Δ(real rate)	ln(1+num)	Δln(Pop.)	Δ ln(NYSE vol.)
C			0.014 (1.75)*		0.245 (2.69)***		0.086 (3.2)***
$t-1$	0.194 (1.83)*	−0.750 (6.26)***	−0.075 (1.16)	−0.291 (2.49)***	0.472 (4.49)***	0.969 (43.75)***	
$t-2$	−0.056 (0.29)	−0.813 (4.67)***	0.037 (0.73)	−0.234 (1.41)	0.352 (3.17)***		
$t-3$	0.293 (2.01)**	−0.592 (3.4)***	0.236 (1.56)	−0.150 (1.13)			
$t-4$		−0.495 (2.96)***		−0.294 (2.89)***			
$t-5$		−0.439 (3.05)***					
$t-6$		−0.243 (2.2)**					
Obs.	110	107	110	109	110	109	110
R^2	0.12	0.45	0.06	0.16	0.60	0.93	
$\bar{R}^2$	0.10	0.42	0.03	0.13	0.59	0.93	
D.W.	1.6	2.0	1.9	2.1	2.1	2.0	2.2

Table 9: Autoregression functions for demend variables and real interest rate. Absolute value of robust t-statistics in parentheses. *significant at 10%; **significant at 5%; ***significant at 1%.

Dependant Variable: $\Delta\ln(1+completions)$			
	(1)	(2)	(3)
$\Delta\ln(\text{FIRE/Emp.})_{t-1}$	0.075 (0.04)	1.97 (0.92)	
$\Delta\ln(\text{FIRE/Emp.})_{t-2}$	2.25 (0.84)	-0.791 (0.24)	2.4 (1.5)
$\Delta\ln(\text{FIRE/Emp.})_{t-3}$	2.28 (1.15)	3.64 (1.47)	
$\Delta\ln(\text{FIRE/Emp.})_{t-4}$	-2.68 (1.43)	-0.917 (0.41)	
$\Delta\ln(1\text{+completions})_{t-1}$	-0.625 (5.58)***	-0.512 (4.54)***	-0.608 (6.19)***
$\Delta\ln(1\text{+completions})_{t-2}$	0.323 (3.03)***	0.226 (1.81)*	0.279 (2.3)**
$\Delta\ln(1\text{+completions})_{t-3}$	0.102 (0.96)	0.135 (1.27)	0.140 (1.3)
$\Delta\ln(\text{NYSE Vol.})_{t-2}$	0.876 (3.72)***	0.793 (3.04)***	0.742 (2.7)***
$\Delta\ln(\text{NYC area pop.})_{t-1}$	2.46 (0.09)	25.8 (0.96)	-2.29 (0.41)
$\Delta\ln(\text{NYC area pop.})_{t-2}$	-3.57 (0.13)	-22.1 (0.89)	
$\Delta(\Delta\ln\text{Dow})_{t-1}$	-0.206 (0.67)	0.028 (0.08)	-0.152 (0.64)
$\Delta(\Delta\ln\text{Dow})_{t-2}$	-0.243 (0.7)	0.211 (0.54)	
$\Delta(\Delta\ln\text{Dow})_{t-3}$	0.008 (0.02)	-0.023 (0.05)	
$\Delta(\Delta\ln\text{Dow})_{t-4}$	0.047 (0.12)	-0.042 (0.12)	
$\Delta(\Delta\ln\text{Dow})_{t-5}$	-0.434 (1.02)	-0.765 (1.78)*	
$\Delta(\Delta\ln\text{Dow})_{t-6}$	-0.352 (1.23)	-0.496 (1.31)	
$\Delta(\Delta\ln\text{Dow})_{t-7}$	-0.611 (2.28)**	-0.732 (2.25)**	
$\Delta\ln(\text{construction costs})_{t-1}$	-3.47 (2.4)·**	-2.45 (1.04)	-3.06 (2.15)**
$\Delta\left(\Delta\text{R. E. Loans}_{t-3}\right)$	2.40 (2.1)**	3.14 (2.36)**	1.61 (1.74)*
$\Delta\text{volatility}_{t-3}$	-0.024 (0.58)	0.033 (0.73)	-0.008 (0.22)
$\Delta\text{real rate}_{t-2}$	-0.021 (1.46)	-0.01 (0.47)	-0.30 (2.86)***
$\Delta\text{real rate}_{t-3}$	0.022 (1.56)	0.018 (0.9)	
$\Delta\text{real rate}_{t-4}$	0.02 (1.33)	0.013 (0.8)	
$\Delta\text{real rate}_{t-5}$	0.015 (1.1)	0.019 (1.19)	
$\Delta\ln(\text{avg. plot size})$		0.040 (0.6)	
$\Delta\ln(\text{avg. plot size})$*dummy	0.027 (0.46)		0.011 (0.21)
constant	0.219 (1.44)	0.150 (0.84)	0.210 (1.39)
Observations	106	85	108
R^2	0.50	0.43	0.40
$\bar{R}^2$	0.35	0.19	0.33
Durbin-Watson	2.1	2.2	2.1

Table 10: Absolute value of robust t-statistics in parentheses. *significant at 10%; **significant at 5%; ***significant at 1%.

Dependant Variable: $\Delta\ln(height)$		
	(1)	(2)
$\Delta\ln(\text{FIRE/emp})_{t-1}$	1.37 (1.93)*	0.487 (1.25)
$\Delta\ln(\text{FIRE/emp})_{t-2}$	−0.707 (1.19)	
$\Delta\ln(\text{FIRE/emp})_{t-3}$	−0.914 (1.63)	
$\Delta\ln(\text{FIRE/emp})_{t-4}$	−0.165 (0.34)	
$\Delta\ln(1\text{+num.})_{t-1}$	0.071 (2.36)**	0.078 (3.36)***
$\Delta\ln(1\text{+num.})_{t-2}$	−0.042 (1.27)	−0.054 (2.56)**
$\Delta\ln(1\text{+num.})_{t-3}$	0.021 (0.64)	
$\Delta\ln(\text{NYSE Vol.})_{t-2}$	0.005 (0.06)	−0.038 (0.5)
$\Delta\ln(\text{NYC area pop})_{t-1}$	0.730 (0.15)	1.32 (0.67)
$\Delta\ln(\text{NYC area pop})_{t-2}$	2.94 (0.64)	
$\Delta(\Delta\ln\text{Dow})_{t-1}$	−0.042 (0.78)	
$\Delta(\Delta\ln\text{Dow})_{t-2}$	0.272 (2.5)**	0.197 (2.54)**
$\Delta(\Delta\ln\text{Dow})_{t-3}$	−0.028 (0.25)	
$\Delta(\Delta\ln\text{Dow})_{t-4}$	−0.108 (0.89)	
$\Delta(\Delta\ln\text{Dow})_{t-5}$	−0.098 (0.77)	
$\Delta(\Delta\ln\text{Dow})_{t-6}$	−0.136 (1.21)	
$\Delta(\Delta\ln\text{Dow})_{t-7}$	−0.146 (1.53)	
$\Delta\ln(\text{Construction})_{t-1}$	2.55 (4.39)***	2.06 (3.1)***
$\Delta\,(\Delta\text{R. E. Loans})_{t-2}$	0.177 (0.48)	0.015 (0.05)
$\Delta\text{volatility}_{t-3}$	−0.027 (1.58)	−0.017 (1.15)
$\Delta\text{realRate}_{t-2}$	0.011 (1.67)*	0.011 (2.67)***
$\Delta\text{realRate}_{t-3}$	0.006 (1.21)	
$\Delta\text{realRate}_{t-4}$	0.000 (0.07)	
$\Delta\text{realRate}_{t-5}$	0.004 (0.99)	
$\Delta\ln(\text{Avg. Plot Size})_{t}$	0.102 (3.8)***	0.098 (4.19)***
Constant	−0.093 (1.85)*	−0.039 (0.88)
Observations	85	86
R^2	0.56	0.47
$\bar{R}^2$	0.37	0.39
Durbin Watson	2.2	2.1

Table 11: Absolute value of robust t-statistics in parentheses. *significant at 10%; **significant at 5%; ***significant at 1%.