Filtering in Commercial Real Estate Preliminary Draft[*]

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Abstract

While considerable evidence exists that residential properties host increasingly lower income tenants as they age, little analogous evidence exists for commercial properties. Using comprehensive data on commercial leasing and occupancy, this paper shows evidence of filtering in commercial real estate. Each year, the typical office property early in its life cycle depreciates by about 0.9 percent. Since leased space per user declines by about 2 percent per year while employment declines by 1.5 percent per year, buildings become more intensively used as they age. These changes are due entirely to shifts in the mix of tenants as buildings age. Tenants in older buildings are less productive and have higher labor shares. Only about one-fifth of these shifts are accounted for by changes in building industrial composition with age.

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1 Introduction

Considerable evidence exists that occupant household income declines in residential buildings as they age (Rosenthal, 2014). Depreciation coupled with the normality of housing services given heterogeneous demand means that the housing market can be characterized as a commodity hierarchy (Sweeney, 1974). Such housing market filtering accounts for neighborhood demographic change (Brueckner and Rosenthal, 2009) and is the largest source of housing supply to low-income occupants (Mast, 2021).

This paper is the first in the literature to consider filtering in commercial real estate. Our analysis uncovers new facts about this process, revealing how uses of commercial building change over building lifecycles. As a byproduct, we recover information about depreciation rates in commercial market segments that are also new to the literature. To fully characterize filtering rates, we separately estimate how rent per square foot, square footage of space leased, employment, sales, and industry composition change with building age. Many of the patterns we find for the commercial sector mirror those documented in the literature for residential properties. For office properties, we find that over the first 20 years of building age, effective rent per square foot declines about 1% per year and 0.3% per year in the subsequent 20 years. These estimates of depreciation net of building maintanence are larger than our estimated post-renovation depreciation rates of about 0.2 percent. Over the first 20 years of building age, space leased per tenant declines about 2.5% per year and employment per tenant declines about 2% per year. Moreover, the tenant mix moves toward less skill intensive and more labor intensive firms and industries. Somewhat less complete information for sales indicates annual declines of about 8% due to tenant turnover. All estimated effects decline only slightly with building age except for lease rates. While our main focus is on the office sector for data availability reasons, we find similar qualitative patterns of results for the retail and industrial sectors. Depreciation rates for retail properties are higher for young buildings but also more convex in age. Those for industrial properties are smaller but more linear in age. We show similar evidence of filtering in the retail and industrial sectors, though establishment composition shifts with building age toward 3-digit industries with lower wage workers is more stark in the retail sector.

These patterns in the data indicate that building occupants become less productive and engage in more labor intensive production as buildings age. While new tenants employ 2% fewer workers per year, with a slightly larger decline in efficiency units terms, they utilize 3.5% less space in efficiency units terms (2.5% in raw space plus 1% net depreciation). Therefore space per worker increases with building age. Average sales per worker and sales per square foot decline markedly with building age. All of this comes as additional tenants keep buildings at near full capacity. This is one notable difference with analysis of the residential sector. As office buildings can be more flexibly reconfigured than residential structures, filtering more easily goes along with densification of use as these properties age.

We integrate three data sets to carry out the analysis. We take information on commercial leases from CompStak, Inc. This information is on over 100,000 leases in the 2016-2019 period nationwide in the United States and includes information about the lease terms, leased space and building but has little information about the tenant. To estimate filtering rates, we turn to establishment level panel data from Dun & Bradstreet (D&B) for New York City married with planning office information on building attributes. While these data sets together allow us to determine detailed building tenant information over time, there is no included price information. For this reason, we carry out the depreciation analysis separately from the filtering analysis.

To rationalize observed patterns of net depreciation and filtering, we develop a model in the spirit of Sweeney (1974) that also incorporates insights from land use theory. Rather than conceptualizing a discrete commodity hierarchy as in Sweeney (1974), we find it easier to connect a continuous commodity quality profile to ideas from residential land use, housing and hedonics literatures going back to Muth (1969) and Rosen (1974). This continuity also makes empirical implementation more straightforward. We think of each building at each point in time as having a location in a continuous commodity hierarchy. While all potential tenants have a greater willingness to pay to locate in younger buildings, there is heterogeneity in this willingness to pay. Those tenants with the greatest additional willingness to pay for younger space outbid those establishments that are closer to indifferent across buildings of different ages. More labor intensive establishments have flatter bid-rent functions because of the smaller real estate share in their production functions. As a result, the static equilibrium allocation of tenants to buildings is such that the more labor intensive establishments endogenously sort into older buildings. As buildings age, this sorting process results in filtering. The filtering rate depends on the relative supply of buildings of different effective ages, which is influenced by maintenance decisions that are endogenous to demand conditions.

Our analysis builds on the empirical literature in two main ways. We derive newly informative estimates of property depreciation rates and we provide a novel characterization of filtering rates of tenants through commercial properties. In addition, we introduce a new conceptualization of filtering that can be applied in residential contexts in addition to our focus on commercial sectors. Existing estimates of property depreciation rates in the literature either focus on the residential sector or use cross-sectional information for large commercial properties. Using American Housing Survey data on single family homes, Harding et al.

(2007) estimate mean depreciation rates gross of maintenance expenditure in the residential sector of 2.5 percent and net depreciation rates of 2 percent. Using transaction prices for large commercial properties, Bokhari and Geltner (2018) estimate convex net depreciation rates of 1.8 percent per year for new properties, which decline to 1.1 percent per year for 50 year old properties. These estimates are for a mix of residential (rental), office, retail and industrial properties that sold for more than $2.5 million. Our leasing data include a somewhat wider range of property types. Rosenthal (2014) finds that tenant household income declines by 2.5 percent per year in rental properties and 0.5 percent per year in owner-occupied properties. Similarly, our evidence on the evolution of establishment sales per worker and sales per square foot indicates declines of about 2.5 percent per year.

This paper proceeds as follows. In Section 2, we introduce the data used for the analysis. Section 3 discusses depreciation and space usage estimates for the office sector. Section 4 explores how tenant composition changes as buildings age. Section 5 presents corroborative evidence for the retail and industrial sectors. Section 6 presents a conceptualization of the results using ideas from the land use and residentail filtering literatures. Finally, section 7 concludes.

2 Data

Our analysis employs information on commercial tenant lease terms, tenant attributes and building attributes. Characterization of the filtering process also ideally employs panel data that allows buildings to be followed over time. Our analysis primarily uses three data sets: commercial lease information from CompStak Inc., panel data on establishments in New York City from Dun & Bradstreet, and building attribute information for New York City from the New York City Department of City Planning. We describe each source in more detail below.

2.1 CompStak Data

We use data from CompStak Inc. for estimating depreciation rates and quantities of space leased by tenants as buildings age. This data set includes detailed information about over 25,000 commercial office leases from 2016 forward across the United States. It is constructed using reports from commercial real estate brokers about terms of past leasing transactions that they have handled, provided in exchange for information on other leases that are typically used as comparables to set terms of newly negotiated leases. We draw upon all leases in the data from July 1st, 2016 through 2019, resulting in 104,934 total office lease observations, of which 44,160 are leases to new tenants in the space. While buildings in larger cities are more heavily represented, suburbs and exurbs of 24 metropolitan areas of the United States have observations in the data. Each observation includes detailed information about lease terms, building attributes and location. We focus on effective rent per square foot and square feet of space leased as the main outcome variables of interest from this data set. Effective rent per square foot is calculated by CompStak to make leases with different payment terms comparable.

Table 1 Panel A presents selected summary statistics by building age. Because depreciation rates differ by building age, most of our analysis breaks out results by building age bins of 0-20, 20-40, 40-60 and greater than 60 years. The majority of leases in our data are in buildings 20-40 years old. Average effective rent per square foot in 20-40 year old buildings is 8 percent lower than in buildings 0-20 years old, reflecting depreciation. Beyond 40 years old we demonstrate below that survivorship bias becomes an important consideration. As such, observed rents increase with age in this range, reflecting in part the fact that only the most desirable buildings survive to these ages. The second row of results in Table 1 Panel A shows that square feet of space in the typical lease declines much more precipitously with building age, at about 51 percent. This reflects a marked change in the tenant mix, as we demonstrate below. The model presented in Section 6 rationalizes the smaller decline in rents than in space utilization through the equilibrium sorting process.

Our analysis incorporates an examination of impacts of years since the most recent major building renovation. CompStak reports building renovation information for 32 percent of leases. These buildings are on average 21 years older than the buildings reporting no renovation information, with an average building age of 53 years.

While the empirical analysis primarily focuses on all office leases, we also report results for sub-samples in central business district (CBD) areas of large metropolitan regions and in offices above the 9th floor of taller buildings. The large metro CBD sub-sample uses all leases that are within in the 5th percentile of CBD distance in the largest 25 metropolitan areas represented in the data set.[1] Metropolitan regions and CBD locations are defined as in Rosenthal et al. (2021). In particular, using an iterative assignment process, we define CBDs as the centroids of zip codes with the maximum employment density in 25 mile radius regions.

2.2 Planning and Building Footprint Data

We use municipal planning department and building footprint information for Boston, Chicago, Los Angeles and New York City to measure attributes of commercial buildings. Unreported

[1]These are Atlanta, Austin, Boston, Chicago, Dallas, Denver, Detroit, Fort Worth, Houston, Irvine, Los Angeles, Miami, Minneapolis, New York, Philadelphia, Phoenix, Portland OR, Sacramento, Salt Lake City, San Antonio, San Diego, San Francisco, San Jose, Seattle and Washington.

building age in the CompStak data is filled in using information from these data sets. For New York City (NYC), we go into more detail and additionally match with 2020 building footprint information constructed by Microsoft and the 2006 and 2018 NYC planning (PLUTO) data, which includes information on parcel zoning designation, building age, square footage by use and height. We merge this NYC building attribute information with Dun and Bradstreet data described in the following sub-section. Construction of a complete panel of commercial buildings for New York City back to 1916 is in progress.

2.3 Dun and Bradstreet Data

Information about tenant attributes comes from panel data on establishments collected by Dun & Bradstreet and accessed via Data Axle. To maintain more complete data coverage and to be able to match more accurately to building attributes from municipal planning data, we focus on establishments in New York City for the 2000-2019 period. This data set includes close to the universe of establishments in New York City in each study year.

Table 1 Panel B presents relevant summary statistics. Of note is that the commercial building stock in New York city is considerably older than that represented in the CompStak data. Of the over 8 million establishment-year observations in this data set, less than 10 percent are in buildings less than 20 years old. Dun & Bradstreet surveys establishments annually about employment and sales. About one-half of establishments report employment information and one-tenth report sales information (with the rest imputed by D&B). Our main establishment-level analysis of the D&B data in Section 4.1 does not use imputed employment or sales information.[2] The typical establishment is small but the distribution has a long right tail. The typical building less than 20 years old has 3 establishments and 32 employees. Older buildings are slightly larger, reflecting survivorship bias.

3 Depreciation and Space Utilization

In this section, we discuss estimates of office property depreciation rates and space leased as functions of building age. We build up to an empirical specification that is flexible enough to capture potential nonlinearities in relationships between building age and outcome variables of interest while including a set of control variables that account for the fact that building attributes and commercial space demand can change with age.

To be clear about our aims, first we lay out some notation. Firms use efficiency units of real estate services (K) and labor (L) to produce in each establishment. Real estate services

[2] The D&B data also report square footage of space rented. Unfortunately this information is often missing and does not match well with the more reliable CompStak measure.

can be broken into floorspace f and the efficiency units of real estate services per unit of floorspace $x(A)$, such that $K = x(A)f$. Floorspace is fixed over time within a lease but $x(A)$ declines each year due to depreciation, as it depends on building age A. We denote an establishment's payments to real estate inputs as $R = rK$, where r is the market price of one unit of real estate services. In the CompStak data, we observe effective rent per square foot $R_f \equiv \frac{R}{f} = rx(A)$.

To recover the $x(A)$ function empirically, we aim to make comparisons between buildings of different ages that are otherwise identical. In particular, they face the same implicit rent per unit of real estate services r, meaning that demand conditions for the comparison properties are identical. Holding r constant,

$$\frac{d \ln R_f}{dA} = \frac{d \ln x(A)}{dA}$$

That is, the rate at which effective rent per square foot falls with building age equals the depreciation rate net of maintenance.

We also aim to recover the change in the equilibrium relationship between the amount of floorspace rented by a typical establishment and building age, $\frac{d \ln f}{dA}$. Unlike depreciation, this relationship fully reflects choices made by optimizing building tenants. But the identification goals are the same in the sense that we also wish to hold r constant across comparison leases used for estimation of $\frac{d \ln f}{dA}$. For this reason, the empirical strategies for recovering estimates of $\frac{d \ln x(A)}{dA}$ and $\frac{d \ln f}{dA}$ are very similar.

Credible empirical implementation requires accommodating flexibility for R_f to depend on building attributes X and market conditions δ in addition to age. Our conditioning on X and δ throughout the emprical analysis in this section serves to control for differences in demand conditions across properties. There is the additional consideration that $\frac{d \ln x(A)}{dA}$ may also depend on X and δ through two channels. First, absent maintenance, different types of buildings may naturally depreciate more at different rates. For example, skyscrapers that are common in downtowns may depreciate more slowly than buildings in suburban office parks. Second, demand conditions influence endogenous maintenance decisions. Landlords with buildings in areas with stronger demand may invest more in maintance. For these reasons, our feasible goal is to estimate average depreciation rates net of maintenance. The model in Section 6 will derive a theory-based adjustment we can implement to account for such endogenous maintenance intensity.

3.1 Nonparametric Analysis

In this subsection, we flexibly explore observational relationships between effective rent per square foot or square footage leased and building age and years since renovation in the CompStak data. Our exploration is done in order to select the set of empirical specifications that are employed below to recover our main estimates of depreciation and input demand.

The identification challenge is to find variation in building age that is not related to other factors driving variation in r and f across buildings. We thus seek to make comparisons of leases across office suites that face (nearly) identical demand conditions, meaning that the market price of an efficiency unit of space is the same. In the conceptual model developed in Section 6, this means that the buildings are sufficiently close substitutes such that (nearly) the same establishment type is observed in both. Because establishments' floorspace input choices depend on factor prices, this same identification condition applies for the floorspace analysis.

The analysis faces two additional practical challenges. First, we seek to allow for as flexible a relationship between building age and outcomes of interest as possible, while at the same time maintaining statistical power. That is, we wish to allow depreciation rates and associated responses in floorspace input choices to depend flexibly on the level of building age. Second, we wish to accommodate the possibilty that major building renovations may affect depreciation rates and input choices.

The two graphs in the first column of Figure 1 present nonparametric relationships between our two outcomes of interest and years since construction (red line) and years since construction or the most recent renovation (blue line). These graphs are scaled to make clear comparisons with outcomes at 0 years since construction and/or renovation. These two graphs depict generally declining profiles with age, though mixing in renovations tends to make the rates of decline smaller. However, there is a stark turnaround at about age 40, at which point these relationships become positive. The graphs in the following two columns show that these positive relationships between age and rents and square footage leased are entirely explained by demand conditions.

To evaluate the sensitivity of these profiles to empirical specification, the remaining columns in Figure 2 show analogous nonparametric relationships after residualizing for potential demand factors. The second column residualizes for zip code fixed effects and the final column additionally residualizes for fixed effects for transaction quarter-year, class of office space, log building size, log building height, a lease renewal indicator, and a quadratic in the minimum and maximum floors in the lease.

The rent results show much more monotonic negative relationships with building age and a clearer difference emerging between age since construction and age since the most recent construction or renovation after 5 years. The inclusion of zip code fixed effects is enough to recover this basic age profile, which reflects the fact that older buildings are disproportionately located in locations with higher demand and market office lease rates. Adding the control variables mostly affects estimated depreciation rates beyond 20 years; of the controls, log building square footage has the largest effect on rent and square footage profiles and so we maintain it as a control throughout our analysis. The convex relationship between rents and building age motivates our use of a linear spline with cuts at 20, 40 and 60 years in our main regression specifications below. Consistent with evidence in Bokhari and Geltner (2018), estimated declining depreciation rates with building age appear in part to be real but in part to be explained by building survivorship bias, which we explore further below. The square footage results also have generally negative relationships with building age, though with a hump at 20 years. This negative relationship is a first indication of shifts in the composition of establishments as buildings age. Absent changes in establishment composition, one would expect the declining rent per effective square foot to go with increases in the amount of floorspace rented through a substitution effect.

3.2 Net Depreciation Estimates

Results in the prior sub-section inform our choice of primary specification for our examinations of depreciation and space utilization. They show the importance of controlling for location as a major driver of demand differences in addition to other demand factors. They additionally show that renovations are not typically valued as equivalent to new construction. Finally, they show that there is convexity in building age responses.

To account for these identification and functional form considerations, we estimate parameters in variants of the following regression equation:

$$\ln y_{ijz} = \alpha_1 A^0_{ijz} + \alpha_2 A^{20}_{ijz} + \alpha_3 A^{40}_{ijz} + \alpha_4 A^{60}_{ijz} + X_{ijz}\beta + \delta_{jz} + \varepsilon_{ijz} \qquad (1)$$

In this equation, observations are indexed by lease i in metro region j and location z. The key regressors are the building age spline variables, where $A^Y_{ijz} = min(A_{ijz} - Y, 20)1(A_{ijz} > Y)$ if $Y < 60$ and $A^{60}_{ijz} = (A_{ijz} - 60)1(A_{ijz} > 60)$. Therefore, each coefficient on age is interpreted as the impact of the building aging one year within a 20 year age range. We evaluate specifications with various mixes of lease control variables X_{ijz} and fixed effects δ_{jz}. Table 2 shows the results for effective log rent per square foot of space leased, with the bottom row indicating the empirical specification. In particular, we present results in which we have zip code fixed effects and all building attribute controls (column 1), submarket fixed effects, CBD distance, and building square footage controls (column 2) and tenant firm fixed effects and building fixed effects (column 3). The final column of each block repeats the specification in column 1 with the addition of a linear spline in years since the most recent renovation of the building. Each block in Table 2 reports results for this set of specifications using a different sample of leases.

The top left block of Table 2 presents our baseline depreciation results using all leases in our data. The specification in the first column corresponds to that in the upper-right panel of Figure 1. Here we see an average depreciation rate of about 0.9 percent in each of the first 20 years of building age and 0.3 percent in each of the following 20 years. We do not report estimates of α_3 and α_4 as we are concerned that survivorship bias is causing them to be upward-biased. We defer our consideration of this issue to the following sub-section, except to note for now that we see little evidence of survivorship bias affecting buildings less than 40 years old.

We show results for the specification in the second column to indicate that CompStak-defined submarket fixed effects, log building square feet and distance to the nearest CBD are sufficient controls to account for the same variation in demand conditions across properties that is captured by zip code fixed effects and the larger control set in Column 1. Identifying variation in the third column is between offices in different buildings that are rented by the same tenant firm. This is one way of controlling for establishment quality, with the caveat that firms may sort less productive establishments into older buildings. Regardless of specification, depreciation estimates in the first three columns are very similar. The stable building age coefficients in the fourth column reflects the fact that major renovations typically occur in older buildings when age depreciation rates are already quite low. Conditional on building age, we estimate a 0.2 percent per year post-renovation depreciation rate on top of a baseline age-based depreciation rate that is near 0.

The other three blocks of results in Table 2 are analogous except for the estimation sample. Results in the top right block show slightly lower depreciation rates in CBD areas of large metros. Results in the bottom left block for new leases show statistically similar results to those for all leases. However, those in the bottom right block show slightly larger depreciation rates in the first 20 years for offices that include space above the ninth floor. For this sample, we estimate a 0-20 year average depreciation rate of about 1.4 percent.

Figure 2 graphs confidence intervals for estimates from the empirical model similar to that in Column 3 of each block of Table 2 but specified to be fully nonparametric in building age. Results show monotonic and convex declines in lease rates with age for all samples. While they represent only 42 percent of the total lease observations, estimates and standard errors for the new lease sample are very similar to those for all leases. In contrast, there is much more dispersion in these nonparametric depreciation estimates for the CBD and tall building samples. This is evidence that the new leases provide most of the identifying signal.

3.3 Accounting for Survivorship Bias

Using a panel of all office buildings in New York City constructed since 1916, we carry out a survival analysis to use in a correction for survivorship bias. Preliminary evidence indicates that fewer than 5 percent of buildings less than 40 years old are ultimately torn down. Therefore, the estimates reported in Table 2 are not subject to appreciable survivorship bias. To extend depreciation estimates beyond this age, however, we must account for the fact that higher quality and better maintained buildings are less likely to be redeveloped.

To account for survivorship bias, we build on ideas in Bokhari and Geltner (2018) and use the observation that the average potential rent for buildings of age A with attributes X in market δ is a weighted average of observed rents in buildings with these attributes and the rent that would have been charged in redeveloped or abandoned buildings with these attributes had they survived to age A. In particular,

$$E[\ln R_f(A)|X,\delta] = S(A|X,\delta)E[\ln y(A)|X,\delta] + [1 - S(A|X,\delta)] \ln R_f^L(A|c).$$

In this expression, $S(A|X,\delta)$ is the survival function: the probability that a building survives to age A or beyond, which may depend on building attributes and location. $R_f^L(A|c)$ is the city c-specific expected rent in redeveloped or abandoned buildings of age A were they still in use.

We construct a measure of expected effective rent per square foot in buildings that do not survive, $E[R_f^L(A)|X,A]$, as follows. As potential rents of torn down and derelict buildings must be below all market rents observed in the data, as an upper bound we assign the minimum effective rent per square foot observed in each market and building age once smoothed and constrained to be non-increasing in age. To calculate this, we first run separate local polynomial regressions of the minimum observed effective rent per square foot on building age for each of the 24 broad geographic regions in the CompStak data c. Using the resulting fitted values $\widehat{R}_f^{min}(A|c)$, we iteratively calculate $R_f^L(A|c) = min[\widehat{R}_f^{min}(A|c), R_f^L(A-1|c)]$ starting at building age 0, iterating to the oldest building in each city. Figure A1 shows the resulting functions, which are flat for all cities after 50 years.

To estimate the building survival function $S(A|X,\delta)$, we look separately at the cohort of New York City office buildings that existed in years (Y) 1960, 1970 and 1980. For each of these samples, we estimate two variants of the survival function. First, we estimate a nonparametric Kaplan-Meier version $S^{KY}(A)$, as in Bokhari and Geltner (2018). Second, we estimate a proportional hazard model that depends on building attributes. Estimates for the 1960 cohort have the advantage of including more buildings for which we observe an end of life. Estimates for the 1980 building cohort have the advantage of including buildings that are more representative of those standing today. With these survival functions estimates in hand, we predict a probability of survivorship $\widehat{S}_m(A|X, c)$ for each buildings in the CompStak data to calculate potential rents.

Remainder to be completed.

3.4 Space Utilization

Table 3 presents our estimates for square footage of space rented using exactly the same samples and specifications as for rent in Table 2. For this outcome we focus our attention on results for the new lease sample in the bottom left panel, as the time of lease origination is when tenants can most flexibly adjust floorspace utilization. Floorspace leased upon arrival into a building best reflects establishments' unconstrained factor quantity demanded absent mobility frictions. As we can observe tenant attributes on arrival into a building but do not observe lease renewal time in the D&B data, these estimates also most closely match those from our establishment panel analysis below.

Results show a decline in floorspace leased by the typical tenant of 2.4 percent per year. Unlike for rental rates, this estimate is notably quite similar for the 0-20 and 20-40 year building age ranges, falling insignificantly to 2.1 for this age range. Post-renovation, we see an average reduction in space leased per additional year of about 1.5 percent. Analogous estimated rates of decline are only slightly smaller and not significantly different when estimated using all leases. Results for leases in CBD areas and in offices above the 9th floor are also similar. Figure 3 shows plots of nonparametric building age coefficients using the specification in column 3 of each block of Table 3. Except for the slight uptick around 20 years of age, we see a very consistent negative and slightly convex relationship between building age and office space leased in individual leases.

We note that declines in space utilization with building age are more linear than rent declines. We present evidence in the following section that this linearity comes primarily from the sorting of smaller and lower productivity tenants into buildings as they age. In Section 6 the conceptual model rationalizes the more convex rent responses with bid-rent ideas. Just as in the monocentric model with income heterogeneity, if residents' household incomes increase at approximately a linear rate with CBD distance, equilibrium rent will decline convexly in CBD distance. It is the same idea here when looking as a function of building age instead of CBD distance.

Adding declines in floorspace demand to depreciation as office buildings age, we calculate the rate at which establishments' demand for real estate services declines. Over the first 20 years of a building's life, this is estimated at 3.3 percent per year for new leases. Over the following 20 years, this falls to 2.3 percent per year, mainly because of declining depreciation rates. The addition of evidence on employment demand in the following section will allow us to recover information about how the composition of tenants changes as office buildings age.

4 Tenant Composition

In this section, we use the D&B data to estimate filtering rates of establishments in office buildings. In particular, we look at how establishment size and industry composition changes as buildings age. Mechanically, the analysis amounts to estimating variants of Equation 1 with three main differences. First, rather than using a cross-sectional sample of leases we use the population of establishments. Second, we use panel data. Finally, this analysis is for New York City only. We intend to extend the analysis to additional cities in the future. Because we have panel data, we do not need to observe many building attributes; instead, we control for building and year fixed effects throughout. The fact that all comparisons are made within building over time means that survivorship bias does not affect these estimates.

4.1 Establishment Level Analysis

Table 4 reports coefficients on building age spline variables in variants of the following regression equation.

$$w_{ibt} = a_1 A_{bt}^0 + a_2 A_{bt}^{20} + a_3 A_{bt}^{40} + a_4 A_{bt}^{60} + b_1 V_{bt}^0 + b_2 V_{bt}^{20} + b_3 V_{bt}^{40} + b_4 V_{bt}^{60} + \delta_\zeta + \tau_t + u_{ibt} \quad (2)$$

Outcome variables are log employment, log sales and age for establishment i in building b and year t. A_{bt}^Ydenotes the age of the building splined as in Equation 1. V_{bt}^Y denotes analogous spline variables measured since the most recent renovation. All regressions have year fixed effects. Each column in Table 4 uses a different estimation sample and/or specification of fixed effects δ_ζ. In column 1, ζ indexes establishment-building pairs ib. In columns 2 and 3, ζ indexes building fixed effects b. In column 4, ζ indexes establishment industry-building fixed effects, $k(i)b$. This variety of fixed effects coupled with use of the full estimation sample in columns 1 and 2 and only the first year in which each establishment is observed in each building in columns 3 and 4 allows us to paint a rich picture of the filtering process.

The first outcome we examine is establishment level employment. Results in column 1 show that employment rises by about 0.7 percent per year on average for establishments in buildings less than 20 years old and about half as rapidly in older buildings. This reflects the natural propensity for establishment size to grow with age. However, as seen in column 2, the average tenant tends to get smaller as buildings age. For buildings less than 20 years old, the average establishment is an estimated 0.6 percent smaller each year. This average size reduction reflects a mix of the within-establishment growth seen in column 1 and the sorting of smaller establishments into buildings as they age. Results in column 3 focus in on establishment transitions by reducing the sample to include only one observation per establishment-building pair. Here we see that new arrival establishments have on average 1.5 percent less employment for each year a building ages over the first 20 years. This rate of change is approximately linear in building age. Evidence in the fourth column indicates that most of the compositional change toward smaller establishments is occurring within rather than between 3-digit industries. These estimates are statistically indistinguishible from those in column 3 yet are about 20 percent smaller in magnitude. Qualitative patterns similar to those in columns 1-4 are apparent up to 20 years since the most recent renovation. Estimates in Table 4 Panel B find show a slightly larger magnitude 2.4 percent decline per year using a sample that only includes establishments in buildings less than 20 years old.

Evidence on changes in the quantity of space demanded in Tables 2 and 3 along with these patterns of labor demand shifts most likely reflects the fact that new tenants have different production technologies than the tenants they replace. In particular, we can infer that the establishment sorting process brings in new tenants with more labor intensive production than the tenants they replace. Take buildings 0-20 years old as an example. While the efficiency units of space rented decline by 3.3 percent per year (2.4% decline in floorspace plus a 0.9% depreciation rate), employment declines by less at an estimated 1.5 to 2.4 percent per year, depending on the empirical specification. Holding factor prices constant, a homothetic production function would imply that both factor quantities should change by the same amount in percentage terms. That the labor input declines by less than the real estate input means that new arrival establishmenhts have a greater labor share in production than departing establishments. While this pattern could either reflect non-homothetic establishment production or sorting, we have two additional pieces of evidence that this pattern is much more likely driven by the sorting process of more labor intensive establishments as buildings age. First, a building-level analysis in the following sub-section shows that buildings host more workers as they age, even after accounting for worker quality. Second, evidence in the next four columns of Table 4 show declines in sales with building age. Optimizing identical establishments would all choose the same levels of output and factor quantities.

The next four columns in Table 4 show even more rapid decline in establishment sales than employment for new arrival establishments as buildings age. While individual establishments' sales typically grow by about 1% per year (column 5), new arrivals' sales decline by about 8 percent per year for buildings less than 20 years old (column 7). The rate of filtering toward establishments with lower sales monotonically declines in absolute value to about 3 percent per year for buildings over 60 years old. Taken together with evidence for employment and space utilization, these results show evidence of declining tenant productivity as buildings age. Sales per worker and sales per square foot are estimated to decline in the typical tenant by 6.7 percent and 4.9 percent respectively for each additional year of building age over the first 20 years, with similar magnitudes of declines for older buildings as well.

This is evidence that less productive tenants move into buildings over time. While a decreasing returns to scale technology could at first blush rationalize the much larger reductions in sales than factor quantities in new arrival establishments for each additional year of building age, the fact that the chosen establishment scale of new arrivals is smaller is evidence that these firms have higher costs (and are thus less productive) than the establishments they are replacing.

The final four columns of Table 4 show results for establishment age that are in line with those for the other two outcomes. New arrival tenants tend to be younger than the ones they replace. As younger firms tend to be less productive, this is further evidence of the sorting of lower productivity firms into older buildings.

The diagram in Figure 4 lays out a conceptualization of our observations about how tenant establishment composition changes with building age. At the initial combination of real estate services and labor, point a, a purple type establishment produces q_0 units of output. The following year, we observe that the typical establishment rents 3.3 percent less efficiency units of space and hires 1.5 percent fewer workers. However, our identification strategy is set up to hold factor prices constant as buildings age, with the factor price ratio given by the slope of the green iso-cost lines. A homothetic production technology would thus move the purple reoptimizing firm to a point to the left of c. Instead, we observe the new optimization point c. This is a point at which the isoquant must be steeper than at point a, matching the orange family of isoquants. These steeper isoquants reflect the greater labor intensity of the new establishment.

4.2 Building Level Analysis

To come to more direct evidence that the composition of establishments changes as buildings age, we now carry out a building level analysis, which amounts to recovering coefficients in the following regression equation.

$$w_{bt} = a_1 A^0_{bt} + a_2 A^{20}_{bt} + a_3 A^{40}_{bt} + a_4 A^{60}_{bt} + b_1 V^0_{bt} + b_2 V^{20}_{bt} + b_3 V^{40}_{bt} + b_4 V^{60}_{bt} + \delta_b + \tau_t + u_{bt}$$

This equation has a differences-in-differences flavor, as identification comes from comparisons of outcomes over time within buildings of different vintages. Table 5 reports these results. Outcomes are number of establishments, aggregate employment, employment by education and wages inferred from establishment industry composition, and aggregate sales.

Results in the first two columns of Table 5 show that as buildings age, the average number of establishments they host tends to increase. For each additional year less than 20, about 0.2 additional establishments move in per year, a 3.6 percent growth. Beyond 20 years, the growth is closer to 0.1 additional establishments per year, or about 2 percent growth. This growth in the number of establishments rationalizes the declines in space per establishment documented in Table 3, with similar offsetting magnitudes.

Evidence in the third column of Table 5 shows that buildings host more workers as they age. The youngest buildings experience annual increases of about 4.6 percent in employment. This rate drops down to closer to 2 percent per year for buildings over 20 years old. Mechanically, the number of establishments increases more rapidly than the annual decline in employment per establishment. Using establishment industry to allocate workers to education groups, the following two columns show that while both low and high education employment is estimated to grow annually, the growth is more heavily concentrated amongst workers with high school or less. This group grows by 5.6 percent per year whereas the some college or more group grows by 3.2 percent per year in buildings less than 20 years old. To be more clear about adjusting for labor quality, the second to last column presents evidence for wages inferred from establishment industry. As expected, these show significant declines, though they are very small. The final column shows the total sales of all establishments in the building. These estimates are mostly positive for most age ranges, though the imputation of sales for about 90 percent of establishment-years potentially renders this result somewhat unreliable.

Figure 5 conceptualizes these building level results in a way that is analogous to Figure 4. A building begins at point A in real estate services-labor space. Buildings depreciate at an estimated 0.9 percent per year in the first 20 years, which is the annual reduction in the efficiency units of real estate services provided by the building. At the same time, we see an annual 4.5 percent increase in building employment (accounting for labor quality) per year of aging for young buildings. If the building production function were homothetic, we would expect a reduction in building employment to go along with depreciation. The only way to rationalize the observed increase in building employment is with a shift from the purple production technology to the more labor intensive orange production technology.

5 Analysis for the Retail and Industrial Sectors

We carried out separate parallel analyses using the CompStak and D&B data sets for the retail and industrial sectors. While qualitative patterns of rent, floorspace, employment and sales are the same as for the office sector, there are some differences in magnitudes and profiles with respect to building age. These results are reported in Tables A2, A3, A4 and A5.

Future versions of the paper will further investigate differences in filtering rates between these three sectors of commercial real estate.

6 Conceptualization

Our empirical characterization of filtering in commercial real estate has shown that this process takes the form of less productive, smaller and more labor intensive establishments sorting into older buildings. However, we have not rationalized why these types of establishments are assigned to older buildings in equilibrium. To better understand this assignment, we propose a model that uses commodity hierarchy ideas from the classical filtering literature, as in Sweeney (1974), along with classical bid-rent ideas from urban theory, as in Muth (1969). In addition to delivering an equilibrium assignment of higher productivity and less labor intensive establishments to younger buildings, the model also rationalizes the observations that depreciation rates decline in building age yet rates of establishment filtering are approximately linear in building age.

In Section 6.1 we take the supply of buildings of different ages and the $x(A)$ function as given. In Section 6.2,we extend the analysis to allow both maintenance decisions and the supply of new (age 0) buildings to respond to demand conditions.

6.1 Bid-Rent Model

Each establishment determines its willingness to pay to locate in each building as the residual profit that makes it indifferent across office spaces in buldings of different ages A. The equilibrium rent per square foot in a building of age A is $\widetilde{r}(A) = rx(A)$. Each establishment has the following generic profit function.

$$\text{Profit} = paF(fx(A), L) - wL - \widetilde{r}(A)f = \overline{\pi}.$$

Establishments may differ in productivity a, production technology F and profit $\overline{\pi}$ and choose f and L to maximize profits. We partition establishments into types indexed by i. Each type consiststs of establishments with the same productivity, production technology and profit, though they may optimize at different factor quantities and building ages.

We solve for the bid-rent $\psi^i(A)$, the maximum type i establishments are willing to pay to locate in a building of age A. Given optimization over floorspace and labor inputs, the bid-rent for locating in a building of age A is

$$\psi^i(A) = max_{f,L} \frac{p_i a_i F^i(fx(A), L) - wL - \overline{\pi}_i}{f}.$$

By the Envelope Theorem, the gradient of bid-rent with respect to building age is

$$\psi^i_A = p_i a_i F^i_K x'(A) \tag{3}$$

This slope is negative because $x'(A) < 0$.[3]

To determine how firms of different types are allocated to buildings of different ages in equilibrium, we compare rent gradients across establishment types at crossing points (holding $\widetilde{r}(A)$ fixed). Differentiating ψ^i_A with respect to p or a yields the same qualitative ordering of bid-rent gradients. As an illustration, imagine that establishment types only differ in the productivity dimension a. Differentiating Equation 3 with repsect to a and constraining factor prices to be the same, we have

$$\psi_{Aa}|_{\widetilde{r}(A)=\overline{r}} = pF_K x'(A) + pa(F_{KK}K^*_q + F_{KL}L^*_q)\frac{dq^*}{da}x'(A) < 0. \tag{4}$$

In this expression, $K^*(r, q)$ and $L^*(r, q)$ are conditional factor demands. There are two forces evident in Equation 4 that contribute to a steeper bid-rent gradient for more productive firms. The primary force is the greater dollar loss in revenue per square foot for more productive establishments because each square foot of leased space brings in more revenue conditional on input quantities. There a also a second-order scale effect that arises if establishments have a decreasing returns to scale production technology.

As the real estate share in the production function is increasing in F_K, we can see by a similar argument that a greater real estate share in production is also associated with a steeper bid-rent gradient. This rationalizes the observation that as buildings age they tend to host tenants that use space less intensively and labor more intensively for production.

Figure 6 visualizes how the sorting of heterogeneous establishments across buildings of different ages generates a convex equilibrium rent function in age. In this diagram, bid-

[3] If the production function also depends directly on building age and $F_A < 0$, this would be an additional force pushing the rent gradient negative.

rents for three establishment types are depicted. The upper envelope of these three curves is the equilibrium rent function. We can see through this diagram that even if filtering through building age happens approximately linearly, the sorting process generates a convex relationship between rental rates and building age.

6.2 Supply Conditions by Building Age and Endogenous Maintenance

To this point, we have taken the supply of buildings of different ages and the $x(A)$ function as given. Because it is based on indifference relationships between locating in buildings with different levels of $x(A)$, the analysis in the prior sub-section applies qualitatively regardless of exact supply conditions and endogenous maintenance decisions provided $x'(A) < 0$ regardless of maintenance. Indeed, one role of controlling for renovations in the empirical work is to make comparisons across more heavily depreciated older buildings and less depreciated younger buildings. In this sub-section, we endogenize the $x(A)$ function to reflect the return on maintenance investment.

To be completed.

6.3 Implications

To be completed.

7 Conclusions

This is the first paper in the literature to document and quantify the rate of filtering in different segments of the commercial real estate market.

To be completed.

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Table 1: Summary Statistics on Key Outcomes of Interest
Office Spaces and Buildings

	Building Age			
	0-20	20-40	40-60	>60
Panel A: CompStak Data				
log Effective Rent Per	3.36	3.27	3.37	3.72
Square Foot per Yr	(0.48)	(0.48)	(0.57)	(0.52)
log Square Footage	8.77	8.08	7.83	8.32
of Space Rented	(1.29)	(1.32)	(1.43)	(1.24)
Total Leases	17,088	52,885	20,762	14,202
New Leases	7,642	21,714	8,351	6,453
Total Buildings	6,018	11,134	4,289	4,760
Panel B: Dun & BradStreet NYC Panel Data				
Employment	21.0	24.3	18.4	13.0
	(254)	(236)	(170)	(114)
Obs	203,237	292,440	509,464	2,607,197
Sales	65	141	101	24
	(1083)	(2641)	(2229)	(828)
Obs	33,470	45,832	81,230	450,878
Establishment-Years	514,128	641,363	1,150,898	5,742,920
Establishments	129,030	128,283	211,743	1,085,999
Total Building	32	50	36	24
Employment	(419)	(501)	(512)	(322)
Bldg # of	3.15	3.93	3.60	3.30
Establishments	(8.53)	(13.46)	(11.94)	(13.48)
Building-Years	163,025	163,066	319,897	1,737,700

Notes: Indicated observation exclude imputed observations for employment and sales in the top part of Panel B.

Table 2: Rent Changes With Age for Office Buildings: Linear Spline

	Full CompStak Data				CBD Areas, Large Metros Only			
Bldg Age, 0-20	-0.00890***	-0.00979***	-0.00917***	-0.00919***	-0.00738***	-0.00884***	-0.00406	-0.00781***
Range	(0.000873)	(0.000803)	(0.00246)	(0.000884)	(0.00197)	(0.00207)	(0.00701)	(0.00210)
Bldg Age, 20-40	-0.00293***	-0.00305***	0.00347	-0.00324***	-0.000156	-0.00239*	0.00590	-0.000306
Range	(0.000915)	(0.000605)	(0.00225)	(0.000912)	(0.00192)	(0.00141)	(0.00765)	(0.00184)
Age since Reno,				-0.00196***				-0.00327**
0-20 Range				(0.000664)				(0.00143)
Observations	104,937	104,935	104,937	104,937	20,615	20,615	20,615	20,615
Unique FE	2,809	627	75,293	2,809	291	53	16,359	291
R-squared	0.774	0.723	0.856	0.774	0.759	0.722	0.901	0.759
	New Leases Only				**Offices Above the 9th Floor**			
Bldg Age, 0-20	-0.00949***	-0.0101***	-0.00976***	-0.00988***	-0.0135***	-0.0119***	-0.00864	-0.0140***
Range	(0.00113)	(0.000924)	(0.00368)	(0.00114)	(0.00271)	(0.00256)	(0.00851)	(0.00284)
Bldg Age, 20-40	-0.00257**	-0.00247***	0.00459	-0.00285**	-0.00338	-0.000861	0.00810	-0.00370
Range	(0.00120)	(0.000729)	(0.00369)	(0.00120)	(0.00254)	(0.00145)	(0.0107)	(0.00248)
Age since Reno,				-0.00254***				-0.00222
0-20 Range				(0.000773)				(0.00164)
Observations	44,160	44,159	44,160	44,160	10,304	10,304	10,304	10,304
Unique FE	2,051	590	36,571	2,051	376	218	8,384	376
R-squared	0.795	0.750	0.900	0.796	0.792	0.778	0.894	0.792
FE	Zip	Submarket	Tenant	Zip	Zip	Submarket	Tenant	Zip
Ctrls	All	Short+CBDDis	Short	All	All	Short+CBDDis	Short	All

Notes: All regressions have log effective rent per square foot as the dependent variable as predicted by a linear spline in building age cut at 20, 40 and 60 years. "Short" controls are log building sq feet and an indicator if this variable is missing. The final specification in each block includes controls for a spline in years since the most recent renovation with cutpoints at 20, 40 and 60 years and an indicator for whether any renovation is observed. Unreported building age and renovation coefficients are insignificant or significantly positive in all cases. "All" controls additionally include dummies for class of office space, log building number of stories and an indicator for whether this is missing, a lease renewal indicator, indicators for building vintage cut at 1943, 1968 and 1993, indicators for quarter in which the lease was transacted, and a quadratic in maximum and minimum floors on which space was rented. Full results for regressions in the fourth column of the top left block are in Table A2.

Table 3: Changes in Leased Space With Age for Office Buildings: Linear Spline

	Full CompStak Data				CBD Areas, Large Metros Only			
Bldg Age, 0-20	-0.0159***	-0.0227***	-0.0173***	-0.0173***	-0.0224***	-0.0327***	-0.0199**	-0.0259***
Range	(0.00300)	(0.00309)	(0.00446)	(0.00306)	(0.00631)	(0.00654)	(0.00920)	(0.00653)
Bldg Age, 20-40	-0.0236***	-0.0377***	-0.0172***	-0.0250***	-0.0206**	-0.0272***	-0.00521	-0.0256***
Range	(0.00374)	(0.00261)	(0.00287)	(0.00399)	(0.00854)	(0.00547)	(0.00876)	(0.00971)
Age since Reno,				-0.0109***				-0.0108***
0-20 Range				(0.00250)				(0.00327)
Observations	104,937	104,935	104,937	104,937	20,615	20,615	20,615	20,615
Unique FE	2,809	627	75,293	2,809	291	53	16,359	291
R-squared	0.445	0.353	0.879	0.446	0.377	0.284	0.913	0.382
	New Leases Only				Offices Above the 9th Floor			
Bldg Age, 0-20	-0.0236***	-0.0324***	-0.0241***	-0.0255***	-0.0193***	-0.0381***	-0.0423***	-0.0212***
Range	(0.00395)	(0.00379)	(0.00716)	(0.00402)	(0.00677)	(0.00911)	(0.0144)	(0.00662)
Bldg Age, 20-40	-0.0206***	-0.0356***	-0.0154***	-0.0222***	-0.00205	-0.00751	0.000521	-0.00532
Range	(0.00502)	(0.00301)	(0.00541)	(0.00528)	(0.00704)	(0.00504)	(0.0122)	(0.00706)
Age since Reno,				-0.0144***				-0.00168
0-20 Range				(0.00287)				(0.00345)
Observations	44,160	44,159	44,160	44,160	10,304	10,304	10,304	10,304
Unique FE	2,051	590	36,571	2,051	376	218	8,384	376
R-squared	0.519	0.412	0.928	0.521	0.379	0.194	0.894	0.380
FE	Zip	Submarket	Tenant	Zip	Zip	Submarket	Tenant	Zip
Ctrls	All	Short+CBDDis	Short	All	All	Short+CBDDis	Short	All

Notes: All regressions have log square footage of space leased as the dependent variable. See the notes to Table 2 for a list of control variables in each specification.

Table 4: NYC Office Sector Results, D&B Data

Outcome	log Employment				log Sales				Establishment Age			
Fixed Effect	Estab.	Building		Bldg-Ind	Estab.	Building		Bldg-Ind	Estab.	Building		Bldg-Ind
Sample	All	All	New Arrivals	New Arrivals	All	All	New Arrivals	New Arrivals	All	All	New Arrivals	New Arrivals
Panel A: All Buildings												
Bldg Age, 0-20	0.00661***	-0.00553***	-0.0152***	-0.0123**	0.0113***	-0.0297***	-0.0824***	-0.0373	0.954***	0.140***	-0.661***	-0.621***
Range	(0.000896)	(0.00172)	(0.00350)	(0.00585)	(0.00272)	(0.00958)	-0.023	(0.0392)	(0.00913)	(0.0256)	(0.0237)	(0.0343)
Bldg Age, 20-4(	0.00400***	-0.0145***	-0.0216***	-0.0165***	0.00974***	-0.0598***	-0.0743***	-0.0420**	0.956***	-0.0314	-0.677***	-0.689***
Range	(0.000675)	(0.00180)	(0.00344)	(0.00545)	(0.00297)	(0.00915)	(0.0149)	(0.0175)	(0.00642)	(0.0345)	(0.0287)	(0.0452)
Bldg Age, 40-6(	0.00321***	-0.00975***	-0.0109***	-0.00765**	0.0101***	-0.0449***	-0.0650***	-0.0584***	0.962***	-0.0662**	-0.754***	-0.761***
Range	(0.000312)	(0.00112)	(0.00230)	(0.00369)	(0.00154)	(0.00917)	(0.0110)	(0.0195)	(0.00443)	(0.0290)	(0.0170)	(0.0236)
Bldg Age >60	0.00342***	-0.00451***	-0.00230	-0.00142	0.0104***	-0.0201***	-0.0340***	-0.0305**	0.964***	0.0564***	-0.657***	-0.652***
	(0.000218)	(0.000507)	(0.00210)	(0.00289)	(0.000954)	(0.00262)	(0.00672)	(0.0118)	(0.00275)	(0.0143)	(0.0196)	(0.0268)
Age since Reno	0.000907**	-0.00257**	-0.00507**	-0.00163	0.00496***	-0.000329	-0.00471	0.00858	0.0135***	-0.0303**	0.0275	0.0208
0-20 Range	(0.000409)	(0.00111)	(0.00208)	(0.00281)	(0.00173)	(0.00449)	(0.00882)	(0.0139)	(0.00511)	(0.0132)	(0.0172)	(0.0254)
# of FE												
Observations	3,048,185	3,048,185	471,649	476,784	497,655	497,655	96,531	99,896	4,338,455	4,338,455	829,947	944,746
R-squared	0.977	0.461	0.423	0.656	0.970	0.570	0.550	0.769	0.982	0.422	0.400	0.624
Panel B: Buildings <=20 Years Old												
Building Age	0.00702***	-0.00617***	-0.0237***	-0.0137	0.0114***	-0.0244***	-0.0827***	-0.0387	0.953***	0.154***	-0.633***	-0.595***
	(0.00104)	(0.00153)	(0.00455)	(0.00943)	(0.00313)	(0.00773)	(0.0234)	(0.0579)	(0.00987)	(0.0283)	(0.0366)	(0.0542)
Age since Reno	-0.000734	-0.00784	0.000983	0.00790	0.0156	0.0124	0.0519	0.0928	0.0747	0.0743	0.117*	0.128
	(0.00383)	(0.00655)	(0.0143)	(0.0226)	(0.0111)	(0.0275)	(0.0883)	(0.161)	(0.0467)	(0.0776)	(0.0674)	(0.122)
Observations	183,863	183,863	39,339	39,712	29,435	29,435	7,461	7,676	281,033	281,033	69,053	78,216
R-squared	0.979	0.487	0.462	0.713	0.976	0.649	0.620	0.831	0.981	0.421	0.408	0.678

Notes: Regressions are at the establishment-year level. Only observations with values of the dependent variable reported by the establishment are included. All observations imputed by D&B are excluded. The Switchers sample only includes one observation per establishment-building whereas the other samples may have multiple observations per establishment-building.

Table 5: Office Building Level Results, NYC D&B -- Building FE

Outcome	# of Establishments	log # of Establishments	log Employment	log Emp, <HS, HS	log Emp, > HS	log Wage	log Sales
Bldg Age, 0-20	0.196***	0.0357***	0.0456***	0.0555***	0.0324***	-0.000336***	0.0238***
Range	(0.00948)	(0.000647)	(0.000891)	(0.00111)	(0.000749)	(7.77e-05)	(0.000882)
Bldg Age, 20-40	0.114***	0.0170***	0.0142***	0.0233***	0.00176***	-0.000449***	-0.000404
Range	(0.0111)	(0.000600)	(0.000758)	(0.000998)	(0.000597)	(7.46e-05)	(0.000790)
Bldg Age, 40-60	0.133***	0.0231***	0.0227***	0.0328***	0.00960***	-0.000597***	0.00822***
Range	(0.00932)	(0.000550)	(0.000728)	(0.000995)	(0.000497)	(5.40e-05)	(0.000655)
Bldg Age >60	0.0946***	0.0208***	0.0244***	0.0342***	0.0104***	-0.000537***	0.00725***
	(0.00775)	(0.000438)	(0.000538)	(0.000744)	(0.000355)	(4.04e-05)	(0.000483)
Age since Reno,	0.0129**	0.00269***	0.00628***	0.00576***	0.00845***	5.05e-05	0.00501***
0-20 Range	(0.00558)	(0.000314)	(0.000410)	(0.000492)	(0.000404)	(4.82e-05)	(0.000468)
Observations	3,158,720	3,158,720	2,854,890	2,854,890	2,805,894	2,805,894	2,777,118
R-squared	0.722	0.824	0.841	0.820	0.852	0.782	0.825

Employment and Sales numbers include imputatations. All regressions additionally include year fixed effects.

Table A1: Summary Statistics -- CompStak Data

	Property Type		
	Office	Retail	Industrial
Panel A: Control Variables			
Class A Space Indicator	0.51	0.08	0.16
	(0.50)	(0.27)	(0.37)
Class B Space Indicator	0.44	0.14	0.34
	(0.50)	(0.34)	(0.47)
Building Square Footage	0.03	0.07	0.07
Missing Indicator	(0.18)	(0.25)	(0.25)
Building Number of Floors	11.98	5.08	1.11
	(13.18)	(8.90)	(0.84)
Building Number of Floors	0.27	0.54	0.44
Missing	(0.44)	(0.50)	(0.50)
Lease Renewal Indicator	0.58	0.68	0.56
	(0.49)	(0.47)	(0.50)
Years Since Building	15.75	17.70	20.15
Renovation	(11.49)	(15.19)	(14.11)
Years Since Building	0.60	0.74	0.90
Renovation Missing	(0.49)	(0.44)	(0.30)
Panel B: Lease Counts in Largest Markets			
Los Angeles	8,812	2,680	4,396
New York	8,941	3,869	897
Dallas	10,059	683	1,996
San Francisco	8,574	934	1,683
Washington	7,255	429	541
Houston	6,206	707	816
Chicago	4,481	910	1,671
Total Leases	104,937	23,732	32,163
Total Buildings	26,201	17,155	21,739

Table A2: Log Rent Results: Retail and Industrial Sectors

	Full CompStak Data				New Leases Only			
Panel A: Retail Sector								
Bldg Age, 0-20	-0.0193***	-0.0219***	-0.0117***	-0.0202***	-0.0196***	-0.0220***	-0.0116**	-0.0204***
Range	(0.00130)	(0.00104)	(0.00268)	(0.00128)	(0.00251)	(0.00164)	(0.00470)	(0.00249)
Bldg Age, 20-40	-0.00244	-0.000969	0.00397	-0.00288	-0.00129	0.000869	0.00693	-0.00162
Range	(0.00203)	(0.00107)	(0.00299)	(0.00201)	(0.00410)	(0.00165)	(0.00573)	(0.00412)
Age since Reno,				-0.00318*				-0.00445
0-20 Range				(0.00175)				(0.00382)
Observations	23,732	23,732	23,732	23,732	7,564	7,564	7,564	7,564
Unique FE	3120	634	17195	3120	2054	559	5958	2054
R-squared	0.696	0.615	0.880	0.698	0.732	0.607	0.924	0.733
Panel B: Industrial Sector								
Bldg Age, 0-20	-0.00159**	-0.000587	0.00105	-0.00189***	-0.000312	-0.000110	0.00164	-0.000575
Range	(0.000639)	(0.000623)	(0.00239)	(0.000633)	(0.000805)	(0.000721)	(0.00398)	(0.000788)
Bldg Age, 20-40	-0.00534***	-0.00183***	0.00316	-0.00567***	-0.00495***	-0.00200***	0.00469	-0.00537***
Range	(0.00101)	(0.000566)	(0.00265)	(0.00101)	(0.00143)	(0.000749)	(0.00481)	(0.00143)
Age since Reno,				-0.00158				-0.00288
0-20 Range				(0.00254)				(0.00312)
Observations	32,162	32,161	32,162	32,162	14,004	14,004	14,004	14,004
Unique FE	2166	517	25883	2166	1572	455	12196	1572
R-squared	0.704	0.631	0.901	0.705	0.745	0.672	0.930	0.747
FE	Zip	Submarket	Tenant	Zip	Zip	Submarket	Tenant	Zip
Ctrls	All	Short+CBDDis	Short	All	All	Short+CBDDis	Short	All

Specifications are identicial to those in Table 2.

Table A3: Log Square Feet of Space Rented Results: Retail and Industrial Sectors

	Full CompStak Data				New Leases Only			
Panel A: Retail Sector								
Bldg Age, 0-20	-0.00584**	-0.00874***	0.00273	-0.00722***	-0.00718	-0.0108***	0.00337	-0.00877**
Range	(0.00250)	(0.00187)	(0.00212)	(0.00252)	(0.00449)	(0.00282)	(0.00443)	(0.00445)
Bldg Age, 20-40	0.00550	-0.00462**	-0.00122	0.00487	0.00208	-0.00423	-0.000715	0.00166
Range	(0.00414)	(0.00190)	(0.00270)	(0.00412)	(0.00836)	(0.00310)	(0.00568)	(0.00832)
Age since Reno,				-0.0142***				-0.0149**
0-20 Range				(0.00391)				(0.00694)
Observations	23,732	23,732	23,732	23,732	7,564	7,564	7,564	7,564
Unique FE	3120	634	17195	3120	2054	559	5958	2054
R-squared	0.325	0.167	0.932	0.329	0.473	0.231	0.960	0.476
Panel B: Industrial Sector								
Bldg Age, 0-20	-0.0180***	-0.0298***	-0.0196***	-0.0177***	-0.0242***	-0.0351***	-0.0241***	-0.0240***
Range	(0.00227)	(0.00224)	(0.00466)	(0.00228)	(0.00277)	(0.00258)	(0.00793)	(0.00277)
Bldg Age, 20-40	0.00263	-0.0249***	-0.0103**	0.00268	0.00375	-0.0204***	-0.0113	0.00354
Range	(0.00394)	(0.00226)	(0.00448)	(0.00399)	(0.00526)	(0.00305)	(0.0106)	(0.00533)
Age since Reno,				-0.0191***				-0.0169*
0-20 Range				(0.00696)				(0.00963)
Observations	32,162	32,161	32,162	32,162	14,004	14,004	14,004	14,004
Unique FE	2166	517	25883	2166	1572	455	12196	1572
R-squared	0.604	0.516	0.947	0.604	0.667	0.574	0.964	0.667
FE	Zip	Submarket	Tenant	Zip	Zip	Submarket	Tenant	Zip
Ctrls	All	Short+CBDDis	Short	All	All	Short+CBDDis	Short	All

Specifications are identicial to those in Table 3.

Table A4: NYC Retail Building Results, D&B Data

Outcome	log Employment			log Sales			Firm Age		
Fixed Effect	Estab.	Building		Estab.	Building		Estab.	Building	
Sample	All	All	Switchers	All	All	Switchers	All	All	Switchers
Panel A: All Buildings									
Bldg Age, 0-20	0.00263**	-0.00283	-0.00844	0.00615**	0.00196	0.0136	0.975***	0.340***	-0.476***
Range	(0.00117)	(0.00252)	(0.00949)	(0.00256)	(0.00827)	(0.0573)	(0.00711)	(0.0243)	(0.0367)
Bldg Age, 20-40	0.00225***	0.000660	-0.00827	0.00641**	-0.0107	-0.0426	0.986***	0.211***	-0.507***
Range	(0.000773)	(0.00146)	(0.00759)	(0.00265)	(0.00754)	(0.0557)	(0.0114)	(0.0332)	(0.0351)
Bldg Age, 40-60	0.00156***	-0.00184	-0.00631	0.00601***	-0.00293	-0.00489	0.993***	0.254***	-0.527***
Range	(0.000576)	(0.00128)	(0.00650)	(0.00181)	(0.00508)	(0.0341)	(0.00806)	(0.0221)	(0.0242)
Bldg Age >60	0.00126***	0.000994**	0.00558	0.00462***	0.00109	0.00131	0.988***	0.238***	-0.517***
	(0.000236)	(0.000485)	(0.00557)	(0.000887)	(0.00186)	(0.0210)	(0.00309)	(0.00972)	(0.0177)
Age since Reno,	0.000840	-0.00159	-0.00868***	-0.000188	-0.00872**	-0.0344	0.000746	-0.0406**	0.0352*
0-20 Range	(0.000523)	(0.00104)	(0.00294)	(0.00157)	(0.00408)	(0.0291)	(0.00520)	(0.0157)	(0.0196)
Observations	837,311	837,311	116,112	113,166	113,166	20,505	1,150,751	1,150,751	204,869
R-squared	0.982	0.608	0.560	0.985	0.828	0.805	0.982	0.520	0.528
Panel B: Buildings <=20 Years Old									
Building Age	0.00351***	-0.00175	-0.00192	0.00625**	0.00904	0.115	0.980***	0.341***	-0.435***
	(0.00101)	(0.00249)	(0.0255)	(0.00301)	(0.00816)	(0.259)	(0.00711)	(0.0259)	(0.0503)
Age since Reno	-0.00683	-0.00356	-0.0348	-1.86e-05	-0.000117	-0.0840	0.0412	0.0689	0.176
	(0.00761)	(0.0112)	(0.0366)	(0.00560)	(0.0172)	(0.483)	(0.0311)	(0.0722)	(0.168)
Observations	42,361	42,361	8,247	5,474	5,474	1,310	56,690	56,690	13,586
R-squared	0.984	0.673	0.642	0.984	0.848	0.842	0.992	0.615	0.631

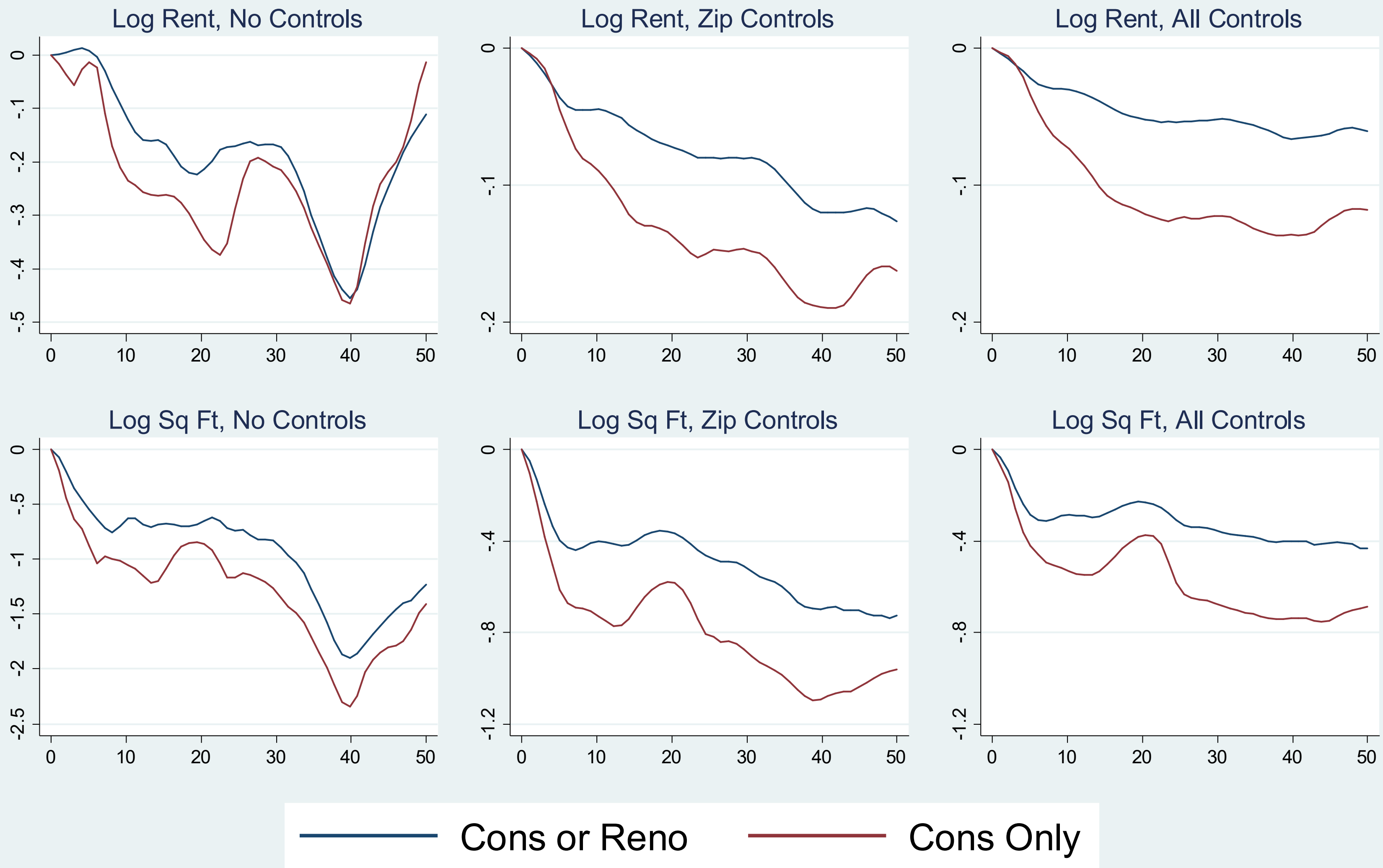
Specifications are identical to those in Table 4.

Table A5: NYC Industrial Building Results, D&B Data

Outcome	log Employment			log Sales			Firm Age		
Fixed Effect	Estab.	Building		Estab.	Building		Estab.	Building	
Sample	All	All	Switchers	All	All	Switchers	All	All	Switchers
Panel A: All Buildings									
Bldg Age, 0-20	0.00602***	-0.00657	-0.0215*	0.00967**	-0.0227**	-0.0584	1.029***	0.452***	-0.577***
Range	(0.00155)	(0.00416)	(0.0112)	(0.00422)	(0.0114)	(0.0366)	(0.0184)	(0.0474)	(0.0711)
Bldg Age, 20-40	0.00407***	-0.00220	-0.00223	0.00291	-0.00721	-0.0243	0.946***	0.301***	-0.441***
Range	(0.00126)	(0.00338)	(0.00960)	(0.00358)	(0.00730)	(0.0259)	(0.0292)	(0.0579)	(0.0886)
Bldg Age, 40-60	0.00476***	-0.00365*	-0.0124	0.00958***	-0.0218**	-0.0391*	1.006***	0.354***	-0.565***
Range	(0.000977)	(0.00213)	(0.00803)	(0.00256)	(0.00840)	(0.0202)	(0.0194)	(0.0436)	(0.0730)
Bldg Age >60	0.00370***	-0.000296	-0.00184	0.00632***	-0.00558**	-0.000267	0.999***	0.359***	-0.463***
	(0.000601)	(0.00168)	(0.00517)	(0.000982)	(0.00239)	(0.0113)	(0.00834)	(0.0262)	(0.0811)
Age since Reno,	0.00180*	-0.00412**	-0.00592	-0.000408	-0.00422	-0.0118	-0.0148	-0.115***	-0.0332
0-20 Range	(0.000967)	(0.00206)	(0.00599)	(0.00425)	(0.0106)	(0.0247)	(0.0196)	(0.0362)	(0.0504)
Observations	571,717	571,717	91,373	136,328	136,328	29,663	675,791	675,791	126,375
R-squared	0.973	0.523	0.484	0.980	0.670	0.630	0.969	0.421	0.528
Panel B: Buildings <=20 Years Old									
Building Age	0.00599***	-0.00617	-0.0201	0.0102**	-0.0169	-0.0106	1.017***	0.445***	-0.622***
	(0.00174)	(0.00393)	(0.0212)	(0.00464)	(0.0145)	(0.131)	(0.0200)	(0.0513)	(0.109)
Age since Reno	0.0112	0.0101	-0.00529	-0.00716	-0.0188	-0.0488	0.0177	0.146	0.581***
	(0.00996)	(0.0119)	(0.0637)	(0.0148)	(0.0468)	(0.334)	(0.0732)	(0.193)	(0.206)
Observations	27,397	27,397	5,931	6,379	6,379	1,796	34,898	34,898	8,638
R-squared	0.980	0.634	0.618	0.990	0.772	0.760	0.978	0.581	0.589

Specifications are identical to those in Table 4.

Figure 1: Residual Relationships with Building Age & Renovation



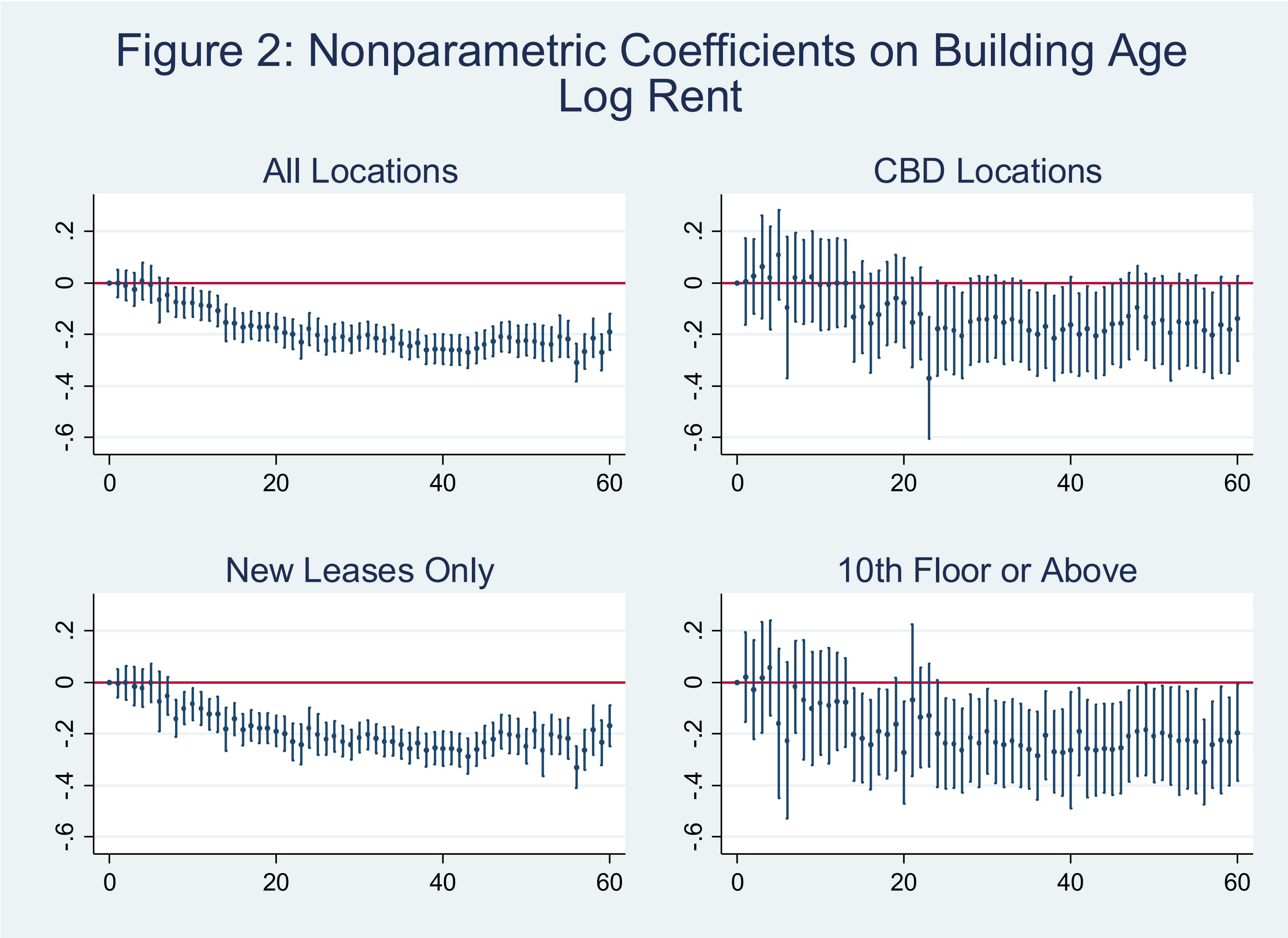


Figure 2: Nonparametric Coefficients on Building Age
Log Rent
All Locations
CBD Locations
New Leases Only
10th Floor or Above
.2
0
-.2
-.4
-.6
0
20
40
60

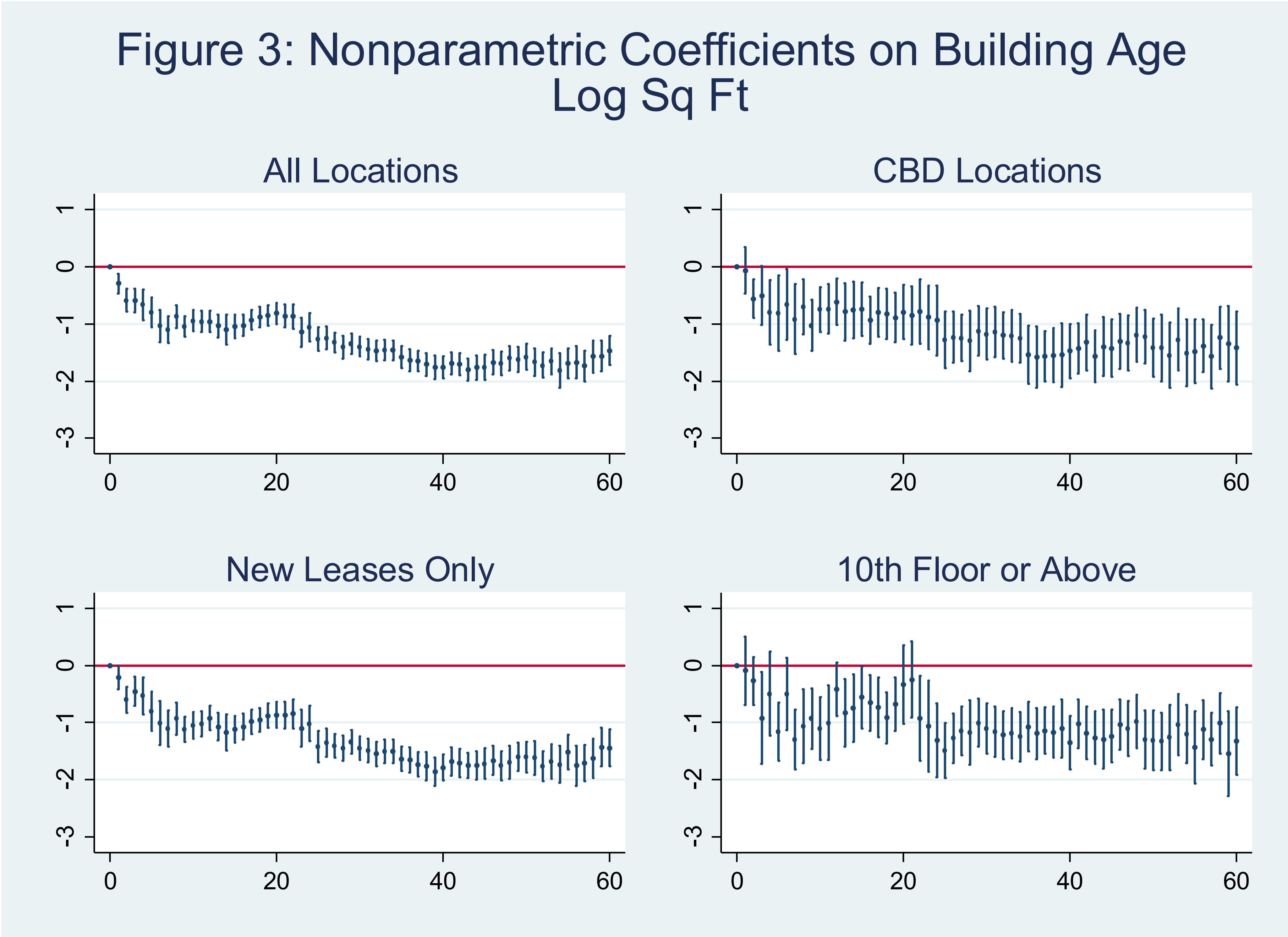


Figure 3: Nonparametric Coefficients on Building Age
Log Sq Ft
All Locations
CBD Locations
New Leases Only
10th Floor or Above
1
0
-1
-2
-3
0
20
40
60

Figure 4: Establishment Production
Building Age 0-20

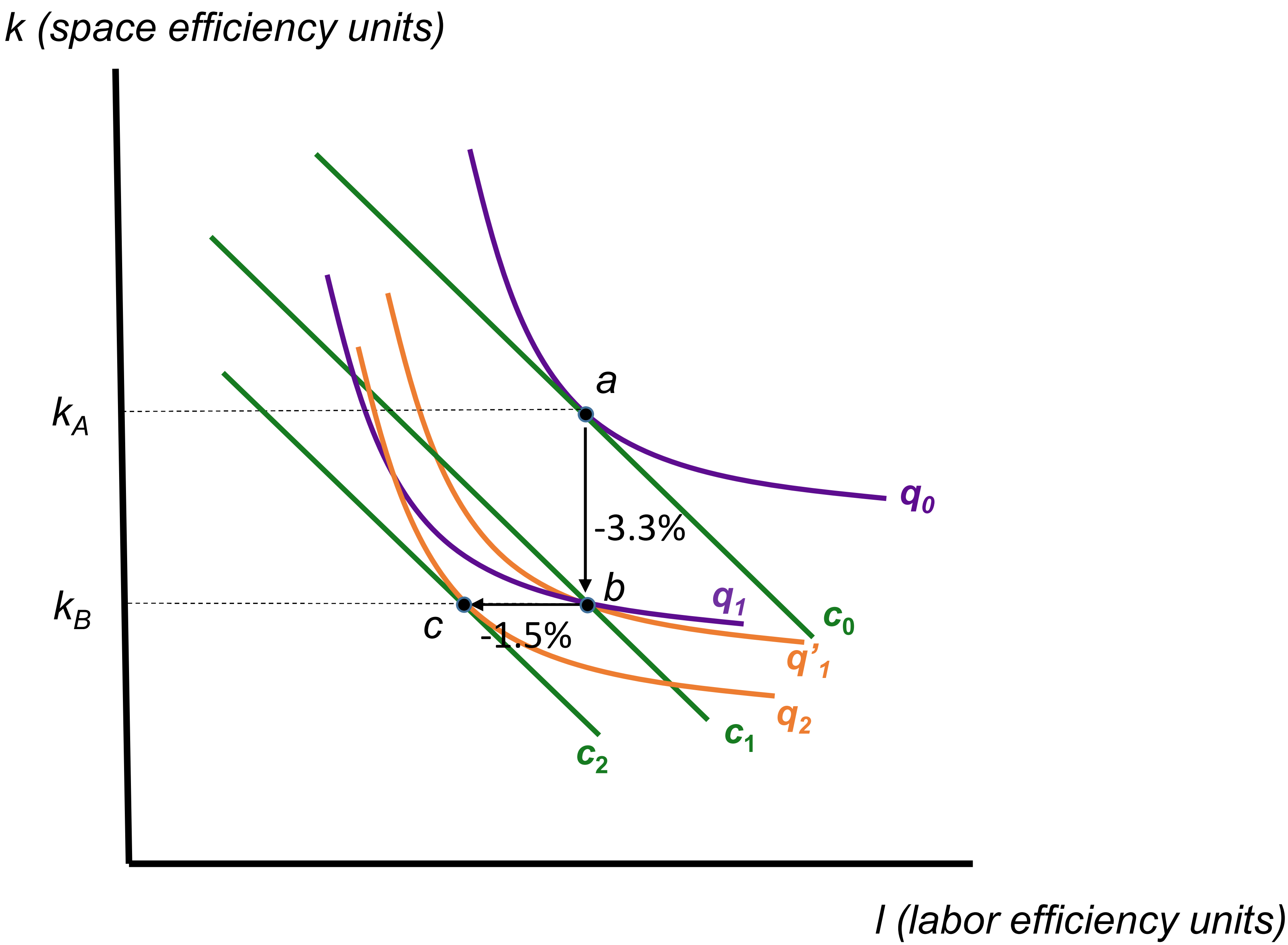


Figure 5: Building Production
Building Age 0-20

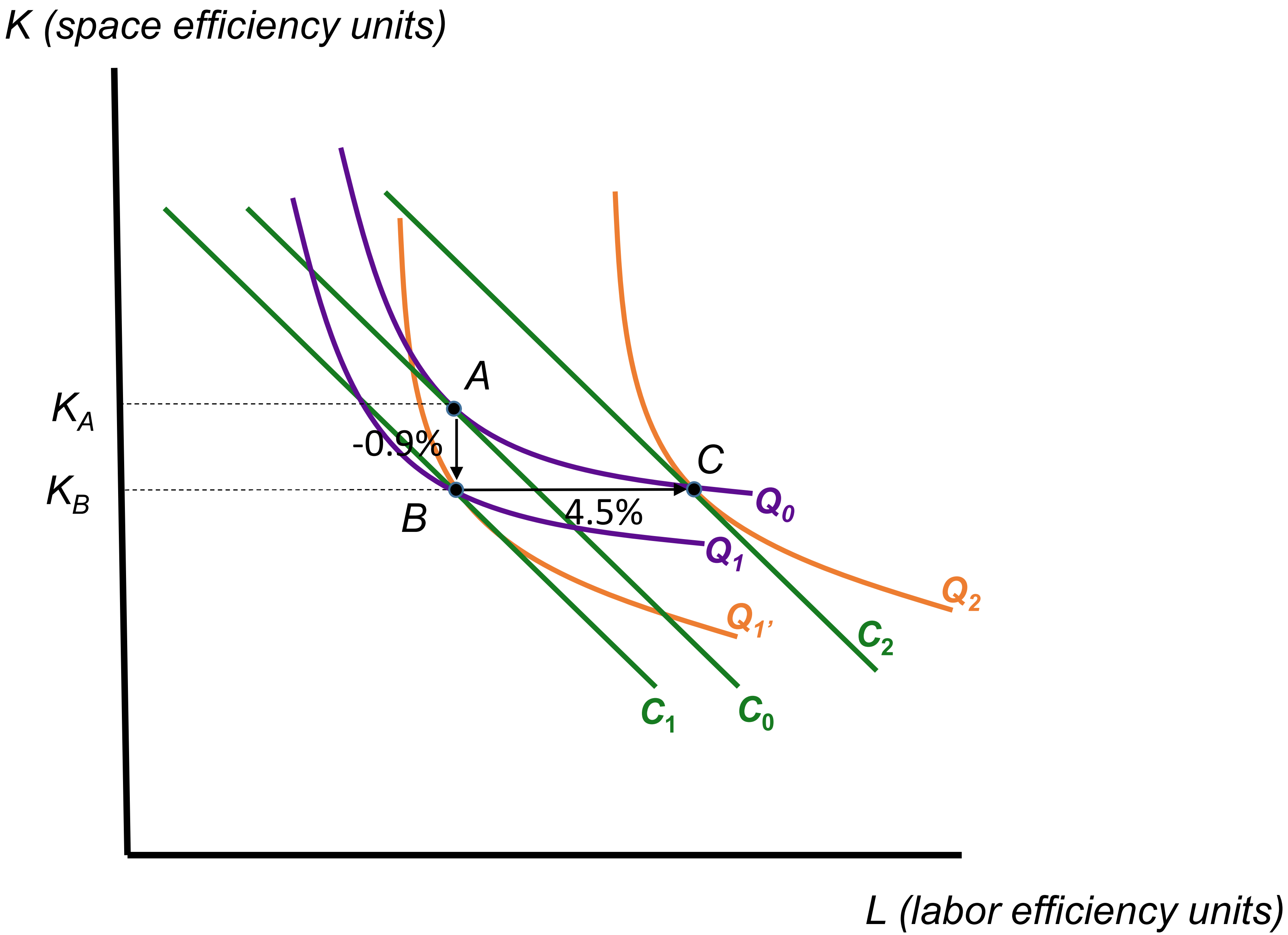


Figure 6: Bid-Rents for Age and the Hedonic Price Function

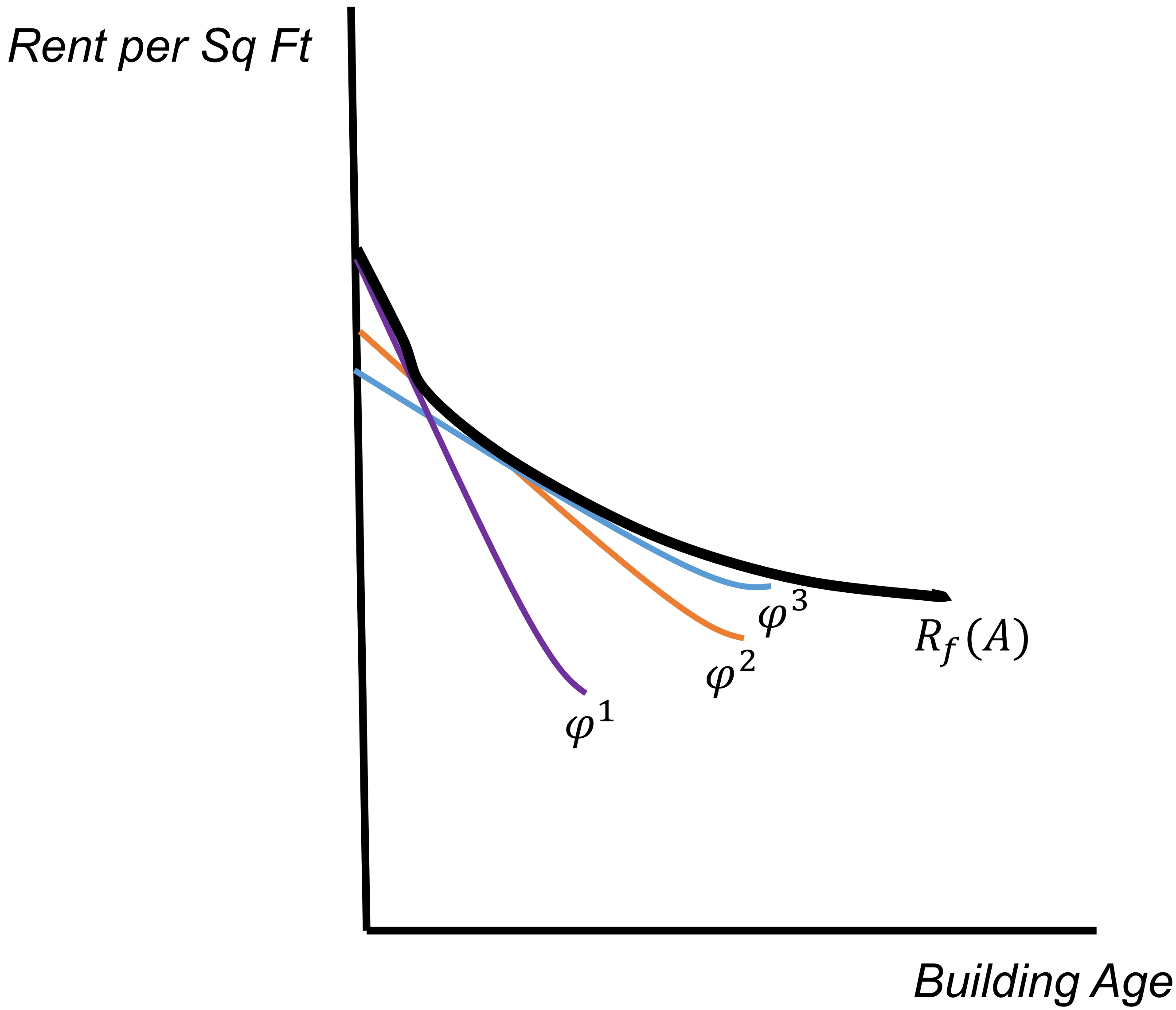
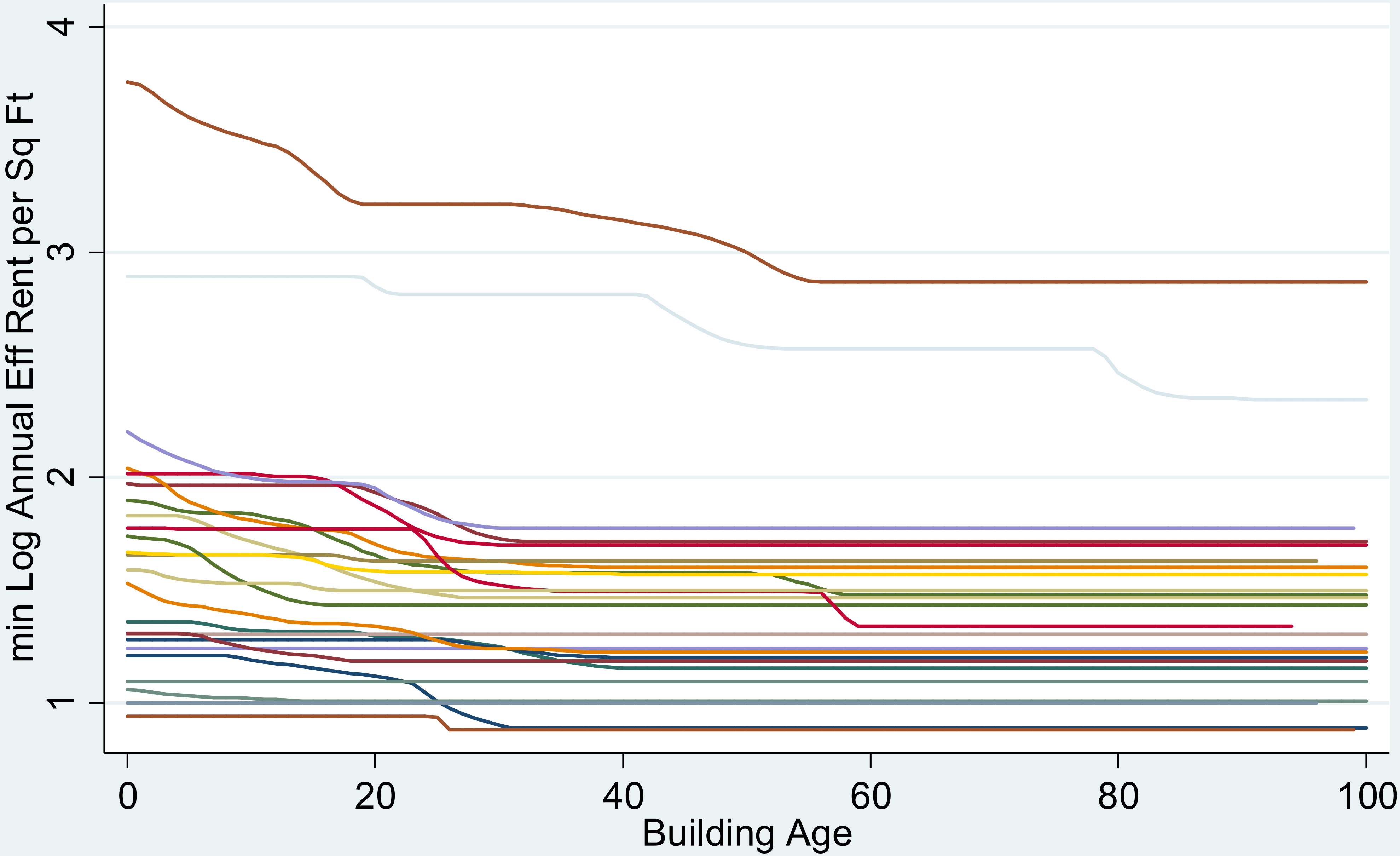


Figure A1: Minimum Rent by City and Building Age



Each line is for a different city.
The top two lines are for San Francisco and New York respectively.