# Take the Q Train: Value Capture of Public Infrastructure Projects *

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**Abstract**

We analyze the impact of the Second Avenue Subway (Q-train) construction on local real estate prices, which capitalize the benefits of transit spillovers. We find evidence of higher real estate prices in the vicinity of areas served by the new Q-train, relative to other areas in Manhattan's Upper East Side. Only 30% of the private value created by the subway leads is captured through property taxes, and is insufficient to cover the cost of the subway. Value capture through targeted property tax increases can help close the funding gap.

**Keywords:** Public Finance, Land Value Taxation, Urban Development, Value Capture

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# 1 Introduction

The growth in major urban centers generates demand for infrastructure improvements, an important component of which is public transport infrastructure. However, the costs of building these urban public transportation improvements is high in the United States. Subway investments, which offer the prospect of carrying the most passengers in the densest locations, carry particularly large costs. Recent extensions of the 7 and the Q subway lines in New York City cost about $2.5 billion per mile of construction. These high costs make it essential to measure the benefits of additional subway construction in order to assess whether this construction is worthwhile.

Prior literature has documented several potential benefits of subway construction projects like the 2nd Avenue Subway (or Q-train), on which we focus our analysis. This line can be expected to improve access to workplaces and amenities due to shorter commuting times (Kahn and Baum-Snow, 2000, 2005; Severen, 2018). Improvements in commuting times itself can boost labor force participation, particularly among women (Black, Kolesnikova, and Taylor, 2014). Additionally, the reduced traffic congestion on roads and other public bus transportation lines can be expected to reduce pollution (Anderson, 2014). In our context, congestion on the 4-5-6 subway line which runs parallel to the newly constructed Q line can be expected to improve. Other associated benefits of transit linkages include less drunk driving (Jackson and Owens, 2011), improved retail, as well as noise and crime reductions around stations (Bowes and Ihlanfeldt, 2001). However, these diffuse and varied benefits are difficult to quantify, and so complicate a straightforward cost-benefit calculation. The public return to infrastructure investment, defined narrowly as the user fees net of operational expenditures and more broadly to include the incremental property, sales, and labor income tax revenues, captures only a part of the total benefit of infrastructure investment because it ignores these positive externalities the infrastructure generates for the private sector. A failure to appropriately account for these benefits will result in important infrastructure investments remaining unfunded.

Our analysis provides an alternate measure to assess the benefits of infrastructure improvements. We take the approach that real estate values in the vicinity of public transportation hubs capitalize the present value of all future benefits that accrue to households and business from transportation gains. To perform this calculation, we must measure how residential and commercial real estate asset values change after the extension of public transportation.

We focus on the 2nd Avenue Subway construction as it represents the most substantial investment in public subway infrastructure in the United States in the past several decades. We define geographical areas that are "treated" by the subway extension in three ways. Our baseline treatment definition considers the 2nd Avenue corridor. The second treatment is defined as the area within a 0.3 mile walking distance from one of the three new subway stops that were added as part of the expansion. The third treatment definition considers buildings whose distance to the nearest subway station on any subway line is reduced after the opening of the new 2nd Avenue subway stations. We compare the changes in real estate values in the treated areas with the changes in corresponding control areas on the Upper East Side in a difference-in-difference setup. Our analysis in the time-series accounts for both anticipatory effects of the construction, as well as the possible negative disamenities resulting from the construction process itself.

Our key result is that we find evidence that the construction of the 2nd Avenue Subway has had any measurable improvements in real estate values. Our benchmark difference-in-difference specification estimates a 10.8% increase in prices when comparing the ten years before 2013 to the 6 years after along the avenue corridor of the subway itself. Since the subway opened in 2017, this allows for substantial anticipation effects. Allowing for six additional years of anticipation effects during the construction phrase raises the estimate to 14.9%. We also estimate specifications which control more finely for building amenity effects through the use of building fixed effects or unit-specific characteristics through a repeat-sales approach. Though smaller, at 2–6% price increases, these estimates still suggest substantial value creation in the area around subway construction.

A key challenge with out identification approach is to identify the relevant set of properties which are potentially affected by the subway construction. Our baseline approach selects all properties between 59th street and 100th street, and between First and Third Avenues (the "2nd Avenue corridor") in comparison with all other properties on the Upper East Side. We conduct several robustness tests on our treatment definition, and find very comparable results. One alternate approach identifies the treatment area on the basis of walking distance to the new subway stops, using a 0.3mi walking distance limit to identify treated properties. This approach yields very comparable results, of price impacts between 4–8%. Another treatment definition focuses on the change in walking distance as a result of the subway construction, and so identifies several properties that are distant from the subway itself but experienced a gain in walking times. This definition, too, yields similar price effects of between 3–9%.

While our estimates are consistent with prior literature, as documented in the following section, we emphasize that these results suggest that a considerable component of the public investment in the subway system have accrued to private landlords and owners. To the extent that the property tax system is able to recoup some of these expenses, this provides a natural mechanism for local governments to finance these investments. However, there are good reasons to think that existing property tax systems will be incomplete. We show that the New York City property tax code only recuperates about 30% of market value increase in present value. As a result; though the subway itself generated more value than the already quite high cost of construction—this value is largely accruing to private landowners, rather than the city government.

This motivates the possibility for additional value capture taxes which may help recoup an additional component of the investment cost, and thereby make possible additional public infrastructure investments. Our findings, therefore, are quite policy relevant given ongoing debates in New York City on the future extension of the 2nd Avenue Subway line, the repair of the L line, and the East Side access. They also have ramifications for the broader debate on how to finance an upgrade to U.S. infrastructure assets and how to provide new infrastructure in developing countries whose governments have limited borrowing and taxation capacities. Given that infrastructure projects entail enormous expenditures of public resources, it is essential to have a full accounting of the total benefits resulting from these infrastructure expansions, which our work helps to provide.

## 2 Literature Review

Bom and Ligthart (2014) conduct a meta-regression analysis, summarizing decades of research measuring the effects of public infrastructure spending on economic output. The authors find that on average for the United States, a 1% increase in the public capital stock (about $134 billion in 2015) would increase private-sector economic output by 0.03% in the short term ($12.7 billion) and by 0.12% in the long term ($18.7 billion). The Congressional Budget Office estimates the effect of the same-size expansion at 0.06% ($9.2 billion). The literature finds a wide range of estimates for the return on infrastructure investment, depending on the assumptions made on the efficiency of an expansion of the public capital stock, the strength of the crowd-out effect on private investment, and the timing vis--vis the business cycle.

The literature tends to find modest to strong increases in the value of residential estate after the completion of transportation linkages. Recent studies have found price premiums for real estate surrounding transit hubs of between 2% and as much as 45% for residential and between 8% and 40% for commercial properties. In a study of San Jose, California, Cervero and Duncan (2002) find that commercial properties within 0.25-mile of a station that was part of the regional commuter system achieved $25 per square foot rental premiums. Hess and Almeida (2007) find a 2-5% premium, on average, for homes proximate to a light rail station in Buffalo, New York. Similar work in Chicago finds that prices of residential properties closer to a new rapid transit line appreciated approximately 7% more than properties further away during the period from 1986 to 1999 (McMillen and McDonald, 2004). Earlier work on Chicago is by McDonald and Osuji (1995) and more recent work by Diao, Leonard, and Sing (2017). The direct price effects of new subway stations have also been studied for Toronto (Dewees, 1976), Taipei (Lin and Hwang, 2004), and sixteen cities among which Atlanta, Boston, Chicago, Portland, and Washington DC by Kahn and Baum-Snow (2005). Other papers have examined the impacts of subway construction on the broader subway network. Fesselmeyer and Liu (2018) finds a 1.5-2% increase in real estate prices around pre-existing subway lines in Singapore, compared with 2-3.2% direct effects on the new lines.

A few studies have identified negative relationships between distance to transit stations and prices, based on the assumption that negative externalities of transit stations (e.g. crowding, noise, crime) are then reflected in lower relative real estate values (Bowes and Ihlanfeldt, 2001; Pan and Zhang, 2008).

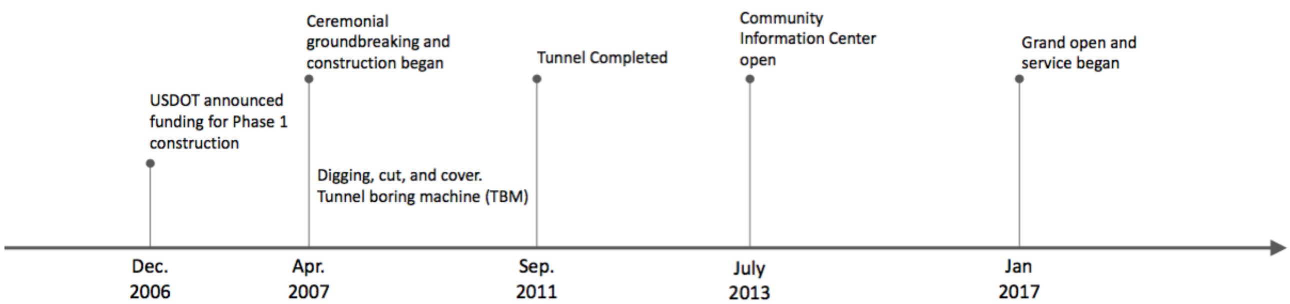
Our paper is the first to study recent subway expansion in New York City. As argued, this expansion was the most expensive per-mile expansion in U.S. transportation history. The urban density and pre-existing transportation network make for a different and interesting context, as does the interaction between the ownership market (condos and coops) and the rental market.

# 3 Background

Elevated rail lines were formerly running on 2nd and 3rd Avenues in New York, as a part of citywide system of "el" trains operated by privately managed and jointly funded companies. This network was gradually replaced with underground subways. A proposed 2nd Avenue Subway, in particular, was a major component of a proposed subway expansion as a part of a fully publicly owned and operated managed entity, the Independent Subway System (IND). Ultimately, the IND, along with two other private companies, were combined and placed under government control. The elevated 2nd and 3rd Avenue lines were torn down in anticipation of a new underground 2nd Avenue Subway. However, construction hit numerous difficulties across several decades, including the Great Depression, World War II, and the NYC funding crisis in the 1970s.

The most recent, and successful, period of construction on the 2nd Avenue Subway

Figure 1: Time Line of Construction




is highlighted in Figure 1. MTA approval for the subway and funding for design and engineering began in 2000, while a bond issue for its funding was approved in 2005. Crucially, the Department of Transportation authorized funding for Phase 1 construction in 2006. This was followed by the beginning of construction in 2007. Construction of the subway tunnel was completed in 2011. By 2013, it was clear that the end of construction was on the horizon and a Community Information Center was opened. The grand opening of the subway was on January 1, 2017. The three new Q-line stops have been in operation since that date.

Figure 2 highlights the subway line itself in the context of the local area. The Q line runs for 8.5 miles, including the 1.8 mile stretch of the completed Phase 1 2nd Avenue Subway extension between 59th Street and 96th Street. The construction included three new subway stations on 2nd Avenue at 72nd Street, 86th Street, and 96th Street.

# 4 Empirical Specification

One key empirical challenge is that the value of real estate depends on a myriad of factors beyond the opening of a new subway line. Other changes in the local economic environment may confound the effects from the transit improvements on real estate values. To

Figure 2: Subway Map on the Upper East Side of Manhattan


address this challenge, we propose a differences-in-differences analysis, comparing valuations on the 2nd Avenue corridor before and after the subway extension, relative to outcomes in a control group.

In our baseline specification, we define the treatment group to be all the land parcels between 59th street and 100th street and between First Avenue and Third Avenue, taking the midpoint of the avenues as the demarcation line. This is what we call the 2nd Avenue corridor. Our control group consists of three corridors that make up the rest of the Upper East Side. The Lexington Avenue corridor is the collection of parcels between 59th street and 100th street and between Third and Park Avenues. The Madison Avenue corridor is the collection of parcels between 59th street and 100th street and between Park and Fifth Avenues. Finally, the York Avenue corridor is the collection of parcels between 59th street and 100th street to the East of the midpoint of First Avenue. Because of the geography of Manhattan, this is a smaller area.

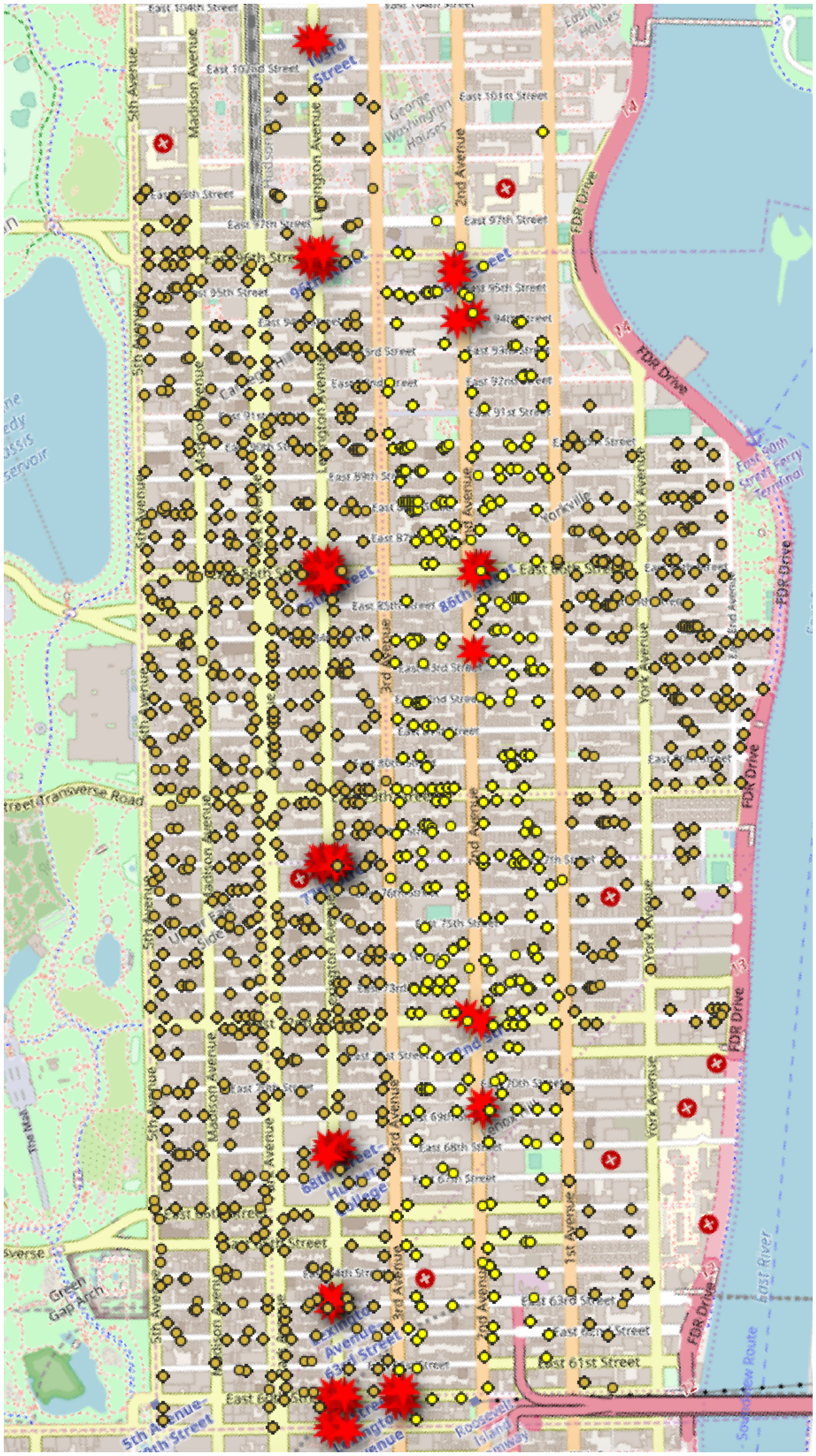
This choice of baseline treatment and control group is driven by a trade-off between minimizing the treatment effect on the control group and maximizing the similarity in terms of common drivers of real estate valuations. By differencing out trends in real estate values in the control group, we remove common drivers in real estate value that affect the entire area (Upper East Side) and are left with the pure effects of the subway extension. The Lexington Avenue corridor is geographically the closest to the 2nd Avenue and may be affected the strongest by the neighborhood trends that affect real estate valuation on 2nd Avenue other than the subway extension. However, the Lexington Avenue control group may also be directly affected by the subway extension. Residents in the Lexington corridor benefit from the new subway line, either because it directly shortens their commutes or because it alleviates congestion on the 4-5-6 subway line, which runs under Lexington avenue and parallel to the Q line. The resulting improvement in transportation from the 2nd Avenue subway extension would support real estate values in the Lexington Avenue corridor. Removing those effects would tend to bias downward our estimate of the value created by the subway extension. A countervailing effect that would tend to bias our treatment effects estimation upward is that the subway expansion may have made 2nd Avenue more competitive in terms of attracting residential, retail, and other commercial tenants away from Lexington Ave.

Residents living in the York Avenue corridor also potentially benefit from the Q line extension. Indeed, for most of them, the new 2nd Avenue subway stations are the closest ones. We consider York Avenue corridor residents to be in the control group in our baseline specification because they are fairly far from the new subway stations, but study different treatment definitions below where this group is part of the treatment group.

Figure 3 indicates the buildings where we have at least one apartment transaction in our sample. Apartments in treated buildings are colored in bright yellow while buildings in the control sample are in light yellow. The large stars indicate subway stations (and all their entrances), including the three new stops on the 2nd Avenue subway.

A second important research design question is when to draw the demarcation line between the before and after period. The subway went into operation on January 1st, 2017. While there was considerable uncertainty about the exact opening date until the last minute, eventual project completion was long anticipated. Construction started in April 2007. In 2011, the original 2013 completion date was pushed back to December 2016. Tunnel excavation began in May 2010 and blasting concluded in March 2013. Forward-looking developers and property owners willing to tolerate the inconvenience of the construction project could capture some of the potential future benefits by acting prior to the subway opening. These anticipatory effects may be reflected in real estate prices, which are forward looking in that they reflect the discounted value of future rents. In our benchmark analysis, we strike a middle ground and take January 1st 2013 as the demarcation line between the before and after. This allows for four years of anticipation effects prior to the inauguration of the new subway line. A subway community information center was opened in the middle of 2013, signaling that project completion itself was no longer

Figure 3: Map of Baseline Treatment and Control



in doubt. This choice also provides a large enough sample in the before and after period. This specification can be expressed as:

$$\ln(y_{it}) \quad = \quad \alpha + \gamma_1 \cdot \text{Treatment}_{it} + \delta_1 \cdot \text{Post}_{it} + \beta_1 \cdot \text{Treatment} \times \text{Post}_{it} + \boldsymbol{X}'_{it} \cdot \theta + \varepsilon_{it}$$

In which $y_{it}$ reflects the sale price of a unit $i$ in period $t$ in real terms. The key parameter of interest is $\beta_1$, which corresponds to the relative price increase on properties in the treatment definition (for instance, the 2nd Avenue corridor), in the period 2013-2018.

To investigate the presence of additional anticipation effects, several empirical specifications split the "Pre" period into January 2003-December 2006 and January 2007-December 2012. We call the latter period the Construction Period. In those specifications, real estate prices in the Construction and Post periods are estimated relative to the omitted 2003-06 period. This specification can be expressed as:

$$\begin{aligned}\ln(y_{it}) \quad &= \quad \alpha + \gamma_1 \cdot \text{Treatment}_{it} + \delta_1 \cdot \text{Post}_{it} + \beta_1 \cdot \text{Treatment} \times \text{Post}_{it} + \boldsymbol{X}'_{it} \cdot \theta \\ &+ \quad \delta_2 \cdot \text{Construction Period}_{it} + \beta_2 \cdot \text{Treatment} \times \text{Construction Period}_{it} + \varepsilon_{it}\end{aligned}$$

The additional parameter of interest is $\beta_2$, which corresponds to the relative price increase in the construction period (2007-12) relative to the earlier period (2003-06); which is a period why may incorporate anticipatory price effects or disamenity effects resulting from the construction itself.

The controls $\boldsymbol{X}$ include: indicators for condo and studio, the year built, number of bedrooms, floor, walking distance to Grand Central, walking distance to Central Park; as well as indicators if these variables are missing. In our repeat-sale specification, we subset on transactions which have a prior sale, and include the log sale amount of the prior sale as an additional covariate.

# 5 Data

For the purposes of our project, we build a new data set of all residential transactions on New York City's Upper East Side from January 2003 until March 2019. The two primary data sources are the New York City deeds records and StreetEasy. The deeds records have information on the the sale price, sale date, address, as well as a tax ID (the BBL code). From StreetEasy we collect information on all past residential real estate sales on the Upper East Side via web scraping. We add properties between 96th Street and 100th Street, which StreetEasy considers to be part of East Harlem. We also eliminate properties that are above 100th Street along Fifth Avenue, which StreetEasy considers to be part of the Upper East Side. StreetEasy has apartment unit and building characteristics, which are absent in the deeds records.

We obtain the exact address of the building, latitude and longitude, apartment unit name (e.g. 17A), the number of bedrooms, number of bathrooms, an indicator variable for condo, an indicator variable of coop, an indicator variable for studio, the square footage of the unit, the year of construction of the building, the transaction date, and the transaction price. We infer the floor of the unit based on the apartment unit name. There is also a text field describing the transaction in more detail.

We only use transactions of condo and co-op units. We eliminate transactions that are commercial space, storage units, maid's rooms, parking spots, garage based on the text field. We eliminate units that have zero bathrooms and zero bedrooms but are not studios. Importantly, we remove all "sales" which are neither reported as "sold" nor as "closing registered." Cross-checking against the deed records database indicates that these "sales" are not sales but merely removed listings.

We express all transaction prices in real terms by scaling by the Consumer Price Index based in December 2017. We then eliminate all transactions with a real price below $100,000 and above $10 million. Transactions below $100,000 (in 2017 dollars) are unlikely to be arms-length transactions for actual apartment units. Transactions above $10 million are unlikely to be affected by the 2nd Avenue subway and will distort sample averages. The final sample contains 51,770 transactions.

Table 1 illustrates basic summary statistics from our data. The top panel reports properties on the 2nd Avenue Corridor, which are treated according to our baseline treatment area definition. The bottom panel reports properties in the baseline control group (Madison Ave, Lexington Ave, and York Ave corridors). We have 20,813 sales in the treatment group and 30,957 in the control group, so that 40.2% of transactions are treated observations.

The average property on 2nd Ave costs $1.11m, is about 1034 square feet large, costs $1067 per sqft, has 1.5 bedrooms bathrooms, and is in a building that is 46 years old at the time of transaction. The treatment group has 40% condos and 60% coops. Buildings in the control group cost substantially more. The typical sale price is $1.86mi or $1,244 per sqft, are 200 sqft larger, have 1.8 bedrooms and 1.8 bathrooms, and are older (59 years). There is a smaller fraction of studios (7% vs. 12%), while the condo-coop breakdown tilts more towards coops at 30%-70%.

Our difference-in-difference analysis accounts for the level differences in prices across the two sets of properties. However, if there are changes over time in property charac-

Table 1: Summary Statistics

*Panel A: Treatment Group*

| | N | Mean | St.Dev | p1 | p25 | p50 | p75 | p99 |
|---|---|---|---|---|---|---|---|---|
| saleprice | 20813 | 1110000 | 1050000 | 190000 | 512000 | 767000 | 1300000 | 5660000 |
| sqft | 14009 | 1033.931 | 585.9456 | 392 | 670 | 857 | 1250 | 3141 |
| ppsf | 14009 | 1066.764 | 444.6545 | 333.6384 | 780.7929 | 978.4375 | 1284.618 | 2451.471 |
| bedrooms | 20793 | 1.473 | 1.006 | 0 | 1 | 1 | 2 | 4 |
| bathrooms | 20193 | 1.517 | 0.851 | 1 | 1 | 1 | 2 | 5 |
| condo | 20813 | 0.395 | 0.489 | 0 | 0 | 0 | 1 | 1 |
| coop | 20813 | 0.605 | 0.489 | 0 | 0 | 1 | 1 | 1 |
| studio | 20813 | 0.123 | 0.329 | 0 | 0 | 0 | 0 | 1 |
| building age | 20807 | 46.08 | 24.315 | 1 | 29 | 45 | 57 | 105 |
| vintage2 | 20813 | 0.055 | 0.227 | 0 | 0 | 0 | 0 | 1 |
| closest pre | 20813 | 0.324 | 0.114 | 0.057 | 0.245 | 0.313 | 0.395 | 0.551 |
| closest post | 20813 | 0.184 | 0.084 | 0.007 | 0.115 | 0.186 | 0.247 | 0.364 |
| dist change | 20813 | 0.14 | 0.129 | 0 | 0.01 | 0.112 | 0.252 | 0.429 |
| treat2 | 20813 | 0.805 | 0.396 | 0 | 1 | 1 | 1 | 1 |
| treat3 | 20813 | 0.787 | 0.409 | 0 | 1 | 1 | 1 | 1 |
| treat4 | 20813 | 0.726 | 0.446 | 0 | 0 | 1 | 1 | 1 |

*Panel B: Control Group*

| | N | Mean | St.Dev | p1 | p25 | p50 | p75 | p99 |
|---|---|---|---|---|---|---|---|---|
| saleprice | 30957 | 1860000 | 1800000 | 204000 | 654000 | 1200000 | 2360000 | 8740000 |
| sqft | 16524 | 1269.866 | 811.7698 | 382 | 730 | 1052 | 1590.5 | 3920 |
| ppsf | 16524 | 1244.108 | 614.8637 | 322.5515 | 838.8815 | 1099.734 | 1474.1 | 3385.767 |
| bedrooms | 30918 | 1.882 | 1.094 | 0 | 1 | 2 | 2.431 | 5 |
| bathrooms | 30010 | 1.849 | 1.039 | 1 | 1 | 1.5 | 2.5 | 5 |
| condo | 30957 | 0.307 | 0.461 | 0 | 0 | 0 | 1 | 1 |
| coop | 30957 | 0.693 | 0.461 | 0 | 0 | 1 | 1 | 1 |
| studio | 30957 | 0.069 | 0.253 | 0 | 0 | 0 | 0 | 1 |
| building age | 30949 | 59.137 | 27.944 | 1 | 42 | 56 | 84 | 109 |
| vintage2 | 30957 | 0.041 | 0.198 | 0 | 0 | 0 | 0 | 1 |
| closest pre | 30957 | 0.343 | 0.223 | 0.022 | 0.162 | 0.282 | 0.503 | 0.851 |
| closest post | 30957 | 0.265 | 0.143 | 0.022 | 0.158 | 0.245 | 0.357 | 0.603 |
| dist change | 30957 | 0.077 | 0.127 | 0 | 0 | 0 | 0.13 | 0.429 |
| treat2 | 30957 | 0.22 | 0.414 | 0 | 0 | 0 | 0 | 1 |
| treat3 | 30957 | 0.342 | 0.474 | 0 | 0 | 0 | 1 | 1 |
| treat4 | 30957 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

teristics of transacted properties which differ between treatment and control group, then that could affect the estimate of the subway extension. Therefore, our main specifications will control for property characteristics. We focus on whether we observe convergence in prices. If the value gap for the 2nd Avenue Corridor is driven by scarce access to public transportation options, we expect price convergence after subway construction.

# 6 Results

## 6.1 Corridors: Baseline Treatment and Control

Table 2 highlights our main effects. Recall that our estimation follows a difference-in-difference specification. The dependent variable is the natural log of the real sale price for apartment units including condos and coops. The key independent variables are the difference-in-difference interactions. The Post variable captures the price impact after January 2013, and so accounts for any general time-series increase in price; relative to the entire pre-period of January 2003-December 2012. Our specifications suggest that these time trends are generally important. In column 1, for instance, the coefficient on Post is 0.0895, suggesting that the post-period is associated with log prices that are higher by nearly 9% in real terms on average. This variable accounts for the general increase in valuation of UES apartments. Comparably, the treatment coefficient captures the value differential associated with being "On 2nd Avenue" in general. As discussed in the data section, this effect is quite negative. Properties in the 2nd Avenue corridor generally transact for 47% less than properties in the control group, i.e, in the rest of the Upper East Side, without considering additional controls.

Table 2: Main Difference-in-Difference Results - Baseline Treatment Definition

| VARIABLES | (1) Log Price | (2) Log Price | (3) Log Price | (4) Log Price | (5) Log Price |
|---|---|---|---|---|---|
| Post x On 2nd Ave | 0.143*** | 0.108*** | 0.0480*** | 0.149*** | 0.0636*** |
| | (0.0151) | (0.00976) | (0.00852) | (0.0115) | (0.0102) |
| Constr. Period x On 2nd Ave | | | | 0.0844*** | 0.0296*** |
| | | | | (0.0117) | (0.0102) |
| Post | 0.0895*** | 0.105*** | 0.110*** | 0.169*** | 0.168*** |
| | (0.00965) | (0.00624) | (0.00538) | (0.00739) | (0.00642) |
| On 2nd Ave | -0.470*** | -0.236*** | | -0.278*** | |
| | (0.00910) | (0.00610) | | (0.00866) | |
| Constr. Period | | | | 0.116*** | 0.104*** |
| | | | | (0.00739) | (0.00643) |
| Observations | 51,770 | 51,770 | 51,770 | 51,770 | 51,770 |
| R-squared | 0.068 | 0.612 | 0.738 | 0.617 | 0.741 |
| Controls | NO | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | YES |

*Notes:* Post is an indicator variable for the period after January 1st 2013. Constr. Period is an indicator variable for the construction period between January 1st 2007 and December 31, 2012. On 2nd Ave is an indicator variable for a unit located in the Second Avenue Corridor as defined in the main text. Controls include: an indicator variable for a condo transaction; an indicator variable for a studio; number of bedrooms; number of bathrooms; the floor of the building; the year of construction; distance to Central Park; distance to Grand Central Terminal; as well as indicators if the control variables are missing. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Our key variable of interest is the interaction variable of Post × On 2nd Ave. This captures the differential price impact of being on the 2nd Ave corridor after 2013, the time period when subway completion was either imminent or achieved. This period captures at least some of the anticipatory effects of subway completion on real estate values, namely those between January 1st 2013 and subway opening on January 1st of 2017. It also contains the subsequent price effects in 2017, 2018, and the first quarter of 2019. The coefficient on the interaction term in column 1 suggests that the 2nd Avenue Subway resulted in a statistically significant price rise of 14.3% for properties transacting on the avenue. This number is in line with the estimates from the literature discussed above and suggests that the construction of the subway was associated with a substantial increase in value. In other words, we observe convergence in prices. Subway construction closes nearly 1/3 of the gap in valuations between the 2nd Ave corridor and the rest of the Upper East Side.

This treatment effect persists in column 2, in which we add a number of important controls to account for the differences in property characteristics documented above. Controls include an indicator variable for a condo transaction; an indicator variable for a studio; number of bedrooms; number of bathrooms; the floor of the building; the year of construction; distance to Central Park (an important recreational amenity); distance to Grand Central Terminal (an important central business district); as well as indicators if the control variables are missing. These control variables boost the $R^2$ value from 6.8% in column 1 to to 61.2% in column 2. The lower coefficient (in absolute value) of "On 2nd Ave" indicates that about half of the unconditional difference in valuations between the treatment and control group disappears once we control for characteristics. More importantly, the estimate of Post × On 2nd Ave remains large and precisely estimated at 10.8%. It indicates even faster convergence of property prices than in column 1: nearly 1/2 of the price difference between 2nd Ave properties and properties in the rest of the UES is eliminated around the time of subway completion.

One possibility is that there are additional property characteristics beyond those included in column 2, and unobserved to us, that matter for real estate values. If the prevalence or the valuation of such latent characteristics changes differentially for treatment and control groups, then we could incorrectly attribute to the second avenue subway construction what instead are compositional changes to the pool of units transacted. One conservative way of dealing with this concern is to include building fixed effects. We estimate such a specification in column 3 of Table 2.[1] This specification is comparing trans-

[1] The coefficient on the treatment variable itself is not separately identified from the building fixed effects so we drop it in the specifications with building fixed effects.

actions in the same building. Our sample is dominated by transactions in large buildings; 92% of observations are in buildings that contain at least five transactions in the Pre and at least five transactions in the Post period. Thus, we should have enough power to identify the building fixed effects accurately. Adding building fixed effects increases the $R^2$ to 73.8%. After controlling for building fixed effects, property values are 4.8% higher on second Avenue in the Post relative to the Pre period and relative to the control group. The estimate is significant at the 1% level and economically large.

## 6.2 Additional Anticipation Effects

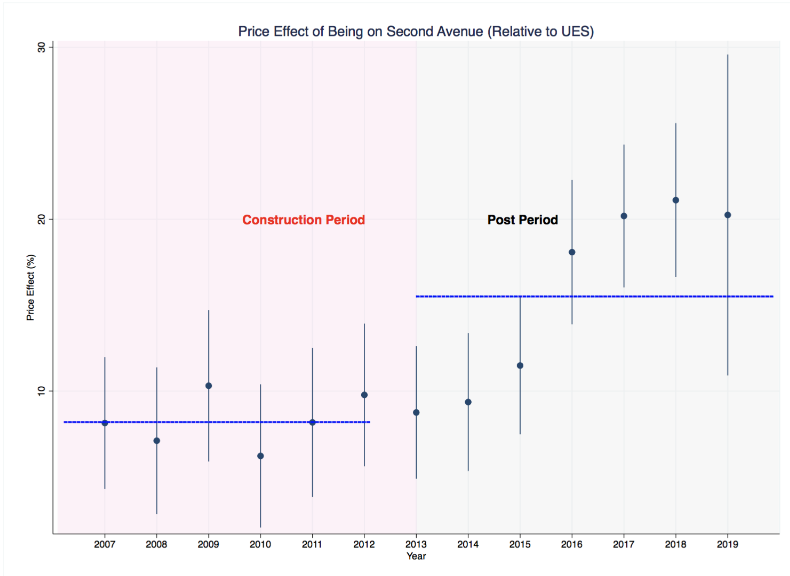
We consider the possibility of additional anticipation effects as far back as 2007 when the decade-long subway construction endeavor first got under way. We include an indicator variable "Constr. Period" which takes the value of 1 for transactions between January 2007 and December 2012, allowing for six more years of potential anticipation effects. This being also the period of heaviest construction, it is plausible that this period experienced a reduction in property values due to disamenities (noise, pollution, closure of retail) related to the construction activity itself. The interaction effect of Constr Period $\times$ On 2nd Ave estimates the net effect of additional anticipation and disamenities on prices in the 2nd Ave corridor, relative to the omitted category of 2003-06. The coefficient on Constr. Period itself shows the price impact associated with this period in general, relative to the omitted category of 2003-2006. Under this specification, the Post $\times$ On 2nd Ave coefficient measures the price change between the period 2013-2019 and the earlier period 2003-2006 (rather than relative to 2003-2012 in columns 1 and 2).

Column 4 of Table 2 shows that the construction period was associated with a substantial increase in real estate values in general on the Upper East Side. Prices were 11.6% higher in real terms in 2007-12 relative to 2003-06, after controlling for property characteristics. Properties on the 2nd Ave corridor appreciated by 8.4% relative to properties in the control group. The point estimate is statistically significant and demonstrates the presence of additional anticipation effects, strong enough to outweigh the disamenity effects from construction.

In the Post period, properties on 2nd Ave are 14.9% more valuable than in 2003-06, relative to the control group. In sum, subway construction triggered an initial appreciation of 8.4% in 2007-12 and a further appreciation of 6.5% (14.9%-8.4%) in 2013-2019.

Figure 4 illustrates this result graphically. It plots the coefficient estimates from a dynamic difference-in-differences specification, in which each calendar year is allowed to have its own treatment effect. Breaking up the baseline treatment effect year-by-year sug-

Figure 4: Dynamic Treatment Effects - Baseline Treatment




gests that we do not see an initial price effect in the years 2005–2007, our control period, in the treatment corridor. We begin to see positive price coefficients in our construction period of 2007–2012; and see even higher coefficients after the beginning of our "post" period from 2013 onwards. The sharp rise in 2013, at which point a community center was built and final construction seemed imminent, provides additional justification for our decision to use this year as the cutoff for the post period. This dynamic analysis further suggests that we see even higher estimates for 2017–2019, after the subway has become fully functional. At this point, prices appear to have stabilized and suggest that the market has largely priced in the subway construction impact.

In column 5 of Table 2, we add building fixed effects to the specification of column 4. The early anticipation effect is smaller at 3.0% but remains statistically different from zero. However, property values in the Post period remain 6.4% higher than in the 2003-06 period on 2nd avenue, compared to the control group. This is an economically and statistically significant difference.

## 6.3 Repeat Sales

In Table 3, we perform a repeat-sales analysis. This commonly used approach in real estate valuation compares the prices of properties with the previous price paid for the same property. It has the virtue of holding all else constant about properties, with the limitation that we are only able to analyze properties that do, in fact, repeatedly transact in this period. The analysis repeats the full-sample analysis on the subset of apartments that transacts at least twice.[2] In all, we have 17,810 repeat sales representing 34.4% of the total number of transactions.

The repeat-sales results in a smaller estimate of the treatment effect. The main specification in column 2, with controls included, results in a 3.5% value creation estimate from the subway extension, compared to a 10.8% effect for the full sample. Adding building fixed effects in column 3 lowers the point estimate on the interaction effect to 1.6%, compared to 4.8% for all transactions.

In column 4 we add the log real sale price of the previous transaction of the same unit, i.e., from the first leg of the repeat sale. The previous price helps control for apartment unit or building characteristics not already included in the control variables. The treatment effect attenuates further to 0.2% and is no longer significant. One explanation for the attenuation after including the lagged price is that unobserved building or apartment characteristics upwardly biased the treatment effect in column 2. Note however, that these missing characteristics would have had to differentially impact valuations in the treatment and control groups after 2013 relative to before 2013. For example, if there are more swimming pools in buildings on 2nd Ave after 2013 than before 2013, but no change in swimming pools for the control group, then the estimated relative value creation on 2nd Ave could be due to swimming pools rather than to the subway. This is unlikely to be a concern for the repeat sales sample since we are effectively controlling for any fixed characteristics such as swimming pools by looking at sales of the same unit in the same pre-existing building. An alternative interpretation of the attenuation is that we are over-controlling by including lagged prices. Lagged prices could (partially) incorporate the value created by the subway extension. We would then be attributing to missing characteristics what is really a subway treatment effect. This concern is more severe the more recent is the previous transaction. Given the evidence we found for early anticipation effects, even repeat-sale transactions where the prior transaction took place as early as 2007 could suffer from the over-controlling problem.

Columns 5–7 revisit the breakdown of the Pre period into the (omitted) 2003-2006 and the construction period from 2007-2012. For this subsample of repeat sales, the early anticipation effect may well be the net effect of a strongly negative disamenity effect and

[2] When determining whether a transaction in our 2003-2019 data set is a repeat sale, we look for transactions in StreetEasy before January 2003 to avoid additional selection on properties that transact twice within the 2003-2019 time frame. Despite the limited data coverage prior to 2003, this results in several hundred additional repeat sales. Also, if a property is the subject of two (or more) repeat sales, both (all) repeat-sales transactions for which the second leg of the trade pair is in our sample period 2003–2019 enter the repeat sales subsample.

a modestly positive anticipation effect. The repeat-sale sample clearly suggests a stronger role for disamenities related to construction in the 2007-2012 period. The interaction effect Post x On 2nd Ave is 0.9% (insignificant) in column 5 and essentially zero in columns 6 and 7. In sum, relative prices for repeat sales on 2nd avenue fell from the baseline 2003-2006 period to the 2007-12 period, and then recovered in the 2013-19 period to 2003-06 levels. The same concern of over-controlling applies to the analysis in columns 5–7.

The complement of the repeat-sales subsample, namely units that transact only once in the sample, shows much stronger price gains from subway construction than the full sample.

Table 3: Repeat Sales Subsample - Baseline Treatment Definition

| VARIABLES | (1)<br>Log Price | (2)<br>Log Price | (3)<br>Log Price | (4)<br>Log Price | (5)<br>Log Price | (6)<br>Log Price | (7)<br>Log Price |
|---|---|---|---|---|---|---|---|
| Post x On 2nd Ave | -0.00353 | 0.0352*** | 0.0159 | 0.00182 | 0.00971 | -0.00694 | -0.0188 |
| | (0.0223) | (0.0128) | (0.0113) | (0.00951) | (0.0179) | (0.0164) | (0.0133) |
| Constr. Period x On 2nd Ave | | | | | -0.0327* | -0.0295* | -0.0337** |
| | | | | | (0.0189) | (0.0166) | (0.0141) |
| Post | 0.0386*** | 0.111*** | 0.111*** | 0.0320*** | 0.207*** | 0.182*** | -0.0176* |
| | (0.0147) | (0.00853) | (0.00752) | (0.00636) | (0.0124) | (0.0111) | (0.00939) |
| On 2nd Ave | -0.348*** | -0.183*** | | -0.0530*** | -0.158*** | | -0.0302*** |
| | (0.0157) | (0.00915) | | (0.00687) | (0.0155) | | (0.0116) |
| Constr. Period | | | | | 0.135*** | 0.0973*** | -0.0663*** |
| | | | | | (0.0129) | (0.0112) | (0.00971) |
| Lagged Log Sale Price | | | | 0.587*** | | | 0.600*** |
| | | | | (0.00487) | | | (0.00498) |
| Observations | 17,810 | 17,810 | 17,810 | 17,810 | 17,810 | 17,810 | 17,810 |
| R-squared | 0.053 | 0.690 | 0.802 | 0.830 | 0.693 | 0.803 | 0.831 |
| Controls | NO | YES | YES | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | NO | YES | NO |

*Notes:* Post is an indicator variable for the period after January 1st 2013. Constr. Period is an indicator variable for the construction period between January 1st 2007 and December 31, 2012. On 2nd Ave is an indicator variable for a unit located in the Second Avenue Corridor as defined in the main text. Control variables are the same as in Table 2. Standard errors are in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

## 6.4 New Buildings

One possibility is that the subway extension had different effects on newer buildings. We define newer buildings to be those constructed after January 2003. The variable "vintage2" in Table 1 shows that 5.5% of units transacted in the treatment group are in newer buildings compared to 4.1% in the control group.

Table 4 estimates the triple interaction effect Post x On 2nd Ave x Vintage2. We find a 13.1% larger appreciation for units in newer buildings in the treatment area after subway construction than for older buildings. The appreciation is 9.9% for older buildings and 23.0% for newer buildings. The additional 13.1% is precisely estimated despite the relatively small share of transactions in buildings built after 2003.

Table 4: Heterogeneous Treatment for New vs. Old Buildings

| VARIABLES | (1)<br>Log Price |
|---|---|
| Post x On 2nd Ave | 0.0989*** |
| | (0.00987) |
| Post x On 2nd Ave x Vintage 2 | 0.131*** |
| | (0.0350) |
| Post x Vintage 2 | -0.227*** |
| | (0.0293) |
| Post | 0.114*** |
| | (0.00630) |
| On 2nd Ave | -0.232*** |
| | (0.00606) |
| Vintage 2 | 0.381*** |
| | (0.0151) |
| Observations | 51,770 |
| R-squared | 0.617 |
| Controls | YES |
| Building FE | NO |

*Notes:* "Vintage2" is an indicator variable which is 1 for units in buildings constructed in 2003 or later and zero otherwise. All other variables are as in Table 2. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

## 6.5 Unpacking the Control Group

In Table 5, we revisit our main specification but unpack the control group into its constituent corridors. Since the omitted corridor is the Madison Ave corridor (spanning from Fifth Ave to Park Ave), all changes are measured relative to the Madison Ave corridor. Since this corridor is the farthest removed from the 2nd Ave subway and since it contains very wealthy residents unlikely to use public transportation, this is a natural choice for the omitted category. We continue to see our main treatment effect: prices appreciated by 11.0% more in the 2nd Ave corridor in the Post period relative to the Madison Ave corridor. In contrast, we see no change for the Lexington Ave corridor and a small (and statistically imprecisely estimated) change for the York Ave corridor. This justifies our choice of combining Madison, Lexington, and York Ave corridors in the control group. Column 1 also shows that property prices on 2nd Ave were the lowest in the pre period, followed by York Ave, Lex Ave, and Madison Ave. The null effect on Lexington Ave suggests that the potential benefits from reducing congestion on the 4-5-6 line did not materialize, or were offset by increased by reductions in prices due to increased competition in the real estate market on 2nd Ave.

Column 2 shows a strong 15.2% capital gain on 2nd Ave, relative to Madison Ave and relative to the pre-construction era of 2003-06. The gain of 8.7% in the construction period again underscores early anticipation effects. Lexington Ave shows no change in either period, relative to Madison. In contrast, property prices on York Ave appreciate in the 2007-12 period relative to Madison Ave (3.7%). The area continued to improvement relative to Madison in the Post period so that prices caught up further (4.9%). This suggests that York Ave may have been at least partially affected by the subway extension. We study this possibility in detail below.

Table 5: Unpacking the Control Group

| VARIABLES | (1)<br>Log Price | (2)<br>Log Price |
|---|---|---|
| Post x On 2nd Ave | 0.110*** | 0.152*** |
| | (0.0141) | (0.0165) |
| Post x On Lexington Ave | -0.0125 | -0.0245 |
| | (0.0156) | (0.0184) |
| Post x On York Ave | 0.0295* | 0.0492*** |
| | (0.0158) | (0.0186) |
| Constr. Period x On 2nd Ave | | 0.0874*** |
| | | (0.0166) |
| Constr. Period x On Lexington Ave | | -0.0215 |
| | | (0.0184) |
| Constr. Period x On York Ave | | 0.0373** |
| | | (0.0185) |
| Post | 0.102*** | 0.162*** |
| | (0.0119) | (0.0141) |
| On 2nd Ave | -0.534*** | -0.574*** |
| | (0.0130) | (0.0156) |
| On Lexington Ave | -0.257*** | -0.243*** |
| | (0.0105) | (0.0144) |
| On York Ave | -0.432*** | -0.447*** |
| | (0.0185) | (0.0207) |
| Constr. Period | | 0.110*** |
| | | (0.0139) |
| Observations | 51,770 | 51,770 |
| R-squared | 0.619 | 0.624 |
| Controls | YES | YES |
| Building FE | NO | NO |

*Notes:* "Post" is an indicator variable for the period after January 1st 2013. "Constr. Period" is an indicator variable for the construction period between January 1st 2007 and December 31, 2012. "Within .3 Miles" is an indicator variable which is 1 for a transaction located within 0.3 miles of one of the three new subway stations on the Second Avenue subway and 0 otherwise. Controls include: an indicator variable for a condo transaction; an indicator variable for a studio; number of bedrooms; number of bathrooms; the floor of the building; the year of construction; distance to Central Park; distance to Grand Central Terminal; as well as indicators if the control variables are missing. Standard errors in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

# 7 Alternative Treatment Definitions

## 7.1 Distance to New Stations

One drawback of our baseline definition of treatment is that we assume that all properties along the 2nd Avenue Corridor are equally treated by new subway construction. This may not be the case if areas far from the subway stops, along 2nd Ave, do not find much of a benefit from using the new subway. To analyze this possibility, we consider a second treatment definition which includes all properties which are within 0.3 miles of one of the three new 2nd Avenue subway stops. Distance is defined by walking distance as calculated by Google Maps.[3] If these are the properties which benefit the most from the subway construction, they should expect the greatest property price appreciation. But, it is also possible that the disamenities during the construction period were greatest close to the subway stops.

Table 1 refers to this alternative treatment definition as "treat2". It shows that 51.7% of the transactions on the 2nd Avenue corridor and 16.8% of the transactions in the Madison, Lexington, and York Ave corridors fall within 0.3 miles of one of the new subway stations. In other words, this treatment is strongly but not perfectly correlated with our baseline treatment. Figure 5 shows the treated and control buildings. The 0.3-mile distance requirement draws diamond-shaped areas around the three new subway stations.

Table 6 revisits our main difference-in-differences estimation for this alternative treatment definition. The structure of this table is identical to that of Table 2 for the baseline treatment definition based on the corridors. In our favorite specifications in columns 2 and 3, we find a strongly positive and statistically significant increase in value due to the subway for those properties that are within 0.3 miles of one of the three new Q-line stations. The headline increase is 8.1% while the increase with building fixed effects is 3.9%. The comparable numbers for the baseline treatment were 10.8% and 4.8%. This comparison suggests that properties in the 2nd Avenue corridor that are not within 0.3 miles from a new station benefitted slightly more from the subway than properties in the Lexington Ave or York Ave corridors that are within 0.3 miles of a new station.

Columns 4 and 5 suggest that the value gain in the Post period reflects the continuation from a relative appreciation during the construction period. Prices in the treatment area appreciated by 11.9% (5.8%) more than the control group, relative to the 2003-06 period, in the specification without (with) fixed effects.

[3]For each one of our buildings, we feed in the street address into the Google Maps API and obtain the distance to each subway station entrance (multiple per station) on the Upper East Side, to Central Park, and to Grand Central Terminal.

Table 6: Treatment Based on Distance to New Stations

| VARIABLES | (1) Log Price | (2) Log Price | (3) Log Price | (4) Log Price | (5) Log Price |
|---|---|---|---|---|---|
| Post x Within .3 Miles | 0.0615*** | 0.0813*** | 0.0394*** | 0.119*** | 0.0579*** |
| | (0.0151) | (0.00971) | (0.00838) | (0.0115) | (0.00999) |
| Constr. Period x Within .3 Miles | | | | 0.0705*** | 0.0325*** |
| | | | | (0.0116) | (0.0100) |
| Post | 0.113*** | 0.109*** | 0.111*** | 0.176*** | 0.167*** |
| | (0.0102) | (0.00657) | (0.00566) | (0.00776) | (0.00673) |
| Within .3 Miles | -0.351*** | -0.155*** | | -0.193*** | |
| | (0.00905) | (0.00599) | | (0.00859) | |
| Constr. Period | | | | 0.123*** | 0.101*** |
| | | | | (0.00783) | (0.00674) |
| Observations | 51,770 | 51,770 | 51,770 | 51,770 | 51,770 |
| R-squared | 0.045 | 0.605 | 0.738 | 0.611 | 0.740 |
| Controls | NO | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | YES |

*Notes:* "Post" is an indicator variable for the period after January 1st 2013. "Constr. Period" is an indicator variable for the construction period between January 1st 2007 and December 31, 2012. "Within .3 Miles" is an indicator variable which is 1 for a transaction located within 0.3 miles of one of the three new subway stations on the Second Avenue subway and 0 otherwise. Controls include: an indicator variable for a condo transaction; an indicator variable for a studio; number of bedrooms; number of bathrooms; the floor of the building; the year of construction; distance to Central Park; distance to Grand Central Terminal; as well as indicators if the control variables are missing. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p/<0.1.

Further investigation, reported in Appendix Table 10, breaks down the treatment group into units that are between 0 and 0.10 miles, between 0.10 and 0.20 miles, and between 0.20 and 0.30 miles from a new Q-line station. The 8.1% price gain in the main specification (column 2) results from a large and precisely estimated gain of 8.2% in properties between 0.2 and 0.3 miles away from the station, and a zero gain closer by (the 2.0% gain in the 0-0.1 mile ring is not significant). This analysis also shows a price depression closest to the station during the construction period. This is exactly where we expect the disamenities from construction to show up. In sharp contrast, prices in the 0.2-0.3 mile ring appreciate 7.7% during the construction period and an additional 4.3% (for a total effect of 12.0%) in the Post period.

## 7.2 Closest Subway Station Becomes Closer

We explore an additional alternative treatment definition which places greater weight on peripheral properties which experienced possibly large gains in transit access. For every apartment in our sample, we compute the distance to the nearest subway station on any line serving the Upper East Side, both before and after the addition of the three stations on the Second Avenue subway line (8 stations in total). Distance is calculated as walking distance based on Google Maps. We calculate the reduction in distance to the nearest subway station entrance triggered by the opening of the three new Q-line stations.

Table 1 reports that for the average unit in the 2nd Ave corridor, the closest station was 0.324 miles away before the Q-line extension and 0.184 miles after, for an average distance reduction of 0.14 miles (225 meters). For the residents of the other three corridors, the average reduction was smaller at 0.077 miles (124 meters). The latter is the combination of a zero reduction for all residents of the Madison corridor and most residents of the Lexington corridor, on the one hand, and a large reduction for the residents on the York Ave corridor, on the other hand. We define an apartment as treated if there is a strictly positive distance reduction to the nearest subway station on the Upper East Side. Table 1 refers to this alternative treatment definition as "treat3". It shows that 78.7% of the transactions in the 2nd Avenue corridor and 34.2% of the transactions in the Madison, Lexington, and York Ave corridors are in a building which experiences a change in distance to the nearest station. Again, this treatment is strongly but not perfectly correlated with our baseline treatment. Figure 6 shows the treated and control group buildings according to this second alternative treatment definition. The largest change with the baseline and the first alternative treatment is that all properties east of Second Avenue are now treated.

Table 7 shows the difference-in-difference estimates. For our main specifications in columns 2 and 3, we find a similar effect from the subway extension: 9.0% without and 3.3% with building fixed effects. In columns 4 and 5 we find a significantly positive effect in the Construction period, and a continuation in the Post period. Prices in properties with an improvement in distance to the closest subway station end up 13.9% (5.4%) above 2003-06 levels in the specification without (with) building fixed effects.

Further investigation, reported in Appendix Table 11, breaks down the treatment group into units that experienced a reduction in distance (i) between 0 and 0.10 miles, and (ii) greater than 0.10 miles. The latter group consists mostly of units east of 2nd Ave. The 9.0% overall price effect is the average of estimated gains in the former group, and 5.7% in the latter group. While one might think that units experiencing a larger gain are "more intensively" treated, we find that the gains are largest for those who experience a modest reduction in distance. This includes residents on Third Ave and even some on 2nd Ave. For several far east residents, it is possible that the 2nd Ave subway remains too far away to be useful. Far east residents may continue to use alternate transportation options.

Table 7: Treatment Based on Change in Distance to Nearest Station

| VARIABLES | (1)<br>Log Price | (2)<br>Log Price | (3)<br>Log Price | (4)<br>Log Price | (5)<br>Log Price |
|---|---|---|---|---|---|
| Post x Change in Dist. | 0.0643*** | 0.0897*** | 0.0327*** | 0.139*** | 0.0536*** |
| | (0.0146) | (0.00972) | (0.00835) | (0.0115) | (0.00994) |
| Constr. Period x Change in Dist. | | | | 0.0945*** | 0.0391*** |
| | | | | (0.0116) | (0.00999) |
| Post | 0.102*** | 0.0983*** | 0.112*** | 0.155*** | 0.165*** |
| | (0.0105) | (0.00701) | (0.00602) | (0.00831) | (0.00718) |
| Change in Dist. | -0.524*** | -0.134*** | | -0.183*** | |
| | (0.00878) | (0.00771) | | (0.00976) | |
| Constr. Period | | | | 0.103*** | 0.0954*** |
| | | | | (0.00843) | (0.00719) |
| Observations | 51,770 | 51,770 | 51,770 | 51,770 | 51,770 |
| R-squared | 0.096 | 0.602 | 0.738 | 0.607 | 0.740 |
| Controls | NO | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | YES |

*Notes:* "Post" is an indicator variable for the period after January 1st 2013. "Constr. Period" is an indicator variable for the construction period between January 1st 2007 and December 31, 2012. "Change in Dist." is an indicator variable which is 1 for a transaction of a unit for which the distance to the nearest subway station became smaller after the addition of the three new subway stations on the Second Avenue subway and 0 otherwise. Controls include: an indicator variable for a condo transaction; an indicator variable for a studio; number of bedrooms; number of bathrooms; the floor of the building; the year of construction; distance to Central Park; distance to Grand Central Terminal; as well as indicators if the control variables are missing. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

## 7.3 All of the Above

A third alternative treatment definition combines the first three treatments. We consider a unit treated if it is treated under all three previous definitions. Table 1 reports that 72.6% of units on the 2nd Ave corridor satisfy this requirement ("treat4") and none of the units on the other corridors, by construction. About 29% of the overall sample receives this combination treatment. Figure 7 shows the treatment and control groups according to this combination treatment definition. This treatment isolates properties on the 2nd Ave corridor, close to a new subway station, for which one of the new stations is the closest subway option (i.e., there is a positive change in distance).

Table 8 shows the difference-in-difference estimates. For our main specifications in columns 2 and 3, we find a 10% and 4.6% subway effect, both of which are precisely estimated. In columns 4 and 5 we find a significantly positive effect in the Construction period, and a continuation in the Post period. Prices in the combination treatment group post-subway construction end up 12.9% (6.3%) above 2003-06 levels in column 4 (5).

The analysis in this section confirms large and robust estimated effects from the Q line subway extension.

Table 8: Combination Treatment

| VARIABLES | (1)<br>Log Price | (2)<br>Log Price | (3)<br>Log Price | (4)<br>Log Price | (5)<br>Log Price |
|---|---|---|---|---|---|
| Post x All Treats | 0.101*** | 0.100*** | 0.0455*** | 0.129*** | 0.0626*** |
| | (0.0164) | (0.0106) | (0.00922) | (0.0125) | (0.0109) |
| Constr. Period x All Treats True | | | | 0.0593*** | 0.0345*** |
| | | | | (0.0127) | (0.0110) |
| Post | 0.114*** | 0.118*** | 0.116*** | 0.191*** | 0.175*** |
| | (0.00889) | (0.00576) | (0.00494) | (0.00683) | (0.00591) |
| All Treats | -0.448*** | -0.187*** | | -0.217*** | |
| | (0.00988) | (0.00660) | | (0.00937) | |
| Constr. Period | | | | 0.135*** | 0.106*** |
| | | | | (0.00687) | (0.00593) |
| Observations | 51,770 | 51,770 | 51,770 | 51,770 | 51,770 |
| R-squared | 0.057 | 0.606 | 0.738 | 0.611 | 0.740 |
| Controls | NO | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | YES |

*Notes:* "Post" is an indicator variable for the period after January 1st 2013. "Constr. Period" is an indicator variable for the construction period between January 1st 2007 and December 31, 2012. "Change in Dist." is an indicator variable which is 1 for a transaction of a unit for which the distance to the nearest subway station became smaller after the addition of the three new subway stations on the Second Avenue subway and 0 otherwise. Controls include: an indicator variable for a condo transaction; an indicator variable for a studio; number of bedrooms; number of bathrooms; the floor of the building; the year of construction; distance to Central Park; distance to Grand Central Terminal; as well as indicators if the control variables are missing. Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

# 8 Value Capture

In this section, we take our baseline estimates for the value created by the subway based on the observed transactions and use them to compute the aggregate value creation for the stock of residential real estate on the Upper East Side. We then use property tax data to compute how much of this value creation flows back to the city in the form of higher taxes. There is a significant shortfall compared to the cost of the subway extension. Finally, we propose a set of micro-targeted property tax surcharges, based on our model, to help finance the shortfall.

## 8.1 Imputing Valuation Gains for the Stock of Real Estate

We start by valuing the stock of real estate in the treatment area in the period before subway construction. This stock consists of owner-occupied residential real estate, renter-occupied residential real estate, and commercial real estate.

### 8.1.1 Owner-occupied Residential Buildings

Imputing the value of owner-occupied residential real estate occurs in three steps.

**Step 1: Transacted Units** For each apartment in the baseline treatment area for which we observe at least one sale, we use the dynamic difference-in-differences specification with controls to impute an annual valuation for 2003 (or year of construction if later) until 2012. The imputation uses the actual apartment and building attributes. We compute its average value over the 2003-06 and the 2003-2012 periods.

**Step 2: Other Units in Buildings with Transactions** Even though we observe more than 16 years of transactions in a liquid market, many condo and coop units never transact in our sample. Our valuation model should be excellent for calculating the value of apartment units that do not trade in buildings where we see other units trade. For some of these units we obtain information on number of bedrooms, bathrooms, square foot, and floor. This could be because these units are for sale at some point, and therefore in our data set, but not actually sold (listing removed). Or it could be that the unit is for rent and those characteristics are available as part of the rental listing.[4] Even if unit characteristics are missing, we know how many units each building has and thus how many units we are missing. We may be able to infer characteristics on missing units.[5] At the very least we can use the average characteristics of the observed units to impute the aggregate value of the missing units. We do so for each year and produce average values for 2003-06 and 2003-2012.

**Step 3: Units in Buildings without Transactions** The valuation model should also be reasonably accurate for valuing units in owner-occupied buildings in the treatment area where we do not observe any transactions, if at least we have basic information on the number of units in the building and the year of construction. Here we use data from the New York City Department of Finance to supplement data from StreetEasy to make sure we cover every lot.

[4] This could be because the building is a mixed owner- and renter-occupied building, or because some condo owners rent out their unit (e.g., investment property).

[5] We can infer from the apartment units we see transact, which units we are missing on each floor, and use the apartment numbers to infer bedrooms and bathrooms. For example, if we see transactions for apartments #20A and #22A, and both are 2-bedroom, 2-bathroom units, we can safely assume that apartment #21A, which we are missing in the sample, is also a 2-bedroom, 2-bathroom unit, and we know it is on the 21st floor. We then use the number of bedroom, number of bathroom, floor, and building attributes to value this unit.

### 8.1.2 Renter-occupied Buildings

Next, there is a large stock of rental-only buildings to consider. After all, the home ownership rate in Manhattan is only 23%. A reasonable assumption is that renter- and owner-occupied buildings experience similar capital gains *due to subway construction*. After all, current and future renters and owners equally benefit from the commuting improvements due to the 2nd Ave subway. Also, the rent-versus-own margin is highly relevant in this area of Manhattan with liquid renter and owner market segments and many marginal households that evaluate this choice. New York City taxes owner-occupied buildings as if they are rental buildings. Following this equivalence, we will value rental buildings in the treatment area as if they were owner-occupied.

Our data source, StreetEasy, has equally detailed information on the characteristics of rental buildings, such as the number of units, number of floors, the year of construction, and a series of building amenities. It also contains substantial information on past rentals of individual apartment units, such as number of bedrooms, number of bathrooms, and sometimes square footage. This data allows us to value each rental unit as if it were owner-occupied and to aggregate up the values to the building level. Units that are not in the rental data base are valued using the same procedure as units in owner-occupied buildings that are not in the data base.

**Quality Differences** The main worry with this approach is that the quality, and hence the price (per square foot), of a rental building may be different from that of an owner-occupied building. Such a level effect in prices would affect the dollar estimate of the subway's value-added. Additionally, the price discount for rental buildings may be changing over time, possibly in ways correlated with the 2nd Ave subway. We pursue two routes to deal with this issue.

First, we use sales of entire rental buildings. We construct the ratio of the observed to the imputed sale price as a measure of the discount factor. We average the discount factor across properties, for each year.[6]

Second, we use data on rents from StreetEasy.[7] We also use the rent on similar units

[6]The alternative approach would be to perform the difference-in-differences approach directly on the multi-family buildings that transact. The problems are: (i) large standard errors due to a small sample, (ii) concerns that the buildings that do transact are not a representative sample of all rental buildings, (iii) missing characteristics data, (iv) difficulty to determine whether ground floor retail or other commercial space is included in the sale.

[7]StreetEasy contains the asking rent for units that are for rent, as well as a history of rents. In many but not all cases, a distinction is made between an actual rent ("rented") and an asking rent. We use the actual rent whenever available and the asking rent in the other cases, flagging it as such. While it is neigh impossible to precisely observe the effective rent paid by tenants, we certainly have a good proxy.

that are for-rent in owner-occupied buildings. Similar units are defined based on geographic proximity, building characteristics, unit characteristics, and year of observation. We then construct the rent discount as the ratio of the actual rent per unit to the rent per unit in the matched owner-occupied unit. We aggregate the discount weighed by rental unit type, year by year.

The two discount measures paint a similar picture in terms of the level of the discount factor. We use the discount over 2003-06 or 2003-12, respectively, to adjust the valuations of rental buildings, obtaining average valuations of the aggregate stock of renter-occupied real estate in the treatment area over 2003-06 an 2003-12.

#### 8.1.3 Commercial Non-residential Properties

The final property type is commercial, non-residential real estate: retail, office, and industrial properties including parking garages. Since the 2nd Ave corridor is nearly exclusively a residential neighborhood, by far the dominant commercial real estate is street-level urban retail (shops and restaurants), followed by parking garages. We suffer from a paucity of actual transactions of such property types as well as difficulties in controlling for the heterogeneous nature of the assets that do transact. Some of the street-level retail space is owned by the coop or rental building in which it is located, while the remainder is retail condos. We use all transactions on commercial buildings in the treatment area to obtain a measure of the price per sqft by narrow property type in each year. We use information from New York City's deed records to obtain a measure of commercial square footage for each lot.

While basic economic logic would suggest a positive correlation between residential and commercial capital gains due to the subway, the exact link between the two is not well understood. We make the simplifying assumption that the percentage gain in value due to the subway is the same as that for the residential real estate. Direct evidence from the evolution of price per square foot is consistent with this assumption.

### 8.2 Tax Pass-through

To assess the amount of property taxes that typically passes through to the city government in response to property appreciation, we make use of tax assessment records for New York City. For owners of condos and co-ops, the city assess property taxes on a portion of the property's market value, the so-called assessed value. This assessed value is calculated using several steps.

First, the property's "NYC market value" is calculated as follows. The city imputes the annual Net Operating Income (NOI) per sqft based on comparable rental buildings, typically the average of three buildings that are geographically close to the building in question, of similar size and similar vintage. This annual NOI is then divided by a cap rate, a ratio of NOI to price, to produce the NYC estimate of market value. The city's records indicate that the cap rate was set uniformly at 12.42% in January 2018. The true market cap rate at that time was likely around 4%, so that NYC's market value estimate is about three times smaller than the actual market value.

Next, the property assessed value is set at 45% of the NYC market value, and owners pay a 12.9% tax rate on the assessed value, minus exemptions. Absent exemptions, the tax rate is 5.8% of NYC market value. Changes in property taxes over time are gradually phased in over a five year period.

While we do not observe exemptions, we have tax paid in 2015 for all properties. This data suggests a non-trivial role for exemptions, and indicates that actual tax paid is 4.8% of the city's assessment of market value or about 1.0% of true market value. We assume that marginal increases in property values due to the subway creation result in the same increase in property taxes as the average increase in value.

Adopting that estimate of tax pass-through, we start with a simple example based on a typical condo building in the 2nd Avenue corridor. Suppose a building has 90 units, and a total of 140,000 sqft. Suppose the true market value is $175 million, or $1,250 per sqft. This is the observed average square foot price in the treatment area in Table 1. Given a NOI of $50 per foot, this valuation corresponds to a 4.0% cap rate. The NYC assessment of market value is based on a 12.42% cap rate and will be $37.65 million, or $269 per sqft. The assessed value will be $16.94 million, or $14 million after the 17.5% condo abatement, a form of exemption. Tax paid is $1.8 million yearly, which is 4.8% of NYC market value and 1.5% of true market value as mentioned above.

Suppose now that the 2nd Ave subway increases the value of this building by 10.8%, the point estimate in column 2 of Table 2, or $18.9 million. The NYC market value will increase by $4.1 million, or an increase in assessed value of $1.8m. By our assumption on average tax paid, taxes paid will increase annually by $194,609 in year 5 and beyond (and gradually be phased in before that). Assuming a government discount rate of 3%, corresponding to NYC's municipal bond yield, then the subway results in $5.78 million in extra tax revenue in present value. The estimate of value capture, or how much of the price increase accrues to the city government is $5.78 / $18.9 m = 30.6%.

We then adopt these estimates to the Second Avenue corridor definition in the Upper East Side, in Table 9. We estimate the total value of real estate in our treatment group as $138 billion across several categories of property ownership. To estimate the market value, we apply the market price paid per square foot in owner-occupied residential properties, in 2012, against the observed square footage in the property tax data. This provides an estimate of the true market price prior to our main treatment period.

We estimate the values of the other two components—renter-occupied buildings, and commercial non-residential—by comparing the city's assessment of estimated market value in these categories with that of owner-occupied residential properties. While we correct for the true level of market prices using transaction data; we currently have limited information on transactions in these other categories. To impute these values, we assume that the city assessment of market value is informative as the relative values of different tax classes, even if it is off in the levels. We are able to use information on all tax classes only in 2015, and so assume that the relative property value of different property sub-segments was unaffected by subway construction.

This table shows the estimated increase in market value across several of our specifications from Table 2, which are displayed again for convenience in the first row. We estimate that the subway construction had a total value increase of between $3.4–10.7 billion, depending on the specification. However, we estimate that the city itself is able to capture only 30.6% of this value, as discussed above. This table displays our estimates of the amount captured by the city government in present value terms from increased property taxation under the row "Property Tax Receipts." We contrast this number with the construction cost of $4.5 billion; and show in the last row the shortfall in revenue. This shortfall is always negative; suggesting that even though the value generated from subway construction was substantial enough to exceed the large subway construction cost; these gains largely accrued to private owners of condo and co-op units; and landlords managing rental and commercial real estate properties.

## 8.3 Value Capture Through Micro-targeted Property Taxes

An alternative mechanism of property taxation would levy on each individual property the maximal amount of property taxes which would leave owners no worse off, and so extract the entire value generation possible for the city government. Assuming that the city has the ability to levy micro-targeted property taxes would allow the city to recoup the full increase in value creation. Strikingly; all of our estimates of the value gain from the Second Ave Subway construction itself exceed the cost of construction. Our estimates suggest that while the cost of construction of the subway is quite high; so is the value generation, at least in densely populated areas such as the Upper East Side. These gains

Table 9: Estimates of Value Creation

| Value Add Under: | Value in 2013 | (2) Standard Controls | (3) Building FE | (4) Constr. Period | (5) Constr. Period + Building FE |
|---|---|---|---|---|---|
| Treatment Effect: | | 0.108*** | 0.0480*** | 0.149*** | 0.0636*** |
| | | (0.00976) | (0.00852) | (0.0115) | (0.0102) |
| Owner-Occupied Residential ($b) | 26 | 2.86 | 1.27 | 3.95 | 1.69 |
| Renter-Occupied Buildings ($b) | 35 | 3.74 | 1.66 | 5.16 | 2.20 |
| Commercial Non-residential ($b) | 11 | 1.18 | 0.53 | 1.63 | 0.70 |
| Total ($b): | 72 | 7.78 | 3.46 | 10.74 | 4.58 |
| Property Tax Receipt ($b): | | 2.38 | 1.06 | 3.29 | 1.40 |
| Shortfall ($b): | | (2.12) | (3.44) | (1.21) | (3.10) |

are sufficiently valuable that city governments could self-finance infrastructure expenses if able to better appropriate the gains from construction, that currently accrue instead to private landowners.

# 9 Conclusion and Next Steps

Though public transit is essential to manage urban commuting, and is associated with a wide array of potential benefits, new subway construction costs have risen to enormous amounts. In order to justify further construction with these costs, transit must demonstrate significant returns either directly or through the capitalization of externalities in real estate prices.

We find evidence of such capitalization using a difference-in-difference framework. Our baseline estimates compare the increase in real estate prices on the 2nd Avenue corridor where the subway was extended, relative to other areas in the Upper East Side. We contrast a number of treatment definitions, including living near the subway stops themselves, experiencing an improvement in commute time, or a combination of these treatments. We control finely for other aspects of property price valuation through building fixed effects. Our estimates suggest price appreciation of treated properties benefiting from Subway expansion of about 5–10% in our benchmark specification.

These estimates suggest substantial externalities resulting from subway expansion, capitalized into prices. However, these benefits largely accrue to private landlords. We estimate that the city itself will only recoup a fraction of this increase in the form of future property taxes, suggesting considerable scope for additional value capture taxation which may provide the basis for future infrastructure funding.

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# 10 Appendix

Table 10: Within Distance Broken Down

| VARIABLES | (1)<br>Log Price | (2)<br>Log Price | (3)<br>Log Price | (4)<br>Log Price | (5)<br>Log Price |
|---|---|---|---|---|---|
| Post x Within 0 - .1 mi | -0.0283 | 0.0200 | 0.0268 | -0.00469 | 0.0159 |
| | (0.0317) | (0.0204) | (0.0173) | (0.0240) | (0.0204) |
| Post x Within .1 -.2 mi | -0.00278 | -0.00626 | 0.000199 | -0.00860 | 0.0103 |
| | (0.0213) | (0.0138) | (0.0119) | (0.0165) | (0.0143) |
| Post x Within .2 -.3 mi | 0.0815*** | 0.0816*** | 0.0331*** | 0.120*** | 0.0493*** |
| | (0.0161) | (0.0104) | (0.00891) | (0.0122) | (0.0107) |
| Constr. Period x Within 0 - .1 mi | | | | -0.0413* | -0.0151 |
| | | | | (0.0244) | (0.0208) |
| Constr. Period x Within .1 -.2 mi | | | | -0.00786 | 0.0207 |
| | | | | (0.0167) | (0.0145) |
| Constr. Period x Within .2 -.3 mi | | | | 0.0774*** | 0.0297*** |
| | | | | (0.0123) | (0.0107) |
| Post | 0.115*** | 0.116*** | 0.115*** | 0.186*** | 0.171*** |
| | (0.00984) | (0.00636) | (0.00547) | (0.00752) | (0.00651) |
| Constr. Period | | | | 0.128*** | 0.102*** |
| | | | | (0.00759) | (0.00652) |
| Within 0 - .1 mi | -0.0894*** | -0.0646*** | | -0.0387** | |
| | (0.0190) | (0.0123) | | (0.0177) | |
| Within .1 -.2 mi | -0.208*** | -0.0368*** | | -0.0353*** | |
| | (0.0130) | (0.00844) | | (0.0125) | |
| Within .2 -.3 | -0.272*** | -0.126*** | | -0.165*** | |
| | (0.00959) | (0.00625) | | (0.00909) | |
| Observations | 51,770 | 51,770 | 51,770 | 51,770 | 51,770 |
| R-squared | 0.048 | 0.604 | 0.738 | 0.610 | 0.740 |
| Controls | NO | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | YES |

Table 11: Change in Distance Broken Down

| VARIABLES | (1)<br>Log Price | (2)<br>Log Price | (3)<br>Log Price | (4)<br>Log Price | (5)<br>Log Price |
|---|---|---|---|---|---|
| Post x Chg. dist 0-0.10mi | 0.121*** | 0.163*** | 0.0568*** | 0.301*** | 0.146*** |
| | (0.0216) | (0.0143) | (0.0127) | (0.0159) | (0.0144) |
| Post x Chg. dist > 0.10mi | 0.0440*** | 0.0573*** | 0.0238*** | 0.140*** | 0.0898*** |
| | (0.0160) | (0.0106) | (0.00906) | (0.0118) | (0.0101) |
| Constr. Period x Chg. dist 0-0.10mi | | | | 0.282*** | 0.168*** |
| | | | | (0.0146) | (0.0130) |
| Constr. Period x Chg. dist > 0.10mi | | | | 0.152*** | 0.120*** |
| | | | | (0.00962) | (0.00825) |
| Post | 0.102*** | 0.0990*** | 0.112*** | 0.0997*** | 0.113*** |
| | (0.0105) | (0.00699) | (0.00602) | (0.00695) | (0.00600) |
| Chg. dist 0-0.10mi | -0.465*** | -0.215*** | | -0.353*** | |
| | (0.0127) | (0.00933) | | (0.0117) | |
| Chg. dist > 0.10mi | -0.550*** | -0.0692*** | | -0.151*** | |
| | (0.00963) | (0.00870) | | (0.0101) | |
| Observations | 51,770 | 51,770 | 51,770 | 51,770 | 51,770 |
| R-squared | 0.098 | 0.604 | 0.738 | 0.608 | 0.740 |
| Controls | NO | YES | YES | YES | YES |
| Building FE | NO | NO | YES | NO | YES |

Figure 5: Treatment Based on Distance to New Stations

Figure 6: Treatment Based on Change in Distance to Nearest Station

Figure 7: Combination Treatment