Developing Densely: Estimating the Effect of Subway Growth on New York City Land Uses

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Abstract

In the early 20th Century New York City grew rapidly in population and developed area. The subway system also grew rapidly to accommodate this new growth, but also as a concerted effort to decentralize the city away from lower Manhattan. Using parcel level data this paper explores the co-development of the subway system and residential and commercial land uses using Granger causality models to determine if transit growth led residential and commercial development or if subway expansion occurred as a reaction to residential and commercial densities. The results suggest that the subway network developed in an orderly fashion and grew densest in areas where development had already occurred while lagged station densities were a weak predictor of residential and commercial densities. This confirms that subway stations tended to open in areas already served by the system and that network growth often followed residential and commercial development. While the subway network acted as an agent of decentralization, routes and stations were sought in areas with established ridership demand. The implications of land use regulations and transit network density on residential and commercial land uses are discussed as are applications to contemporary transportation and land use planning debates.

Introduction

In contemporary planning debates many argue that transit service will lead to increased residential densities and mixed-use neighborhoods. Substantial investment in rail transit has been made over the past thirty years in order to influence the built environment and boost ridership through new users. Yet this contemporary debate assumes that transit investment leads land development, which is an assertion of a causal relationship that is not certain. A more accurate way of thinking about transportation and land use development is that each is dependent on the other. Transportation infrastructure is designed and built to serve economic and social needs, and land development is dependent on access to transportation (and thus economic and social opportunities). In order to improve our understanding of the complex co-dependence of transportation and land use, this research explores the development of New York City during the era of subway growth.

The New York City subway system developed rapidly in the first half of the 20th Century. Private companies competed to provide new transit service to the growing metropolis, creating a system that features fast, affordable rail transit centered on lower Manhattan and stretches into the outer boroughs. This paper uses historical subway and parcel-level land use data to explore the relationships between residential development, commercial development and subway expansion. The data are analyzed using Granger causality methods to test whether subway growth led land development or if land development led subway expansion in the boroughs of Manhattan, Brooklyn, Queens and the Bronx in New York City.[1]

[1] Staten Island was omitted from this analysis because of its geographic isolation and limited transportation connections to the other boroughs. The island is not connected to the subway system and only directly accessible from Manhattan by ferry and Brooklyn by the Verrazano Narrows Bridge.

This research focuses on the interdependent development of subway expansion and land uses. Unlike many previous studies of urban growth, this research treats subway expansion as part of the land development process. The New York subway was built in response to extremely high residential densities in lower Manhattan and a desire to separate commercial development from residential land uses. Because of this, it is expected that subway growth is a predictor of development in the city, and that commercial and residential land uses will exhibit different effects. However, the subway was built under somewhat competitive circumstances and much of the growth of the network occurred in areas where the subway already existed. This allows for testing the effect of network density on land development, where areas served by multiple lines and more stations use land most intensively.

New York is a valuable lesson in transportation and land use development. Two important factors highlighted here are that the subway was built privately (but through public concessions) by three companies that were consolidated in 1940. Because of this lines and stations were built under semi-competitive conditions rather than public monopoly of supply, leading to some areas that are much better served by the subway than others. Under these competitive conditions transit companies sought profitable routes more than extensive coverage and reach into the outer boroughs. This has implications for the co-development hypothesis in that companies seeking profitable routes are likely to follow existing development rather than lead new development. The end result is a dense network of transit that can support very high residential and commercial densities.

The other relevant factor for this research is that other than Manhattan, New York City largely featured unrestricted zoning between the first zoning code in 1916 and the first comprehensive zoning map in 1961. For most of the city developers and land speculators were able to build the types of structures and uses that held the greatest value, and where zoning controls did ascribe specific uses or densities, such as single-family residential, developers regularly requested and received variances in order to build denser development (Revell 2002). These two factors offer novel insights into the role of transit network density on land use development intensities.

Hypothesis

Two hypotheses are tested in this research. First, the claim that subway growth led development is explored. This has been taken as an obvious truth as decentralizing the population of the city was an explicit goal of civic leaders and transit officials. However, the system was built privately and operators sought profitable routes, though these routes were regulated through concessions. In order to ensure profits, the transit companies sought routes where ridership already existed rather than routes in undeveloped areas. New routes that extended far into the boroughs were riskier than routes with an established rider base. These conditions make it less likely that new subway construction always led land development as transit operators preferred routes that were immediately profitable upon opening.

The second hypothesis tested is that development intensities are greatest where subway network is densest. Simply providing access to transit is not necessarily enough to generate high densities unless the network is sufficiently valuable, and the effect of network density on land use development is poorly understood and rarely examined in the literature. In the case of the New York subway system, access to multiple lines and stations vastly improved the connectivity of an area to destinations. The idea that station density is critical to the intensity of land development and thus transit use is important for contemporary planning debates about infill development, transit-oriented development and transit planning.

To test these hypotheses multiple methods are used. Correlation coefficients are calculated to examine the potential connections between subway growth and residential and commercial densities. Parcel level data then combined with subway station data to test causal relationships using Granger causality methods. These methods and data are described in detail below.

Background

Untangling the relationship between transportation and land uses is a major concern to planners, officials and researchers. In the present institutional climate the public plans, builds and operates the transport systems and the private sector largely develops land. The primary control local governments have over land use is through zoning, other regulatory measures and financial incentives that are used to guide development (Frug and Barron 2008). These are crude tools for integrating transportation and land use development. Looking historically at how cities developed in the absence of strong regulations and public incentives and transit systems were built privately as speculative properties provides a real world example of the value of transit access for developers. In areas with the highest accessibility developers maximize the value of their land by building as densely as possible. These incentives limit the potential for the subway to “suburbanize” New York City as the subway technologies spread out the population new construction where the network is most complete is a countervailing force that concentrates residents and businesses, though at a lower intensity than previously existed.

There are multiple ways to think about how transportation affects the built environment and vice versa. This paper is concerned with the intensity of development near subway stations. A common refrain heard from transit advocates is the rail investment will lead to improved land development (Calthorpe and Fulton 2001; Litman 2005), but this claim rarely accounts for the network density of the transit system. Having access to one station or line is not as valuable as having access to multiple stations or lines. This is a difficult causal relationship to estimate in contemporary metropolitan areas for a number of important reasons. First, in order to densify regions must have population and economic growth. Increased densities of residential and commercial areas reflect redistributive efforts, where people and firms locate in closer proximity than they otherwise would. Yet the redistribution is not of existing firms and households; it is of future firms and households.

Of course, examining development patterns from early last century has limitations. The largest issue is that cars were not ubiquitous in urban areas. This has multiple implications, but mostly that transit offered substantial improvements for accessibility and mobility. Rapidly expanding transit lines ushered in an early era of urban sprawl, though in a very different form than what is considered sprawl today.

Rapid transit proponents in New York were concerned with maintaining the economic vitality of the city in the face of crushing residential and commercial building densities. Parts of lower Manhattan featured densities of over 100,000 per square mile in the early years of the century, and Wall Street skyscrapers were placing tremendous strain on the narrow streets below. Sidewalks were shielded from daylight and the crowds of people, horses and other activities congested the area and disease was rampant (Derrick and History of New York City Project. 2001). In these conditions rapid transit was seen as a necessary *decentralizing* force that would lower densities and promote development elsewhere. Another major change in city structure and control from the overcrowded conditions was the eventual creation and adoption of the city's landmark 1916 zoning code.

The role of rapid transit in suburbanizing New York is quite different than the expected urban transformations led by transit development in the 21st century. By the time that the boroughs consolidated into one city in 1898 it was clear that the existing transit system of elevated trains, horse-drawn street cars and electric trolleys was inadequate for dispersing the population of lower Manhattan. These early transit technologies lead to some land speculation and development on the island all the way north through Harlem, but business interests and politicians were adamant that the city needed faster service in order to shift the patterns of development (Cheape 1980).

By the late 1910s, it was clear that public transit was competing with automobiles for speedy travel (Schrag 2000). The streetcar lines and other remaining transit technologies were losing ridership to subways and to automobiles. Auto registrations in New York City jumped from just over 39,000 in 1915 to over 610,000 in 1927 (Schrag 2000). This was during a period when the subway system was expanding quickly, but the even faster rise in auto registrations suggests that a transit-oriented New York was not destined and that there was potential for the outer boroughs of the city to grow around the automobile. In many areas this is the case, such as eastern Queens and Brooklyn and certainly Staten Island. But the subways and their nickel fares were viable competitors with cars as long as development in the city supported transit use.

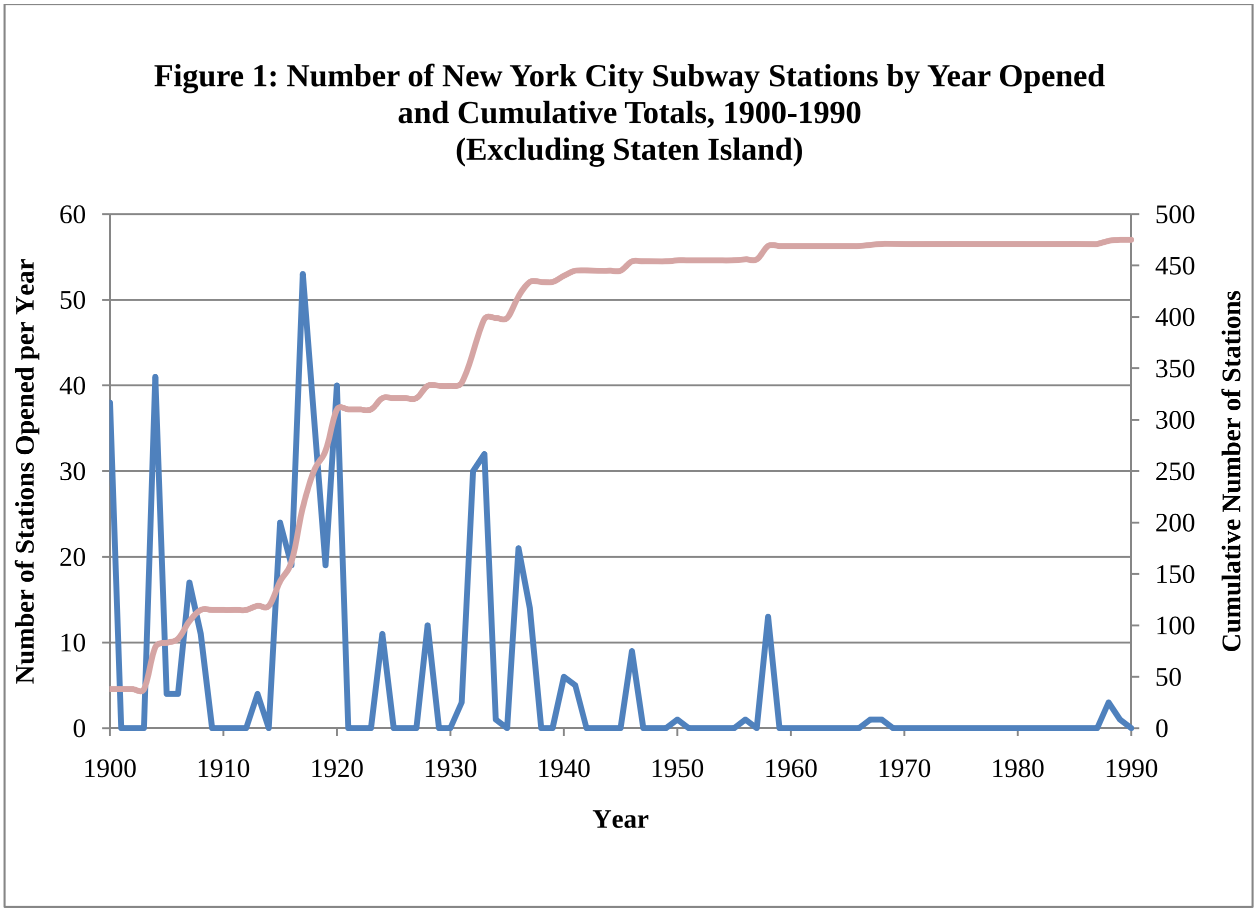
Subway history

In 1900, New York City was a newly consolidated metropolis centered on lower Manhattan. The city was served by a series of elevated trains and surface rail dating to the period just after the U.S. civil war. Manhattan had most of the lines and service. Three elevated lines ran north from South Ferry at the tip of the island and one ran north from City Hall. In some cases these elevated lines were simply replaced by subway lines decades later, such as the line that ran north into the Bronx and terminated at Bronx Park, now home to the Bronx Zoo, was replaced by the number 6 subway. There were very few east-west crossings and much of Manhattan remained underserved by transit, and there was no service in Manhattan north of 155th Street in Harlem (Derrick and History of New York City Project. 2001). After a few decades of popularity the elevated lines declined in popularity and ridership and were increasingly criticized for ruining neighborhoods through noise, blocked sunlight and other problems (Divall and Bond 2003). Some of these areas featured crushing densities reaching around 100,000 people per square mile in parts of the current Lower East Side of Manhattan. At the same time, most of the outer boroughs—Queens, Brooklyn, Staten Island and the Bronx—were largely semi- rural and underdeveloped, though Brooklyn did have an established and large downtown.[2] Civic leaders were eager to develop a mass transit system that promoted decentralization and encouraged development of the outer boroughs. In 1894 the New York state legislature authorized a new Rapid Transit Commission (RTC) that was charged with administering a new rail system for New York City (Hood 1995).

[2] The Brooklyn Bridge opened in 1883 and greatly improved access to lower Manhattan. The Brooklyn waterfront was also busy with ship building. However, the eastern and northern sections of the borough were largely undeveloped or agricultural.

In 1903 the elevated system was sold via a 99-year lease to the Interborough Rapid Transit Company (IRT), which was contracted to build the first subways in the city(Divall and Bond 2003). The New York subway officially opened in 1904 and grew rapidly in the years thereafter. Figure 1 shows the number of stations opened per year and the cumulative number of stations. The current system has about 470 stations[3] The number of stations does not grow consistently over time as subway lines tended to open all at once rather than sequentially. The rapid growth of the system was over by 1940, though quite a few stations opened in the years since. The last new station in terms of new service rather than a replacement station opened in 1989. Currently there is one new line under construction along 2nd Avenue on the east side of Manhattan. It is expected to open in 2017.

[3] Due to the ongoing budget crisis of the New York Metropolitan Transit Authority, many stations are being closed and lines are being eliminated. For this reason the precise number of stations is not given as it is likely to change between when this paper was written and when it is published.



Zoning controls

Between the first zoning code in 1916 and the 1961 zoning reform, the outer boroughs had limited zoning regulations. Densities were largely unrestricted and uses were nominally separated. These features help demonstrate how development occurs in concert with transportation systems. In many ways the New York zoning code was created in order to help disperse the concentrated development in lower Manhattan. Tenement housing on the Lower East Side exceeded 100,000 people per acre in 1905, a density that was unsafe and undesirable. Yet land developers were reluctant to build new residential structures in un- or under-developed areas of Manhattan and the outer boroughs due to the risk of problematic neighboring land uses (Revell 2002). Without zoning controls in place there were no assurances that a residential would not be crowded by a future factory or manufacturing development, thus reducing the desirability of the area.

The enduring effects of land development from the period of rapid subway expansion are a critical aspect of this research. Tables 1 and 2 provide the average densities per assessed parcel in the city by borough. To provide a baseline understanding of density effects, a buffer of 800 meters was created around all existing stations. This buffer approximates a ½ mile radius that is a desirable distance for transit oriented development (Cervero and Kockelman 1997; Dittmar and Ohland 2004).The current commercial, residential, office and retail densities were calculated as square feet per acre by borough for areas close to stations and those farther away. The results are striking in that density is substantially higher for all building types in all boroughs.

Manhattan, as expected, has the highest building intensities, but even on the island there are substantial differences in density between lots that are close to subway stations and lots farther away from stations (Table 1). These differences hold for commercial and residential land uses, though the densities on Manhattan are overall much greater than those in the other boroughs. For instance, the residential lot densities on Manhattan but not near a subway station are nearly as high as the densities in Queens near rail transit. The greatest difference between residential densities near and far from subway stations is in Brooklyn, where lots near stations are more than four times denser than those farther away.

Table 1: Average Residential Square Feet by Lot by Distance from Subway Station, 2009

	<800m of subway station	>800m of subway station
Manhattan	127,631	24,702
Queens	28,958	11,884

Brooklyn	41,010	9,584
Bronx	38,432	12,292

For commercial densities, proximity to subway stations result in approximately two to three time the densities of lots with poor access. Table 2 shows that commercial lot density, that is building uses including office, retail, and all other commercial uses, is two to three times as dense near subway stations for the outer boroughs. In Manhattan the difference is even more pronounced. The data is these tables are suggestive of the effect that subway access has on land use development.

The 1916 zoning code did have height and bulk requirements, but famously had the city been built out to the allowed code it would house over 55 million people (New York City Department of City Planning 2009). While the new ordinance designated residential districts much of the area in Queens, Brooklyn and the Bronx was left as “unrestricted” land, meaning developers were able to largely build what they wanted and thought they could successfully market. Where restrictions did exist it was relatively easy to apply for and receive variances, though most of these were for building more densely than the code allowed (Revell 2002). In many cases developers sought to build multifamily housing near transit even if the land was zoned for less intensive development.

Table 2: Average Commercial Square Feet by Lot by Distance from Subway Station, 2009

	<800m of subway station	>800m of subway station
Manhattan	91,304	19,187
Queens	11,705	4,030
Brooklyn	14,811	5,360

Bronx	12,818	4,767

In 1961 the city introduced a major change in the zoning code including more prescribed uses and restrictions than previously existed. The 1961 code is the basis for the current zoning throughout the city. The New York Department of City Planning describes the change:

> "New theories were capturing the imaginations of planners. Le Corbusier's "towers-in the- park" were influencing urban designers of the time and the concept of incentive zoning—trading additional floor area for public amenities—began to take hold. The last, still vacant areas on the city's edges needed to be developed at densities that recognized the new, automobile-oriented lifestyle. And demands to make zoning approvals simpler, swifter and more comprehensible were a constant." (New York City Department of City Planning 2009)

The new zoning code was the end of the line for transit supporting densities as a guiding factor for subway expansion.

Data and Methodology

The analysis presented here uses the New York City Primary Land Use Tax Output (PLUTO) data for Manhattan, Queens, Brooklyn and the Bronx combined with datasets of subway stations and lines. Staten Island was omitted from the analysis as the subway does not reach the island. PLUTO is a parcel-level data source that includes the areas of each parcel, size of building area, year constructed and space devoted to each use among other factors. The dataset was developed by the New York City Department of City Planning. The subway data is for each of the 479 stations in the existing New York system. For each station the year the facility opened was determined and is used, which allows for estimation of the line effects and station effects.

The data presented organizational challenges. Because the PLUTO dataset is parcel level data, there were hundreds of thousands of individual datum. While this level of disaggregation provides a wealth of detail, it is impractical and not desirable to estimate the co-dependence or transportation and land use at such a small scale. [4] The data was assembled in three ways to determine the best fit for the models. Initially all parcels within 800 meters of subway stations at the full extent of the network were selected for analysis, and these were aggregated by which decade the nearby subway stations opened. These data are discussed below and provided descriptive statistics for the intensity of development near subway stations. However, the data was poorly suited to include station density as a potential influence on intensities of land uses.

The second method of aggregation used current zip codes as boundaries and applies these borders to historical parcel data. The main advantage of this approach was that zip codes were already included in the data, resulting in a relatively quick and easy processing. This approach provided more robust results than the 800 meter buffer, but in many parts of the city zip codes are extremely small and other areas they are quite large. A particular problem was that zip codes are smallest where land use and subway densities are greatest, and ultimately zip code level aggregation did not well suit the methods used here.[5] The bulk of this analysis uses the data aggregated to one mile square cells. Hawth's Tools in ArcGIS 9.3 was used to create a new

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[4] Another concern was computational power. The processing time for assembling and manipulating hundreds of thousands of parcels into useable tables is considerable. The PLUTO data is divided by borough in order to make is useable through conventional software and personal computers. ArcView 9.3 running on a 2 GHz dual core processor with 3.5 GB of RAM is capable of processing a bit fewer than 100 features per second. Each data point created for the analysis required processing about 600,000 features.

[5] A similar problem exists for using US Census tracts as boundary files. In some cases zip code or tract boundaries are smaller than an 800 meter buffer around stations.

shapefile of grids which were used to join the parcel and subway data. Even though each grid potential is larger than the conventional ½ mile (or 800 meter) radius around stations that is used for planning transit oriented land use, the grids allow for more robust statistical analysis. The cells that did not have any subway stations at the full reach of the system were omitted from the analysis.

The PLUTO data was used to calculate the lot densities by decade for building uses by year of construction. For most of the area under study the original structures are still in place, though a great number of them have been modified. There are some areas of Manhattan where the original building have been replaced, but these are relatively few and reflect the growing density of the metropolis. More importantly, the new skyscrapers of midtown are not as likely to have residential uses as building elsewhere in the city. There may be some bias in the data from these newer and large buildings, they are a very small overall share of the total density, and it is only the marginal increase in density that may have a distorting effect. This diminishes the potential bias in the results.

Correlation Tests

Route selection for subway lines and stations was important for the viability of the system. Transit operators, whether private or public, do not want to supply transit service in areas where there is no one to use it. As travel is generally considered a derived demand, it follows that transit supply should follow residential demand. If transit is supplied to areas without established demand new technologies (such as automobiles) may usurp patronage and cause a downward spiral of decreasing demand and usage. As transit connections are made based on population growth in new areas, the system will grow in an orderly fashion following predictable routes. Levinson described this as the 'orderly hypothesis' (2008). New York presents a challenge to the orderly hypothesis as the subway was intended to spread out the population rather than provide new service to underserved areas.

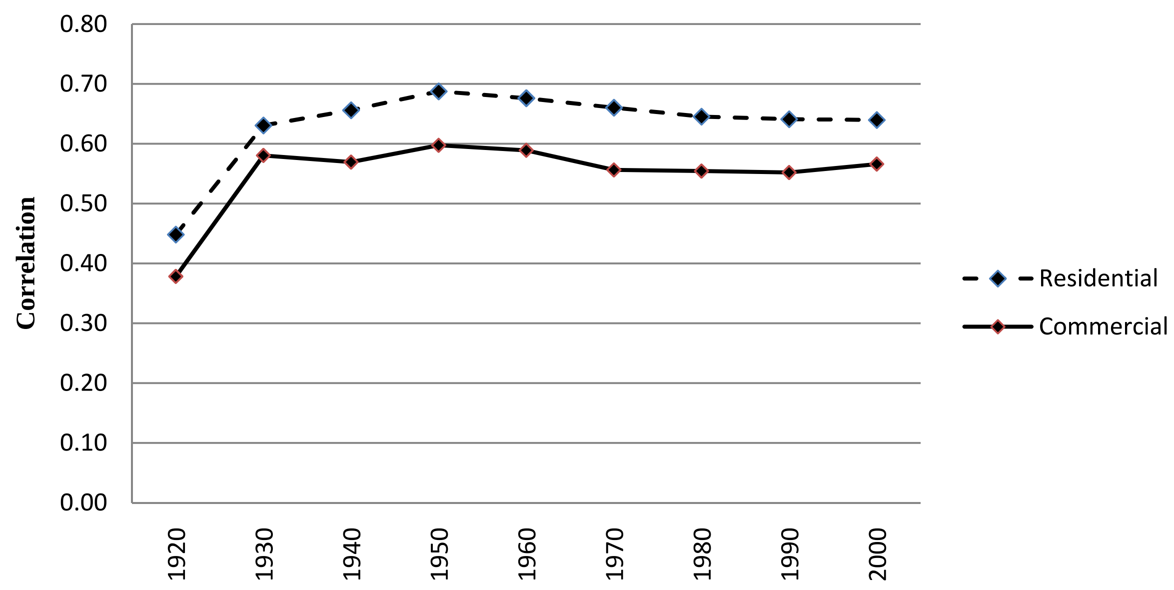
The co-dependence of land use development and subway growth is first tested using Spearman's rank correlation tests calculated using pairwise deletion of cells with missing values. Figure 3 shows the rank correlations between subway station density and land use densities. In the early decades of subway growth the correlations were weak among the relationships tested, but over time the correlations strengthened. For the entire period the residential rank correlations are consistently higher than the commercial correlations. By 1930 both commercial (.58) and residential (.63) rank densities strongly correlated with station densities, and the residential continued to strengthen until reaching a peak in 1950 (.69). At this point the system was largely complete and the city's population growth had stabilized at around 7.8 million, where it remained for the next few decades.[6] Since these peaks the correlations have remained mostly stable with slight decline and still remain strong (>.55 for commercial and >.64 for residential ranks).

The subway was intended to suburbanize the city away from lower Manhattan, so these correlations conform to expectations. Additional points of interest from these data are that the correlations started to weaken somewhat when subway construction slowed after the public takeover of the systems. The city did not continue to densify once the system was mature, but this is not surprising under the circumstances, namely that the population of the city stopped growing. Because of this there was simply no reason to build denser in areas where the buildings

[6] The city's population remained around 7.8 million until the 1970s when the population declined substantially. By 2000 the population recovered and now stands around 8.3 million.

were only a few decades old at most. Two other factors that certainly had smaller effects but are not tested here were the turn towards automobility in the city, perhaps best embodied by the parkways and other roads built by Robert Moses,[7] and the more restrictive zoning code for the whole city introduced in 1961. The zoning code limited potential densities through height, bulk and use restrictions as well as introducing parking requirements throughout the outer boroughs and northern Manhattan in order to better serve auto oriented development. Parking requirements often reduce the buildable size of lots to levels below what is allowed (Shoup 2005), and reduce the likelihood of transit supporting densities.

Figure 2: Correlation of Residential and Commecial Density Ranks by Station Density



Data: New York City PLUTO, New York City Transit

The strong correlations between land use densities and stations partially reflect the durability of the built environment. While subway stations are moved occasionally, there have

[7] See Caro, R. A. (1974). The power broker: Robert Moses and the fall of New York. New York,, Knopf. for full details of Moses' road building.

been few closures since the 1940s when redundant stations were shuttered. There are few areas of the city where subway service has declined since it was introduced, at least by measure of access to the system.[8] However, these correlations require a caveat that they are limited to the intensity of development and not actual population or employment. This caveat does not diminish the usefulness of the data but does limit the generalizable lessons.

Models

Granger causality models are used to estimate the leading indicators of subway and land use development. Sets of time-series data are compared to see if one set of variables *Granger causes* a change in another set, meaning does one lagged variable predict the current value of another. These models are based on the work of Clive Granger who developed these techniques for econometric modeling in order to determine the direction of causality among related variables (Granger 1969). In the case of this research, the causality of land use types and densities on subway development are compared, as are subway development on land uses. The data series are compared to see if land development led subway development or if subway development leads land development. Other researchers have used similar methods in transportation research to estimate the effect of road expansion on vehicle-miles traveled (Fulton, Noland et al. 2000; Cervero and Hansen 2002). Others have looked at municipal competition (Binet 2003). More recently scholars have applied these techniques to the transit and land development in the Twin Cities (Xie and Levinson 2009) and London (Levinson 2008).

The models were estimated conventionally using the correlated panels corrected time series command in Stata 11 (xtpcse). A linear transformation of the variables was also tested but

[8] The most tragic loss of subway access is at the site of the World Trade Center, which has not had a subway station since the terrorist attacks in 2001. There is a new transit complex slated to open in 2015 at the site. There are other nearby subway stations on different lines that serve the area, however.

the transformation did not improve the fit of the model or significantly alter the effect sizes. Three models are shown. The first has residential densities as the dependent variable, the second has commercial densities as the dependent variable and the third has station densities as the dependent variable. In the latter model both lagged residential and commercial densities are included as explanatory variables. Otherwise commercial was omitted from residential analysis and vice versa.

The explanatory variables in the models include lagged variables that feature the densities from the previous period. These models are estimating to what extent the previous characteristics influence the new densities as opposed to new construction. For instance, residential densities in 1930 may have a larger impact on residential densities in 1940 than new subway construction between 1930 and 1940. Conversely, if the subway was built in response to residential demand new subway construction (and increased station densities) will be more dependent on residential densities from the previous period than the presence (or lack thereof) of stations in the previous period. The relationships tested here are used to determine which came first, land use densities or subway construction.

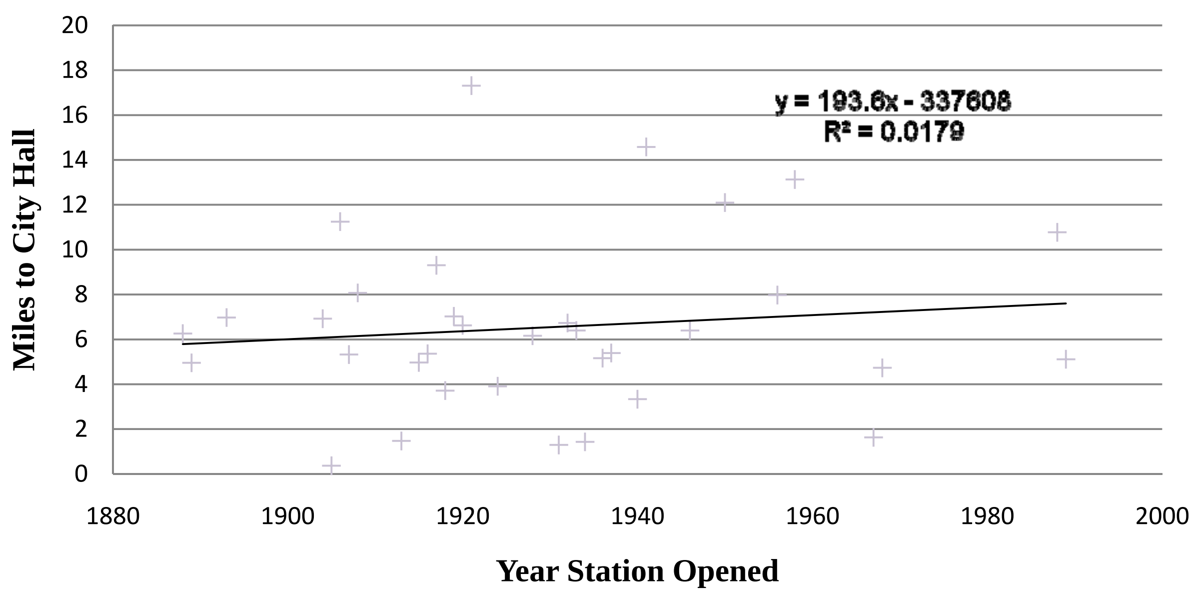
The distance from City Hall from each grid centroid is included as an explanatory variable under the assumption that the subway continued to grow outward to serve new populations. The City Hallis used as the proxy for the center as this station was where the first subway station opened and sits at the base of the Brooklyn Bridge in lower Manhattan.[9] The subway system was built radially outwards from lower and mid-Manhattan and even today it is difficult to use the subway to travel between the outer boroughs. The radial network features

[9] The City Hall subway station was originally opened as a demonstration of using pneumatic power to propel underground trains. The area near City Hall featured many elevated transit lines and other technologies that existed before the subway was built. The first line opened was the 1 which runs along Broadway and the west side of Central Park up into the Bronx.

extremely high station density in many areas of Manhattan and downtown Brooklyn and other lines that offer the only rail transit service in areas of Brooklyn, Queens and the Bronx. Yet there is no obvious correlation between the distance from downtown and the year the stations opened (Figure 3). There is a slight positive correlation between the year a station opened and its distance from City Hall as shown with the trend line, but this is a very weak relationship. What the figure shows is that the subway network was strengthening in areas near existing service rather than entering brand new areas.

Station effects are estimated using the density of stations in an area. As station density increases the overall accessibility of the area increases, which should result in greater intensity of development. More simply stated, a neighborhood with multiple stations is likely to have greater residential and commercial density than a neighborhood with a single station, thus station effects should be larger than distance effects.

Figure 3: Station Distance to City Hall by Year Opened



Data: New York City PLUTO, New York City Transit

Results

The results from the Granger models are shown in Tables 3-5. Table 3 shows the influences on residential lot densities. The lagged residential density (the value from the previous decade) has a strong positive effect on the estimated period densities while station density is not statistically significant and has a very small coefficient. This is also the case with distance from City Hall, which has no meaningful effect on residential densities. These results suggest that station density did not necessarily precede residential density. Rather, dense areas grew denser.

Table 3: Lagged influences on residential densities, 1910-2000

Observations	2777
Groups	320
R-squared	0.93
Wald chi-sq	2818.3

Dependent variable
Residential density$_{m,t}$

Variable	Coefficient	Standard Error	P-value
Residential density(t-1)	0.95	0.03	0.000
Average distance	2.91E-07	2.51E-07	0.248
Station density(t-1)	0.04	0.04	0.230
Constant	0.01	0.02	0.589

Table 4: Lagged influences on commercial densities, 1910-2000

Observations	2777
Groups	320
R-squared	0.9572

Wald chi-sq	654.19

Dependent variable
Commercial $density_{m,t}$

Variable	Coefficient	Standard Error	P-value
Commercial density(t-1)	1.02	0.05	0.000
Average distance	1.79E-07	2.39E-07	0.455
Station density(t-1)	-1.92E-03	0.01	0.763
Constant	0.01	0.01	0.399

Table 5: Lagged influences on station densities, 1910-2000

Observations	2777
Groups	320
R-squared	0.9403
Wald chi-sq	767.28

Dependent variable
Station $density_{m,t}$

Variable	Coefficient	Standard Error	P-value
Residential density(t-1)	0.19	0.07	0.007
Commercial density (t-1)	0.16	0.05	0.002
Average distance	5.28E-06	1.78E-06	0.003
Station density(t-1)	0.93	0.07	0.000
Constant	-0.04	0.02	0.031

Table 4 shows the results for commercial densities, and they are similar to those for residential densities. The lot density from the previous period is the best predictor of the estimated period density, and station density is a poor predictor. Taken together, Tables 3 and 4 suggest that the subway was not the primary influence on residential and commercial lot densities in the city.

Table 5 paints a somewhat different picture, as the lagged station density variable is statistically significant for predicting station density, though the lagged residential and commercial variables are also significant and positive, though with smaller coefficient s (.19 and .16, respectively) than station density. For residential intensities the lagged station density is not significant at all, nor is the lagged commercial variable. These results suggest that the subway network was growing denser. Rather than a network that relied on individual lines stretching far into the boroughs, the subway lines were built to serve the existing demand as well as serve new areas.

The models were re-estimated for the period 1910-1950 to gauge the effect that subway construction had on densities during the periods of rapid transit expansion, but these models did not meaningfully change the significance, effect size or direction of the explanatory lagged variables. This was a surprising result but one that strengthens the overall results that the subway system grew as a dense network which allowed for extremely intensive land uses in the areas that are well served.

From the estimates in tables 3 and 4 we see that station density at previous time periods are not a statistically significant predictor of residential and commercial densities. This runs counter from the expectations of the second hypothesis, which is that land development will be most intensive where station densities are most intensive. The durability of land uses has the largest effect on lot densities, and while the densest parts of the city are well-served by subways the model results shown here do not support the hypothesis. There are benefits to density that are not incorporated into the model and may help explain why residential and commercial densities are not predicted by subway station density. This also may be due to Type 1 error.

Conclusion

The historical development of the New York subway system involved two eras relevant to the hypotheses tested here. The first era of rapid subway growth, 1904-1950, successfully helped decentralize the population and led high density development. This is clearly seen in the correlation between station densities and land uses in Figure 2. Yet as the network grew denser as much as it grew outward the greatest land use intensities are in the areas best served by subway stations.

During the second era, 1951-1989, the subway network grew denser as new lines and stations opened in areas already partially served by the system. While the subway network was densifying, the city was also undergoing a transformation towards the automobile. Parkways and other new roads opened throughout the city, and many miles of Interstate freeways were built at the expense of neighborhoods in the south Bronx and elsewhere (Caro 1974). Yet even with the growth in auto travel in the city the residential and commercial densities has remained strongly correlated with subway station densities.

Two hypotheses were tested in this paper. The first was that the subway was guided development of residential development in order to decentralize and de-densify lower Manhattan. Certainly Manhattan became less dense, but this analysis demonstrates that transit providers pursued routes in areas where demand existed. Some of the centrifugal forces away from downtown were met by centripetal forces pushing development towards the transit system. Under these unique circumstances New York was able to reduce undesirable and density while creating development intensities that support major transit investment. Subway investment largely followed development, but once the subway network reached its full extent the correlation between densities and subway stations has only weakened slightly.

The second hypothesis tested is that development intensities increase where the subway station densities are greatest. It is empirically true that densities are greatest where station density is greatest, but there was weak evidence that station density was a causal factor for development density. This is not a shocking result based on the evidence that the subway followed development, but one that may be the result of exogenous factors not captured in the models or data.

In New York City subway development gained political and business support as a means of decentralizing population and commercial interests. Three potential explanations for why the transit and land use co-development were so successful. First, transportation technologies are a much more effective decentralizing force than a centralizing one. New transportation technologies lower the cost of travel and alter accessibility of areas. By starting from an extremely dense city, transit improvements were able to effectively redistribute existing ridership and demand rather than generate new demand. Second, New York grew substantially in population during the period of subway growth. Much of the growth in the city was from immigration, and the new growth was accommodated by the new system.[10] This means that redistributing the population was only part of the ridership base and new riders were able to maintain growth in the system. Third, land development was loosely regulated through the

[10] An interesting note for contemporary planning is that the population growth in the New York region in the 1990s and 2000s was accommodated by the transit system. Transit saw large gains in ridership while auto travel remained at the consistent levels.

zoning code. Developers were largely able to pursue speculative activities and could relatively easily receive variances to build denser or more intensively than allowed under law.

For current transportation and land use planning these are important qualifications. Susan Handy touches on these issues is her review of Smart Growth research (2005). She argues while many transit advocates argue that new rail investment will lead development, this is only the case when certain conditions are met. New York City met these conditions of regional growth and zoning that will accommodate dense development, but the city has stopped adding population and actively pursued auto-oriented policies that make it unlikely that it will ever replicate the transit-oriented growth of the past.

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