

**The Vertical City:
Rent Gradients and Spatial Structure**

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Abstract

Tall commercial buildings are equivalent in scale to small cities. Nevertheless, urban economists have typically treated tall buildings as black boxes, with all employment at ground level and all tenants paying the same rent. This paper challenges this practice. Evidence from three unique datasets shows that vertical rent gradients are non-monotonic, with a ground floor premium of roughly 50%, rent increasing by roughly 0.6% per floor beyond the second floor, and by even more near the top of a building. Moving up one floor has a similar effect on rent as adding 2,500 workers to a building's zipcode. Furthermore, within-building employment has a larger marginal impact on rent than zipcode employment, consistent with agglomeration economies that attenuate with distance. The paper's theory shows vertical spatial structure to be determined by a tension between access costs and various sorts of amenities that increase profits for a commercial tenant, with both rising as one moves to higher floors. This explains why access-oriented industries like retail sort into ground-level locations, while amenity-oriented establishments like law sort into higher locations. It also helps to explain why the most productive office establishments occupy the highest floors.

JEL Codes: R00 (General Urban, Rural, and Real Estate Economics), R33 (Nonagricultural and Nonresidential Real Estate Markets)

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I. Introduction

Cities, like the world itself, are not flat, but urban and real estate economists have often treated them as if they were.¹ This is an important omission. Cities are defined by the tall buildings that make up their skylines, and their economies are dominated by the office activities that these buildings host. To take one famous example, the World Trade Center's twin towers in total had roughly 50,000 workers in 10 million square feet of space, making each equivalent in scale to a small town.² And the differentiation within such tall buildings probably exceeds what one might see in a small town. Within a tall building there are prestigious and downmarket "neighborhoods." There are educated workers engaged in a range of high-value production activities and uneducated workers who carry out more routine activities. There are also infrastructure issues analogous to those facing a city, such as the management of the building's elevators. In other words, tall buildings are like small cities in composition as well as in scale. And tall buildings are increasingly important, with recent years witnessing a renewed burst of skyscraper construction worldwide.³ Despite this and the great complexity of the economic activity taking place within tall buildings, economists have typically paid little attention to what takes place inside tall buildings, effectively treating these buildings as black boxes.⁴

This paper will begin to fill in this gap by considering vertical spatial structure. It builds on the standard urban model of Alonso (1964), Mills (1967), and Muth (1969), with its analysis of general equilibrium in a monocentric setting. This has been the workhorse model in urban economics, generating important insights regarding how the interactions among markets govern the nature of cities. The monocentric model also is fundamental for real estate, explaining in a precise way the aspects of location that impact real estate prices. This model has only a crude treatment of verticality, however. It allows the production of residential space to employ variable capital to land ratios. This translates directly into building height. It is typically assumed that capital prices do not vary with space. This means that the capital-to-land ratio and building height both vary inversely with distance to the exogenous city center. In these treatments, all activity at a particular distance from the city center is treated as taking place at ground level. In other words, the standard model ignores what takes place within a building at a particular location, and in that sense treats the world as flat.

¹ This is evident in literature reviews by Brueckner (1987), Glaeser and Kahn (2004), Combes and Gobillon (2015), and Duranton and Puga (2015).

² See <https://www.nysm.nysed.gov/wtc/about/facts.html>.

³ The burst in construction has included several successive tallest buildings in the world (Petronas Towers, Taipei 101, and Burj Khalifa). There has also been a skyscraper boom in New York, as well as in other North American cities. See *Economist* (2015) and <http://www.nationalgeographic.com/new-york-city-skyline-tallest-midtown-manhattan/>.

⁴ As discussed in greater detail below, the few recent papers on tall buildings (Barr, 2012, Koster *et al*, 2014a, Ahlfeldt and McMillen, 2015) have focused on building height rather than internal structure.

This paper's analysis is guided by a theoretical model that extends standard economic analysis by considering verticality. Specifically, the buildings are each literally "long narrow cities" in the sense of Solow and Vickrey (1971). The vertical transportation costs that motivate our research are quantitatively important relative to the more traditional horizontal transportation costs at the heart of the Solow-Vickrey analysis. Census data indicate average one way commutes of 24 minutes (Rosenthal and Strange, 2011). Calculations based on an IBM (2010) survey of office tenants show a typical tenant spending 22.36 minutes in elevators in a business day. In addition to being unique in considering vertical transportation, the paper's analysis is also unique in providing a spatial model of commercial real estate markets. These commercial markets are vast, larger than the market for corporate bonds. While there is an extensive financial literature on commercial real estate, focusing on Real Estate Investment Trusts (REITS), there has been very little research on the spatial nature of these markets. The model generates predictions about both the vertical rent gradient and vertical spatial structure.

The model's predictions are then tested. We make use of three unique data sources, two of which have only recently become available. First, we make use of a set of confidential offering memoranda (OM) that lay out the tenant stack (tenant locations) and rents by floor for 93 tall buildings spread across 18 metropolitan areas. Second, we make use of a new commercial rent dataset produced by CompStak Inc. (CS). These data report rents and occupancy for a largely random set of tenants within buildings spread across portions of eight metropolitan areas. Third, we employ establishment-level Dun and Bradstreet data (D&B). Although D&B does not report rents, it does report floor number and a wide range of firm and establishment characteristics that help us to understand sorting patterns within tall buildings in response to vertical amenities that make high locations attractive despite inferior access. In some applications we match the D&B data at the tenant level with occupants of the OM buildings. In other instances we match building-level and zipcode-level employment from D&B and Census to individual tenants in the CS data. In still other extensions we develop a separate D&B-only database drawn from 12 metropolitan areas to examine systematic vertical patterns of labor productivity (based on sales per worker) for law offices and other common industries in tall buildings.

The empirical analysis reaches a number of important conclusions. The first is that verticality matters. Both pricing and spatial structure vary vertically in ways that standard urban models fail to capture. Second, the vertical rent gradient is non-monotonic. Rents initially decrease sharply as one moves above the ground floor and access worsens. In other words, there is a ground floor premium. Above the second floor, however, rents rise as some sort of amenity outweighs the growing adverse access effect. This amenity is more complicated for the commercial markets that we consider than it would be in a residential setting. For the latter, it is easy to believe that residents value the views that high floors create. See, for instance, Pollard (1980, 1982), and the literature on the hedonics of views that

follows.⁵ In a commercial setting, however, rents can rise as access deteriorates only if *profit* rises as one moves higher in the building. We will argue below that this can occur if workers view height in the building as a workplace amenity. It can also arise through signaling that may help to attract talented workers or convince clients of service quality.

The magnitudes of these effects are substantial. Moving up from the ground floor to the second floor, rents drop roughly 50% depending on the model and sample. Moving up from the second floor causes rent to increase by roughly 0.6 percent per floor with a steeper rent gradient high up off the ground (e.g. above floor forty). It is worth emphasizing that the magnitudes of these estimates differ across individual buildings and appear to vary systematically with building height and other features of the building and location. However, the core qualitative pattern is robust: a sharp ground floor premium with rents rising above the second floor at an increasing rate.

The paper's third main conclusion derives from these magnitude calculations. In models where we added zipcode-level employment and within-building employment to our rent models, we find a stronger relationship between rent and building employment than with employment in the building's zipcode. More precisely, the effect of within-building employment is more than three times larger than the effect of zipcode employment. To put the various estimates in context, adding 2,500 workers to a building's zipcode increases rent by an amount about equal to moving up one floor. While this paper is not primarily concerned with agglomeration, these results are consistent with agglomeration economies that attenuate with distance, echoing findings in Rosenthal and Strange (2003, 2004, 2005, 2008, and 2012) and Arzaghi and Henderson (2008). Moreover, adding employment to the rent models has almost no effect on the estimated vertical rent pattern and vice versa. This means that both traditional "horizontal" measures of nearby economic activity as well as vertical location have important effects on commercial rent. Our findings also suggest that these effects are largely independent of each other.

The paper's fourth main conclusion follows naturally from the vertical rent pattern: vertical spatial structure is determined by tension between access and amenities. There are many manifestations of this. For instance, access-oriented retailers tend to occupy the lowest floors of tall buildings, while amenity-oriented office uses occupy higher floors. Within the office category, some activities are consistently found high in the building, while others are not. Law firms, for instance, are frequently found on high floors. More generally, establishments that display high labor productivity, in the sense

⁵ See Sirmans et al (2005) for a review of the broader hedonic literature in which the view literature resides. Rodriguez and Sirmans (1994) exemplifies this line of research, one that is entirely residential. The implications of amenities related to building height in a commercial setting have not been considered at all, and the issues are different in important ways. The broader issue of vertical transportation costs has also been considered in a limited way within urban economics. Sullivan (1991) shows how tall buildings can make sense even on cheap land when the advantages of vertical transportation are great, as they are, for instance, with elderly households. This is also a residential paper.

that sales-per-worker is high conditional on employment at the site, tend to be located higher. This result is consistent with high productivity workers valuing view amenities to an especially great degree, which would be the case if view amenities were a normal good. Furthermore, we also find that establishments with high employment also locate on high floors. All of these results are robust to inclusion of MSA fixed effects, zipcode fixed effects, or building fixed effects. Overall, we tend to observe establishments that are in some sense high fliers to locate towards the top of the buildings in our samples.⁶

The paper builds on several lines of research. The first concerns the theory of urban spatial structure. See Brueckner (1987) and Duranton and Puga (2015) for insightful surveys of the research that followed the initial contributions of Alonso-Muth-Mills. The long narrow city paper of Solow and Vickrey (1971) is one particularly relevant paper, since with tall buildings, the long-narrow assumption holds exactly, in contrast to actual cities. There have been few papers that have considered vertical structure. Urban historians, see Glaeser (2011) or Bernard (2014) for instance, have noted that prior to the elevator, residential buildings were typically under six stories, with the top occupied by the lowest income tenants. Elevators were crucial to the development of modern cities because they allowed increases in density. While this is presumably because they have increased accessibility, this literature does not examine what takes place within a building. Our contribution here is to carry out this examination.

The second line of research concerns the empirics of urban spatial structure. As noted by Duranton and Puga (2015), much of the empirical research assessing the predictions of the monocentric model has been carried out at an aggregate level despite the model offering strong predictions at the individual property level. The analysis here is micro. With regard to both the empirical and theoretical literatures, the paper breaks new ground in its focus on the spatial structure and pricing for commercial real estate. The prior literature has instead focused almost entirely on residential issues. Ahlfeldt et al (2015) is a notable exception, focusing on spatial interactions between households and their employers. Finally, by focusing on within building variation, the paper avoids some of the pitfalls noted by Duranton and Puga for estimation of residential models. In particular, the omitted variable problems that have plagued estimates of residential rent gradients as with unobserved local amenities are less serious in this setting, since suites in the same building will tend to have identical or at least similar unobservable characteristics. We also do not face the difficulty associated with defining the employment center; within a building, the first floor naturally plays a central role. This paper's analysis is thus a particularly clean treatment of the crucial issue of spatial equilibrium.

⁶ The most high-performing such tenants are often referred to in the real estate industry as “trophy” or “anchor” tenants. In the specific case of retail tenants, the term “anchor” refers more narrowly to large tenants who generate externalities for others.

The third line of related research concerns commercial real estate. As noted above, commercial real estate is a very important asset class, but it has perhaps received less academic attention than it has merited. There is a well-established financial literature on commercial real estate. There is a tendency in this literature to take rents as primitive and then compute asset values, capital structures, or asset allocations based on these primitive prices (see, for instance, the textbook by Geltner et al, 2007). One line of economic research has focused on the valuation of buildings. Colwell et al (1988) estimates a relationship between building price and height. Shilton and Zaccaria (1994) is another paper in this tradition. Another line of research has considered commercial leasing. Grenadier (1995) considers decision to lease in particular, exploring the option issues that arise out of the dynamics of the leasing decision. Wheaton and Torto (1988) consider the macroeconomic dynamics of office markets. Finally, other related literature has examined retail malls, focusing on the role of anchor tenants. Brueckner (1993) provides a seminal model of the incentive issues. Konishi and Sandfort (2003) present a newer model with a search structure that also considers anchor tenants. Gould and Pashigian (1998) and Gould, Pashigian, and Pendergast (2005) carry out an empirical survey of these and related issues. With respect to the present paper, prior work on commercial real estate has only lightly touched on spatial issues – they are mentioned in some of the papers on malls – and has not touched at all on vertical issues. Our paper, therefore, fills a large hole in the understanding of one of the crucial markets in a city’s economy.

Finally, the fourth line of relevant research concerns building height. This literature combines elements of the three lines of research described above. On the theory side, Helsley and Strange (2008) present a game theoretic model where builders derive payoffs from having a tall building independent of the rents that might accrue. On the empirical side, Barr (2010, 2012) carefully documents the patterns of building heights in Manhattan and analyzes the forces at work. Koster et al (2014a) employ rich data from the Netherlands to consider the relationship of office rents to building heights. They find that an office in a taller building will command a greater rent, which they show can reflect views or the landmark nature of tall structures. Ahlfeldt and McMillan (2015) document a robust relationship between building heights and land rents using Chicago microdata that spans more than a century. In addition, their paper shows that the spatial dispersion of tall buildings can be explained by the dissipative competition for height modeled by Helsley and Strange.⁷ These papers are notable as papers that move beyond the flat earth approaches of classic urban economics. The present paper is distinct from them by virtue of the microdata that we have assembled, allowing us to look *within* buildings in ways that have not been possible using previous data.⁸

⁷The present paper and Ahlfeldt-McMillan (2015) were both submitted in June 2015 for consideration for presentation at the Urban Economic Association 2015 meetings. Neither author team was aware of the other’s work. The similarity in titles was accidental.

⁸ Koster et al (2014a) have some observations of an office suite’s floor in their data, but fewer than 100.

The remainder of the paper will be organized as follows. Section II presents a theoretical model laying out some of the microfoundations of commercial markets and presenting some predictions that will be confronted with data. Section III describes the unique data that have gone into this paper's analysis. Section IV computes vertical rent gradients, while Section V presents results on which tenants locate where. Section VI concludes.

II. A theory of vertical bid rent and spatial structure

This section lays out a theory of the vertical allocation of activities to commercial space. The demand structure is stylized, with rents depending on two factors: access to the ground floor and amenities that rise (in some situations) with height off the ground. As noted above, the concept of amenities is quite different for the commercial space that we consider here than for residential space. We cannot simply borrow from the more developed residential amenities literature, and so we will develop more precisely below the way that height can contribute to profit. The section will proceed incrementally, beginning with the vertical bid rent of the retail tenants of one building. These tenants are assumed to care only about access. We then move on to consider office tenants who care about both access and amenities. We then consider both sorts simultaneously. The model generates a number of predictions that will be the basis of the empirical analysis that comprises the remainder of the paper.

A. Retail activities

Consider a building with a large pool of potential retail tenants. In this "open" framework, potential tenants bid for locations. Each tenant consumes a fixed amount of space, s , normalized to unity. Each tenant employs a fixed number of workers, n , also normalized to unity. These and other simplifying assumptions are relaxed later in the section.

The tenants serve a pool of customers of size M . This includes both customers from outside the building and also those who work in the building and also make purchases there. We assume that both groups appear at the ground floor of the building. Each tenant has the potential to serve a share η of these customers. A given customer may buy from multiple tenants, for instance shoes and a shirt. Supposing that customers are matched with particular tenants is a convenient way to capture this sort of matching.⁹ A customer's gross utility from a purchase is v . The customer incurs two sorts of cost, a price p that is set by the retailer and the vertical transport costs associated with the trip from the ground floor to another part

⁹ It is worth pointing out that spatial competition among tenants in the spirit of Hotelling is a much less tractable model. Since this section's model is meant to illustrate the roles of access and amenities, we have opted for tractability.

of the building. Let the retailer be located on floor z .¹⁰ Then transport costs associated with buying from the retailer equal $\tau^R z$. The customer will buy from every retailer with which there is a match provided the total costs incurred, both price and access costs, are sufficiently low relative to the utility generated from a purchase.

The retailer incurs three sorts of costs, labor, rent, and other costs. For retailers, we will simply suppose labor costs equal a fixed retail wage w^R for its one unit of labor. A retailer incurs marginal cost of c for each customer it serves. The total rent paid by a retailer on floor z is $sr(z)$, which equals $r(z)$ with the normalization $s = 1$.

A retailer located on floor z chooses price to maximize its profits. In this setup, retailer profit equals

$$\pi(z) = (p-c)m(z,p) - w^R - r(z), \quad (\text{II.1})$$

where $m(z,p)$ gives the number of consumers served on floor z at a price of p . If $p \leq v - \tau^R z$, then the tenant serves its share of potential customers, $m(z,p) = \eta M$. In this region, the profit-maximizing price would be $p = v - \tau^R z$. If $p > v - \tau^R z$, the firm serves zero customers, $m(z,p) = 0$, because the customers are deterred from buying the good by its price. Taking rent and labor costs as fixed for now, the retailer will choose to serve its customers when $p = v - \tau^R z \geq c$.

In this setup, the retailer reduces price at higher floors to keep from losing customers. It extracts the entire surplus from the transaction. The retailer then serves its full share of customers, ηM , as long as it is capable of earning non-negative profit by doing so. Profit may be re-written as,

$$\pi(z) = (v - \tau^R z - c) \eta M - w^R - r(z). \quad (\text{II.2})$$

As usual, in an open model of this sort, bidding among potential tenants results in rent adjusting to give zero profit. The retailer bid-rent is thus

$$r(z) = \eta M (v - \tau^R z - c) - w^R. \quad (\text{II.3})$$

There are two features of retail bid rent that are important for our purposes. First, retailer bid-rent is negatively sloped,

¹⁰ With a multi-floor retailer, access costs would depend on the floor on which a particular department is found. We ignore the details of this by treating each retailer as being located on one floor.

$$\partial\tau/\partial z = -\eta M\tau^R < 0 \quad (\text{II.4})$$

Rent falls as one moves to upper floors because the product becomes less accessible and thus less attractive to consumers, resulting in a reduction in price. Other specifications of demand would lead to a similar conclusion. For instance, if consumers differed in the utility that they received from purchase, then the firm would trade-off price and quantity as usual. Higher locations would offer a less favorable tradeoff, leading to the reduction in rent. The negative slope discussed here depends crucially on the assumption that amenities are typically not important for retailers. We believe this to be correct most of the time. One notable exception is high floor restaurants, where the view is bundled with the meal, and customers may be willing to pay more at higher floors. The analysis in the next subsection can be employed to capture this.

The second key feature of retail bid rent is that at a sufficiently high location, retail-bid rent becomes negative. Setting $r(z)$ from (II.3) equal to zero, gives

$$z^* = [\eta M(v - c) - w^R] / \eta M\tau^R. \quad (\text{II.5})$$

When access is sufficiently poor, retailers cannot make competitive bids for space. Retailers will not, therefore, occupy this space.

We now turn to the office tenants who can make positive bids for these higher floors.

B. Office activities

Suppose the demand structure for office activities is parallel to the structure for retail activities. Specifically, there is a pool of customers at street level of size N . Customers incur access costs, denoted τ^O . As above, an office tenant will serve a share ϕ of these customers as long as its price is less than or equal to the gross utility from the purchase, $p^O \leq v - \tau^O z$.¹¹

There are two important differences between the demands for office and retail. First, the costs of accessing the higher floors are lower for office transactions than for retail transactions. Let τ^O denote vertical transport costs in the office sector, with $\tau^O < \tau^R$. The assumption that vertical transport costs in retail are high reflects that these trips are typically taken with a slow mode of travel such as stairs or an escalator. Office trips are typically taken with a fast mode, such as elevators. Finally, it may take fewer

¹¹ It is straightforward to consider differences in utility, v , between retail and office customers. This will not affect the slope of bid rent, but it will affect the level.

trips by the customer to create value. For instance, Ascher (2011) suggests that this is true for law offices. Any of these will result in the ranking we have assumed for vertical transportation costs. This ranking will generate a sharp empirical prediction, one that will be tested later in the paper.¹²

The second difference between office and retail tenants is that some valuable “amenity” may accrue to the tenant from its high location. In the case of a residential high-rise, the amenity is easy to understand. Views are better and noise is minimized at high levels. In addition, there may be prestige associated with high locations. These effects result in a high-floor premium in residential buildings.

The role of amenities, broadly conceived, is more complicated in commercial real estate. One possibility is that the consumers of the firm’s output value the output more if it is purchased on a high floor. It is difficult to believe that this can account for a large enough increase in revenues to generate the patterns discussed in the Introduction and that will be explicated in detail below. A more plausible explanation is that there is signaling. Signaling has been offered as an explanation for various corporate activities, including the issuance of dividends, the provision of CEO mansions, and the purchase of lavish office space.¹³ The heart of the signaling argument here would be that occupying a high floor indicates unobservable elements of the value of service to customers, resulting in greater revenue at high floors.

Yet another amenity effect operates through the labor market. While customers are likely to spend little time enjoying the view from a high floor office that they visit, employees spend considerable time in their offices. An office with a commanding view is an important and visible perk, one that is likely to be valued by employees. This is especially so since many classes of office workers have high incomes, which is likely to raise the value they would assign to a “perk” such as a view. In this situation, workers will accept lower wages, raising profit. This, in turn, will raise bid-rents for high floor offices.¹⁴

We capture these various amenity effects as follows. First, we suppose that revenue rises with floor height (the first two effects). For simplicity, we suppose that the profit function is linearly separable, with the additional revenue equal to αz . Second, we suppose that worker utility rises by ωz , resulting in an equal reduction in labor costs.

In this specification, an office firm’s profit equals

$$\pi(z) = \phi N(v - \tau^O z - c) + \alpha z - (w^O - \omega z) - r(z), \quad (\text{II.6})$$

¹² We have ignored the fixed costs of taking an elevator and the related decision of whether to walk between floors or take an elevator. In our model, the assumption that vertical transport costs for retail are higher than for office should be interpreted as capturing the willingness of customers to walk a few floors even at high cost in the presence of fixed costs for the low per-floor technology of the elevator.

¹³ Miller and Rock, (1985) is a seminal reference on dividends as signal.

¹⁴ See for example, Rajan and Wulf (2006) for a discussion how perks can be an important element of the utility derived from compensation and thus be used to motivate far more cost-effectively than equivalent amounts of cash.

where w^0 is the wage required for an office worker on the first floor, consequently enjoying no amenities. Competition among office tenants gives the office bid rent as:

$$r(z) = \phi N(v - \tau^0 z - c) + \alpha z - (w^0 - \omega z) \quad (\text{II.7})$$

In contrast to the bid-rent for retailers, the office bid rent is of indeterminate slope:

$$\partial r / \partial z = -\phi N \tau^0 + \alpha + \omega \quad (\text{II.8})$$

Absent a strong enough amenity effect of some sort, bid-rent will fall as floor height rises, as with retailers. The presence of a positively sloped bid-rent – as discussed in the Introduction -- suggests the presence of some sort of amenity.

C. Vertical spatial structure

In this section there are two types of tenant. Retailers are *access oriented*, while office employers can be *amenity oriented*, supposing that the amenity effects on profit are strong enough to outweigh the negative effects on access of moving higher up in a building. In any case, the lower level of vertical transportation costs will tend to give office tenants a comparatively stronger orientation to amenities and a comparatively weaker orientation to access.

The equilibrium vertical allocation of space within a building to competing potential tenants will be determined, as in the horizontal models in the Alonso-Mills-Muth tradition, by bid rents.¹⁵ In the empirical analysis to follow, we will allow for a range of differences in access and amenity orientation. Our purpose here is to illustrate the forces at work, and we can do that in a model that has two sorts of potential tenants, one access oriented retailer and one amenity oriented office tenant. The office tenant's amenity orientation is such that the bid rent is positively sloped (see equation (II.8)).

The relative positions of the two tenant types depend on the slopes of the bid rent curve. Retailers have a negative slope, while office firms have a positive slope. It is therefore unambiguous that office firms will occupy higher floors and retailers will occupy lower floors, provided that both types are present. A necessary condition for the retailers to be present is that the retailers have a positive bid rent for the bottom floor ($z = 0$) and can outbid the offices there. A necessary condition for the office firms to

¹⁵ It is worth reiterating that the paper has followed the structure of traditional monocentric models by supposing that access to a particular location is inherently valuable. In a follow-up paper, we will consider agglomeration effects that operate within buildings.

be present is that they have a positive bid rent for the top floor ($z = Z$) and can outbid the retailers at the top of the building. These require, respectively, that

$$\eta M(v - c) - w^R > \phi N(v - c) - w^O \quad (\text{II.9})$$

and

$$\phi N(v - \tau^O Z - c) + \alpha Z - (w^O - \omega z) > \eta M(v - \tau^R Z - c) - w^R. \quad (\text{II.10})$$

(II.9) will hold if retail demand, ηM , is large enough relative to office demand, ϕN . (II.10) will hold if the difference in access costs is large, $\tau^R - \tau^O$, and amenities are valuable either to customers or as a signal, α , or to workers, ω . These conditions will give a building divided into retailers below and office tenants above.

In reality, there is obviously a much finer gradation of tenants according to their access and amenities orientation. Tenants with greater access orientation will tend to be lower in the building, while those with greater amenities orientation will tend to be higher. This is an important extension of the classic analysis of urban spatial structure. To the extent that firms do indeed differ in their access and amenities orientations, then we will not see a single land use at a particular street address in a business district. Instead, establishment types will sort both horizontally and vertically, with certain types of activities found at different heights above ground level.

The following are the key implications of this section's theory:

- (i) The vertical rent gradient will be non-monotonic, falling with height at the lowest floors, and later rising at the highest.
- (ii) Retail tenants will occupy the lowest floors, while office tenants will occupy the highest.
- (iii) The specific patterns of occupation will depend on amenities and access orientation, with a weaker access orientation and a stronger amenities orientation being associated with the occupancy of a higher floor

As noted above, firms will tend to have a stronger amenity-orientation when the view is somehow more valuable to either their workers or their customers, possibly as a signal. In both cases, one would expect to see high productivity firms located on higher floors. In a signaling equilibrium, high type firms signal

their type by locating high. In the case of workers and amenities, high productivity workers will tend to value amenities more highly. Taken as a group, the three implications all mean that verticality matters, both in pricing and spatial structure.

D. Extensions

The model has been specified parsimoniously to allow us to illustrate how the tension between amenity and access orientation governs vertical sorting in buildings and the accompanying equilibrium rent relationship. This section will sketch some extensions that bear on the empirical analysis to follow.

The first concerns the horizontal structure of cities. This is the subject of traditional monocentric analysis. Our model extends easily to incorporate this. Suppose that x gives the distance to the predetermined center of the city. At greater distances, buildings have less floor level retail and office demand. This can be captured by making the demand variables functions of x . If $M(x)$ and $N(x)$ decline in x , then we will have the result that bid rents for both retail and office tenants decline with horizontal distance.

The second concerns the “captive” retail demand that comes from other tenants in the building. If M depends on building height, then it is immediate that retail rents will be larger at the bottom of tall buildings and that retail will be a more competitive bidder for space, ultimately occupying more floors in equilibrium. This also implies that the ground floor rent premium relative to rents just above ground level will be larger in taller buildings. Since buildings will tend to be taller near the city center when rents are higher, captive demand and horizontal structure will tend to work in the same direction.

The third concerns the management of the building. This is more complicated, suggesting the possibility of the allocation of space depending on non-Walrasian forces that are absent from standard bid rent analysis. See Han and Strange (2015) for a survey of search models for housing, and see Grenadier (1995) for a rare instance of a non-Walrasian model of space for the commercial sector. The issue is that a landlord may not simply allocate space to the highest bidder if the discounted expected value of another bidder’s payments would be greater over the duration of the contract. For instance, a tenant who offers high rent but also has a high likelihood of default will not be preferred to one who offers almost as much rent but has a very low default probability. This sort of calculation is likely to be most important at the top of a building, where rents are highest.

These extensions suggest an additional three predictions that can be empirically tested:

- (iv) Rents will be higher in dense central locations.
- (v) Ground floor rent premium will depend on building height.

- (vi) Tenant risk will impact the allocation of space.

We now turn to the empirical analysis of these and the previously mentioned issues.

III. Data

A. Three primary data sources

The data for this paper are unique and open up a new set of opportunities for research on the spatial structure of cities. We draw upon three primary data sources, each of which is described in detail below. Collectively, our data enable us to observe actual commercial rents paid, the identity and location of establishments within a given building (known as the tenant stack), and attributes of the leases.

Our first data source is a set of the confidential offering memoranda (OM) that are made available to prospective investors when a building is up for sale. Drawing on contacts in the real estate industry, we obtained access to such memoranda for 93 tall buildings spread across 18 metropolitan areas in the United States that were up for sale at various times from 2003 to 2014. The memoranda typically provide complete detail on the tenant stack in the building – the identity and location of all tenants – along with extensive information on the cash flows, rents, and lease arrangements associated with each tenant. While the tenant stack is public information the rent data are confidential and we are not at liberty to share those data.

Our second key data source is from CompStak Inc., a newly created company (as of 2012) that collects and markets data on commercial rents, leases, and other related measures for commercial buildings for a number of major metropolitan areas in the United States. CompStak (CS) operates in some respects as a co-operative. Commercial leasing agents are allowed to draw a specified number of “comps” – the lease and rent terms associated with a comparable office space – for every comp that the agent contributes to the data base. In New York city, as an example, the CS database currently includes information on rent terms, lease, and other related attributes for roughly 24,000 office suites spread around the city. Most of the CS data reflect agent reports submitted since 2012 for tenants that moved into their suites between roughly 1999 to present. The nature of the CS database is that it will grow and become more complete over time as the networking aspects of the data encourage additional agents to participate and also with additional turnover of office suites. We currently draw on CompStak data for buildings in New York, Chicago, Los Angeles, San Diego, Atlanta, Washington DC, San Francisco, and the San Francisco Bay Area outside of San Francisco itself. We have selected these metropolitan areas because they offer richer data. The list of cities for which lease comparables are collected from continues to expand. Given our focus on tall buildings in urban areas, when drawing on the CS data, we work with

only buildings that are at least 10 stories tall (CS data also includes suites in many buildings under 10 stories tall).

The CS and OM data have different strengths and weaknesses. Both provide detailed information on commercial office rents, leases, and the location of tenants in a building. The OM data contain information on the complete set of tenants in a building at a given point in time. The CS data provide information on a subset of tenants in a given building, but thousands of buildings are represented in the database. In addition, because of the nature of the CS data collection process tenants in the CS data are skewed towards recent arrivals, although not exclusively so. Regarding rents, the OM data report actual rent paid at the time the offering memo was produced, while the CS sample includes effective rent, where actual rents are adjusted to account for various landlord concessions such as free months of rents and fitting out allowances. The OM data are laborious to collect as it was necessary in many instances to transcribe information embedded in the offering memo text into a machine readable form. As an example, Appendix A displays abbreviated information regarding the tenant mix (stacking plan) from the offering memorandum for Prudential One and Two in Chicago with the rent information removed. These memos were entered into the public domain as part of a CMBS (commercial mortgage backed security) filing with the SEC (Securities and Exchange Commission).¹⁶ Appendix B displays an example of information on rents known as the rent roll for a portion of the building known as 999 Peachtree Street in Atlanta, Georgia which is also in the public domain through SEC filings.¹⁷ The information on rents is similar to what is contained in our offering memorandums, but with less detail. The 93 offering memo data used here were transcribed over a one and one-half year period from 2013 to 2015. In contrast, the CompStak data are commercially available and are not subject to restrictions based on confidentiality. The CompStak data also cover over 100,000 office suites spread across thousands of buildings. Not all of the CompStak records indicate floor or suite number, however, and others contain other types of missing information.¹⁸ Our cleaned CompStak file with all of the key variables present includes 37,007 suites spread across 1,922 buildings.

Our third major data source is Dun and Bradstreet (D&B), obtained through the Syracuse University library. Rosenthal and Strange (2001, 2003, 2005, 2008, and 2012) have previously used D&B data in a series of papers in which the data were obtained already aggregated to the 5-digit zipcode

¹⁶<http://www.secinfo.com/dsvrn.v4Mq.htm>

¹⁷<http://www.sec.gov/Archives/edgar/data/1031316/000117152013000210/ex10-1.htm>

¹⁸As such, we also use data from CoStar, a company that collects and markets data on commercial real estate lease and sale transactions. Currently, CoStar does not permit downloading of leases. The lease information that CoStar reports is relatively sparse compared to CompStak. CoStar's lease information in most cases only includes the floor(s), suite number(s), start date of the lease, end date of the lease and in a few instances the asking rent for each tenant. No information exists on rent concessions nor effective rent in general. The CoStar data is matched with portions of the CS data from Chicago to fill in missing suite and floor numbers in some instances.

level. Recently, Syracuse University obtained a site license with Dun and Bradstreet that permits us (given Rosenthal's Syracuse affiliation) to download establishment level data. Approximately, D&B data cover the universe of establishments in metropolitan areas across the U.S. These data provide detailed information on employment and sales at an establishment's site (i.e. suite), establishment type (i.e. single site, branch, headquarters), corporate status (corporation, partnership, sole proprietorship), risk attributes, sales and employment of the overall firm for multi-site companies, and many other attributes of the establishments. Among these other features includes the establishment's full SIC code which we draw upon at the 2-digit level in most applications.

Critical to our work, the D&B data also provides the complete street address of the establishment which, in many instances, also indicates the floor number and/or suite number in which the establishment is located. A limitation of the D&B data is that at most one floor number is indicated. For tenants that occupy space on multiple floors this injects a degree of measurement error. However, we have confirmed using the offering memo data and also CompStak that the large majority of tenants in commercial office buildings occupy space either on a single floor or on adjacent floors. This reduces concerns about measurement error when using floor number information from the D&B data. In addition, as will become apparent, we use the D&B floor number data primarily when evaluating vertical patterns of productivity for law offices and other related service areas (e.g. financial services). These sorts of companies are especially likely to occupy space on a single floor. Moreover, floor number in these instances is used as a dependent variable and for that reason classical measurement error does not bias our estimates.

In some applications we merge the D&B data at the tenant level with tenants in the 93 tall buildings from our offering memos. This enables us to examine location within the tenant stacks by industry SIC classification. In other applications we use D&B data to measure employment in a building's zipcode and also within the building itself, and then match that information to the CS data.¹⁹

The offering memos identify tenants only based on their name while D&B identifies tenants by name and also their unique D&B assigned DUNS number. To match OM and D&B tenant data, we searched the web by tenant name for each of the roughly 6,000 tenants in the offering memo data and determined their DUNS number which was then coded to the CS file and used to match with D&B records. The match rate was close to 70 percent from among all of the tenants in the OM data, held down in part because the D&B data to which we have access are current whereas some of the OM data reports tenants as far back as 2003.²⁰ When matching zipcode-level D&B data to the CS data, the match rate was nearly perfect as zipcode is provided in the address fields for both datasets. When matching building-

¹⁹ Census data on year-2013 employment at the zipcode level based on zcta area designations was also merged with the CS data for selected applications.

²⁰ It is also worth noting that whereas CS and D&B emphasize accurate data on current tenants, some of our offering memos go as far back as 2003.

specific employment from D&B to CS data, we were forced to use street names in a given zipcode. In this instance the match rate was roughly 85 percent.

In other portions of the empirical work to follow we rely solely on the D&B data for five select industries in twelve metropolitan areas. Details on this portion of the D&B sample are provided later in the paper.

B. Summary statistics

Table 1 provides summary measures on key data from each of the three data sources described above. In all cases here and throughout the remainder of the paper, all dollar valued variables (e.g. rents, sales) are reported in 2014 dollars.

Panel A summarizes the size and time period of each of the databases including number of tenants, number of buildings, number of cities or MSAs in which buildings are located, and time period covered. Note that in the OM data 5,750 tenant-suite observations are spread across 93 buildings in 18 cities. In the CompStak data, 37,007 tenant-suite observations are spread among 1,922 buildings in the 8 metro areas covered by CS as mentioned earlier. These include a number of well-known buildings, such as the Empire State Building, Trump Tower, Chrysler Building, Citigroup Center, John Hancock Center and Willis Tower. The D&B data is matched to each of the buildings in the OM and CS data as described above. In addition, for five select industries including law offices (SIC 81), advertising offices (SIC 7311), brokerage offices (SIC 62), insurance carriers (SIC 63), and agents, brokers and services (SIC 64), D&B data were collected for all such establishments in 12 MSAs (New York, Chicago, San Francisco, Los Angeles, Atlanta, Washington DC, Cleveland, Detroit, Dallas, Denver, Houston, and Seattle). For this data file we have 57,748 tenant-suite observations spread across 19,721 buildings based on the street addresses reported in the data.

Panel B summarizes the composition of tenants in the 93 OM buildings. Summary measures are presented for all floors combined, ground floor and below (the concourse levels), between floors 2 and 40, and floor 40 and above. We highlight the industries that are most heavily represented in commercial office buildings. This includes retail (SIC 52-59), FIRE (SIC 60-67), business services (SIC 73), law offices (SIC 81), and Engineering-Accounting-Management (SIC 87).

As seen in the first column, FIRE and Law offices account for 23.4 percent and 20.3 percent, respectively of all establishments while Engineering-Accounting-Management makes up 12.1 percent. Retail is just 6.8 percent of establishments in tall commercial buildings. A quick skim of the remaining columns, however, indicates that the composition of activity differs sharply with height off of the ground. On the ground floor, retail accounts for near 33 percent of establishments while law offices just 8.2 percent. From floors 3 up to 40, retail is just 2.3 percent of establishments while FIRE is 25.7 percent and

law offices are 20.6 percent. Above floor 40, retail is 3.4 percent – all of which are restaurants – and FIRE is 25.4 percent. Law offices dominate, however, and make up 43 percent of establishments above floor 40. These patterns provide graphic evidence of spatial stratification of activity within tall office buildings as implied by the conceptual model discussed earlier. We will return to this point later.

Panel C provides summary measures on rent per square foot in the 93 offering memo buildings and the 1,922 buildings drawn from the CompStak data. The average rent per square foot across the OM data is \$38 per square foot while for the CS data average rent is \$36 per square foot. These values are broadly consistent with the residential rents for Manhattan: a recent report indicates that the average rent per square foot for residential space in Manhattan as of January, 2013 (in \$2013) was \$50.71.²¹

Two other important patterns are also evident in Panel C. The first is that there is considerable variation in rents across office suites. In the OM data, rents at the 25th, 50th, and 75th percentiles are \$22, \$33, and \$51 per square foot. For the CS data corresponding values are \$17, \$33, and \$49 per square foot, respectively. The second pattern to note is that the rent distributions in the OM and CS data are of similar general magnitude, with the effective rents from the CS data slightly lower than the actual rents from the OM data. This provides an implicit check on the coverage and quality of the two data sources, although differences in rents across individual buildings are to be expected.

Panel D of Table 1 characterizes the distribution of building heights across the OM and CS samples. It does this in two ways. The first two rows of Panel D report summary statistics on building height calculated across the buildings in the sample. Here, we see that the mean height is 32.7 stories in the OM data and 21.5 in the CS sample. The last two rows of Panel D report summary statistics calculated by tenant suite. There are more suites in a given tall building than in a given smaller building, and this means that the suites in the two samples tend to be drawn more heavily from taller buildings. The means in these samples are consequently larger, at 39.5 floors for the OM sample and 30.5 floors for the CS sample. In the OM data, 59.9% of observations are at or above floor 30, and 10.5% are at or above floor 60. In the CS data, 46.9% of observations are at or above floor 30, while 3.9% are at or above floor 60. Overall, the OM sample is somewhat more skewed towards taller buildings.

Finally, Panel E reports employment for zipcodes in which CS buildings are located. Again, we compute summary statistics in two ways, this time by zipcode and by tenant suite. Average zipcode employment calculated by zipcode is 36,210. Calculated by tenant suite, the average rises to 85,110. This again reflects the tendency to oversample suites from taller buildings since such buildings tend to be located in locations with substantial employment. There is also considerable variation in employment across our sample, with an interquartile range in the zipcode calculations of 26,170 and a larger

²¹See http://www.millersamuel.com/files/2013/02/Rental_0113.pdf.

interquartile range when calculated by suites.

We are now able to begin reporting our results on vertical rents and spatial structure.

IV. Vertical rents

A. Baseline estimates of the vertical rent gradient and ground floor premium

Table 2a reports estimates of vertical rent gradients using the OM data (in columns (1) and (2)) and the CS data (in columns(3) and (4)). These regressions control for building fixed effects, so identification is based on within building variation in rents. For both data sources, two models are reported. The first regresses the log of rent per square foot on log of floor number.²² The second is a log-linear model in which floor number is entered linearly. Additional controls are included to allow for a ground floor premium and, in the offering memo data, a concourse (below ground floor) discount. We allow the ground floor premium to vary with building height by including an interaction term. In all cases, rent is reported in 2014 dollars and standard errors are clustered at the building level.

In all specifications and for both datasets, there is a large, highly significant, and positive ground floor premium. Columns (1) and (3) report results from the double-log models. In the OM data the premium for a 30 story building is 72 percent (equal to $30 \times 0.007 + 0.5148$) while in the CS data the corresponding premium is roughly 33 percent. The below-ground coefficient for the OM data in column (1) is small and not significant (the t-ratio is -0.25). Estimates for the log-linear models in columns (2) and (4) are mostly similar. The ground floor premium for a 30 story building here is 61 percent for the OM sample and 25 percent for the CS sample. On the other hand, the below ground discount is now large and significant for the OM sample. These results suggest that the ground floor is especially valuable relative to locations both just above and below ground level. The theoretical model suggests that these findings reflect the value of access. Two additional remarks are in order. First, the advantages of the ground floor may arise from other mechanisms than the one presented in Section II's theory. In particular, the ground floor provides greater exposure to foot traffic, which is likely to increase sales and so profit. Second, the large ground floor premium is a consequence of very high transportation costs of moving up or down one floor. This, in turn, results from the fixed costs of taking elevators, which lead customers to walk or take an escalator (both slow) for a one floor trip instead of taking an elevator (fast).

There is also robust evidence of rents that rise with floor number beyond the second. In the double log models (in columns (1) and (3)), the elasticities of rent with respect to floor number are 28.5 percent in the OM data and 8.6 percent in the CS data. In the log-linear models (columns (2) and (4)), a one floor increase in height above the ground level increases rent by 1.73 percent in the OM data (with a

²² More precisely, the key independent variable is the log of floor number + k where k is set to one unit larger in absolute value than the lowest numbered concourse floor in the data, -5 for the OM data and -1 for the CS data.

t-ratio of 2.73) and 0.6 percent in the CS data (with a t-ratio of 17.81). These estimates indicate that despite rising access costs, rents rise with height off the ground. Coupled with the previously noted ground floor premium, the vertical rent gradient is nonmonotonic.

Table 2b explores these patterns further and demonstrates that the vertical rent gradient is steeper higher up off the ground. In Table 2b, Panel A presents results for the double log model, while Panel B presents results for the log-linear model. For each specification, the first three columns are based on OM data while the second three columns are based on CS data. The samples are further stratified into three groupings of floors with separate regressions for each: estimates for floors 3 to 29 are in columns (1) and (4), estimates for floors 30 to 59 are in columns (2) and (5), and estimates for floors 60 and higher are in columns (3) and (6).

The key result in Table 2b is that rents rise beyond the first floor at an increasing rate. Reading across columns from lowest to highest floor groupings, in the double log specification, the rent elasticity coefficients from the OM data are 0.1447, 0.1352, and 5.40, respectively (with t-statistics of 4.31, 0.81, and 649.37).²³ For the CS data, the corresponding coefficients are 0.0763, 0.2873, and 1.274 (with t-statistics of 16.60, 7.29 and 4.20). Estimates for the log-linear model display a similar pattern. In the OM sample, the gradients for the three bins are 0.82 percent, 0.33 percent, and 6.2 percent. In the CS sample, the gradients are respectively 0.58 percent, 0.68 percent, and 1.61 percent. These estimates indicate that the rent gradient is rather gentle for the low floors of buildings, but it becomes steeper higher up off the ground.

The estimates in Tables 2a and 2b are completely new to the literature and have three immediate implications. First, in contrast to the maintained assumption of the standard urban model, it is apparent that there is not a single rent value at a given street address. Instead, within a typical building large, systematic differences in rent are present as one moves up off the ground. Second, the fact that rents increase with height once above the ground floor confirms that height-based amenities must be present and that height-based amenities must increase at a rate sufficient to offset rising access costs. Third, the tendency for rent gradients to be steeper on the higher floors of a tall building could reflect that height-based amenities increase at a non-linear rate as one moves up above the obscuring effect of adjacent buildings. However, a different mechanism also likely contributes to this pattern. A familiar result from the standard monocentric model is that sorting across locations between heterogeneous agents with different bid functions can impact the curvature of the equilibrium rent function, a principle that applies here. The convex pattern of vertical rent gradients in Table 2b, therefore, could indicate that tenants who place greater value on height sort into higher locations. We revisit this possibility later in the paper when

²³ It is important to note that the OM sample contains only 4 buildings above 60 stories. The high suites in these landmark buildings (all in NY or Chicago) are clearly different from other buildings in our data.

we consider more direct evidence of vertical sorting patterns. Before doing this, however, it is useful to evaluate whether and in what fashion nearby agglomeration of economic activity affects commercial rents and the vertical rent gradient.

B. Vertical vs. horizontal rent gradients: magnitudes and agglomeration

As noted earlier, the standard monocentric model in urban economics solves for equilibrium rents and spatial structure in a horizontal setting. Locations farther from the central business district (CBD) in ground level distance will differ in employment, productivity, wages, and rents from locations that are closer. Even though this literature recognizes that higher rents in locations offering superior access to the CBD will prompt developers to use land more intensively, causing building heights to rise, the buildings themselves are treated as if they were flat, with all employment at the ground level. This section expands our rent regressions by adding controls for employment within a building's zipcode and also within the building itself. This will allow us to evaluate the relative magnitudes of vertical and horizontal rent effects, in addition to assessing the degree to which our estimates of the vertical rent gradient may be sensitive to nearby agglomerations of employment.

To this end, Table 3a presents a series of rent regressions that extend the specifications in Table 2a. All of the models in this table are estimated using just the CS data because this data source offers greater geographic coverage compared to the 93 buildings in the OM data. Except where noted, building fixed effects are also replaced with MSA fixed effects as this allows us to explore the impact of nearby employment. Columns (1) to (4) present estimates from double-log models while columns (5) to (8) report estimates from log-linear models. For each group, the first column (columns 1 and 5) controls only for zipcode-level employment for the zipcode in which the building is located; the second column (columns 2 and 6) controls for vertical location and building height but omits any control for nearby employment; the third column (columns 3 and 7) combines controls for both zipcode-level employment and vertical location. The models in columns (4) and (8) repeat the building fixed effect models from Table 2a. In the present context, it is worth noting that the building fixed effects capture proximity to nearby employment as well as proximity to other valued location specific attributes. The fixed effects also, of course, control for unobserved attributes of the buildings themselves.

In columns (1) and (5), zipcode employment has a positive and highly significant effect on rent. In the elasticity model (column (1)), doubling zipcode employment increases rent by roughly 10.7 percent while the gradient in the log-linear model (column (5)) indicates that adding 1,000 workers to a zipcode increases rent by 0.23 percent (the corresponding t-ratios are 5.4 and 7.6, respectively).

These estimates establish a core stylized fact that has been widely assumed but only rarely demonstrated: densely developed locations have higher commercial rents, resulting in sharp horizontal

spatial variation in office rents across business districts and cities. The estimates are also consistent with a large literature on agglomeration economies that has established that spatial concentration contributes to productivity. Most often, that literature has focused on wage effects from agglomeration. See, for instance, the surveys by Rosenthal and Strange (2004), Combes and Gobillon (2015), and Behrens and Robert-Nicoud (2015). As in Roback (1982), however, the productivity effects from agglomeration should also be reflected in higher commercial rents. However, despite the strong theoretical foundations, few papers in the voluminous agglomeration literature have used commercial rent as the outcome measure, and no previous paper has looked at agglomeration economies at a highly local level using commercial rents. Our estimates of the rent-employment relationship are, therefore, without precedent. Bearing this in mind, as a very rough comparison, the 10.7 percent rent elasticity obtained here is larger than corresponding wage elasticities in the literature, which typically suggest that doubling city size increases wage by 2 to 5 percent (e.g. Rosenthal and Strange, 2004 and 2008), or by even less (Combes et al, 2008). That rents capture a substantial share of agglomeration economies is a point made by Drennan and Kelly (2011) and Koster et al (2014b).²⁴

Columns (2) and (6) revisit the vertical rent regressions from Table 2a with the primary change that building fixed effects are replaced with MSA fixed effects and building height has been added to the specifications. The important point to note here is that the estimates are nearly identical, both qualitatively and in magnitude, to those in columns (4) and (8) which repeat the Table 2a specifications.

The models in columns (3) and (7) combine the controls for zipcode employment and vertical location as described above. Comparing estimates in these models to the employment-only and vertical-only models yields a striking result. It is apparent that adding controls for vertical location has little effect on the estimated influence of zipcode employment, and controlling for nearby employment has essentially no effect on the vertical rent pattern. Moreover, the vertical rent coefficients are also nearly the same when building fixed effects are included in columns (4) and (8). The building fixed effects, of course, control for zipcode employment and building height, as well as a host of unobserved local and building-specific attributes.

The remarkable stability of estimates across the models in Table 3a suggests that the processes that drive vertical rent patterns are different from the processes that account for the positive impact of nearby employment and other horizontal drivers of rent. The theory in Section II emphasizes the role of vertical access costs and height-based amenities as the drivers of systematic patterns of vertical rents. The agglomeration literature highlighted above emphasizes the positive productivity spillovers arising from labor market pooling, sharing of intermediate inputs, and knowledge sharing (e.g. Rosenthal and

²⁴These papers do not allow the computation of building level employment, which is necessary to consider the sorts of local effects examined in Table 3a.

Strange (2004)). Our estimates from Table 3a are consistent with the view that these are different and distinct underlying mechanisms that both affect commercial rents.

It is also useful to consider the magnitudes of the estimates in Table 3a. For these purposes, we focus on estimates in the log-linear model in column (7) which permits direct and intuitive comparisons of vertical and horizontal rent patterns. For a 30-story building, the ground floor premium is roughly 28.4 percent ($0.0076 * 30 + 0.056$). This is roughly equivalent to the estimated increase in rent associated with moving up 39 floors ($0.0073 * 39$). It is also roughly equivalent to an increase in zipcode employment of roughly 140,000 workers, about equal to the 75th percentile among office suites in our sample (see Table 1, Panel E). If instead, we add 100,000 workers to a zipcode – about the same as the inter-quartile range for our sample of office suites – rent would increase by an amount about equal to moving up 27 floors. These comparisons make clear that nearby employment and vertical location both have economically important effects on rent.²⁵

Table 3b builds on the model specifications in Table 3a. The key extension here is that zipcode-level employment is decomposed into employment in and outside of the building. This allows us to consider whether the intensity of activity inside a building might affect vertical rent gradients. Prior evidence based on both arrivals of new establishments and wages (e.g., Rosenthal and Strange, 2003, 2008) suggests that agglomeration economies attenuate rapidly with geographic distance. The analogue here would be that employment inside a building should have a larger effect on rent than employment outside of the building. Evidence of such a pattern would reinforce the conclusion above that different mechanisms are driving the vertical and horizontal rent patterns in Table 3a.

To control for building-level employment, we matched tenant records at the street address level to corresponding street addresses in the Dun and Bradstreet data. D&B data were then used to determine the level of employment within each of the buildings represented in the CS data file. The matching process relies on city and street address because the CS data do not provide DUNS numbers for their tenants (the DUNS number is a unique identifier for each establishment in the D&B database). This and other features of the matching process make the matching process laborious. For that reason, we have matched only those CS records found in New York City, the portion of Chicago located in Cook County, and the portion of San Francisco located in San Francisco County. This leaves us with 28,324 suite observations spread across 1,192 buildings, roughly 63 percent of which are in New York, 20 percent in Chicago and 17 percent in San Francisco.

²⁵ It is worth noting that if we omit the MSA fixed effects and estimate the models by OLS, the vertical rent gradient remains similar to the estimates in Table 3a while the elasticity with respect to zipcode-level employment rises to roughly 75 percent. This reflects that high employment zipcodes are mostly found in the largest cities (e.g. New York and Chicago) which tend to have higher rents.

Six different models are presented in Table 3b, each of which utilizes a log-linear specification as we feel that is a more intuitive model to interpret when employment is decomposed into different parts. Column (1) controls for just zipcode-level employment while column (2) decomposes zipcode employment into employment outside versus inside of the building. Column (3) controls for vertical location and building height but omits nearby employment. Columns (4) and (5) add the controls for building height and vertical location to the employment-only models in columns (1) and (2). Column (6) adds building fixed effects which cause employment and building height to drop out of the model.

Two important patterns jump out from Table 3b. First, the coefficient estimates for the restricted sample in Table 3b are quite similar to those presented for the larger sample in Table 3a, both with respect to the influence of zipcode-level employment and vertical location.²⁶ Second, in columns (4) and (5), it is clear that within building employment and zipcode employment outside of the building both cause rents to increase but the effect of within-building employment is 3-1/2 times larger. This echoes results from Rosenthal and Strange (2003, 2004, 2005, 2008, and 2012) and Arzaghi and Henderson (2008) that agglomeration economies tend to attenuate rapidly with distance. It is noteworthy that this pattern persists even after controlling for building height, given that building height is positively correlated with building-level employment.

There is, thus, a highly robust vertical rent gradient. Rents are not at all constant at a given street address. Instead, rents are characterized by a significant ground floor premium, and an initial sharp decline moving just above the ground floor. Moving further up within a building, rents rise gradually at low floors and then more rapidly near the top of the building. Moreover, these patterns are economically important and appear to be driven by mechanisms that are different from forces that cause nearby agglomeration of employment to also have a positive and important effect on rent. The next section will show that the activities that take place within a building are also not randomly distributed throughout the building, instead exhibiting a particular spatial structure.

V. Vertical spatial structure

This section addresses two fundamental questions about vertical spatial structure. The first question is who locates where: in other words, is there systematic sorting by tenant type into different parts of the building (e.g. ground floor versus above)? The second question is: why? Answering these questions will provide evidence of the underlying mechanisms that drive the rent gradients just documented.

²⁶ The coefficient on zipcode-level employment in column (1), for example, is 0.0024 compared to the corresponding estimate of 0.0023 in column (6) of Table 3a. The coefficient on floor number in column (3) is 0.0087 while the corresponding estimate in Table 3a (column (6)) is 0.0074.

A. Vertical sorting

We begin by considering who locates where. Table 4 describes the vertical distribution of where tenants are located in the OM data. Distributions are reported for all industries combined (column (1)) as well as retail (SIC 52-59), not retail, law offices (SIC 81), business services (SIC 73), brokerages offices (SIC 62), insurance companies (SIC 63), and insurance and brokerage agents (SIC 64). In all cases we focus only on tenants merged with the D&B data which provides information on the tenant's SIC code. For each industry we report the distribution of floor numbers as reflected in the 1st percentile, 25th percentile, 50th percentile, 75th percentile, and 99th percentile floor number.

The values in Table 4 reveal a striking stratification of industries into different parts of tall buildings. Retail is almost exclusively concentrated on the ground floor or just above, with a median location at ground level and the 75th percentile at floor 5. Law offices are especially concentrated higher up off the ground as are brokerage offices, both of which have median locations just above floor 20 and 75th percentile locations just above floor 30. These patterns reinforce the summary measures in Table 1c described earlier.

B. Mechanisms: access and amenities

We now move to the second question. Panel B of Table 1 and Table 4 together provide compelling evidence that retail establishments are heavily concentrated on the ground floor. Section II's theory shows that access costs can explain this pattern. Retail establishments rely on frequent interactions with customers who must travel to the establishment. In this context, total product price to the customer includes sticker price plus access cost which increases with height off the ground. In the absence of a positive amenity effect associated with height, retail bid-rents decline with height and retail should sort into the ground level space as observed. In this sense, we view retail as an access-oriented industry.

Outside of the retail sector the frequency of face-to-face office visits with clients and/or input providers is much reduced. In addition, the value of the service provided is often much higher both in comparison to retail and relative to access costs. If this were all that differed between retail and non-retail, we would have a sufficient condition to ensure that non-retail would sort into locations above the ground floor, as observed in Table 1 (Panel B) and Table 4. In such an environment, however, office rents would have to decline in equilibrium with height off the ground to compensate non-retail establishments for greater travel costs. This, of course, is not consistent with the positive rent gradients documented in Tables 2a, 2b, 3a, and 3b. To allow for those patterns, it must be the case that non-retail establishments perceive height off the ground as a positive amenity sufficient to offset reduced access. These arguments confirm a role for both access and amenities and suggest that both increase with height.

Tables 5 and 6 help to clarify how to interpret the positive amenity effect associated with higher locations in a building. The tables report results from a series of models in which location (measured as the log of floor number) is regressed on tenant and site characteristics. In all cases, the tables draw exclusively on D&B data from twelve large metropolitan areas. For reasons to be described shortly, in most models we restrict our samples to single-site firms in law offices (SIC 81), advertising offices (SIC 7311), brokerage offices (SIC 62), insurance carriers (SIC 63), and agents, brokers and services (SIC 64). In one model we instead focus exclusively on headquarter establishments for multi-site firms. In that instance establishments are drawn from all industries.

In both Tables 5 and 6, the two key regressors in the single-site firm models are the sales-per-worker ratio for the site and the number of employees at the site. Both sales-per-worker and employment are likely positive correlates with labor productivity. Conditional on employment, a higher ratio of sales-per-worker suggests that labor is more productive. Productive establishments also tend to grow larger and operate at a larger scale with more workers on staff. Importantly, higher productivity also likely affects the intensity of amenity orientation. More productive establishments tend to pay higher wages. Since amenities such as views are almost certainly normal goods, this will increase the value that the establishment's workers place on a location high up in the building, as in Section II. Our motivating hypothesis is, therefore, that establishments with high sales-per-worker ratios and larger numbers of workers will have a stronger amenity orientation and greater willingness to pay for locations up high. This also suggests that companies with high sales-per-worker and larger numbers of employees may favor higher locations so as to signal to prospective clients and business contacts that they are productive.

Additional controls include 1-0 dummies for whether the establishment belongs to a firm that is publicly traded or whether the establishment is a subsidiary. Only a small fraction of firms are publicly traded. Our maintained hypothesis is that these establishments are higher quality in some sense, possibly rising to the level of "trophy" tenants. For related reasons we also control for subsidiary status although our prior of how such establishments are perceived is less clear. We also include 1-0 dummies for D&B's assessment of risk based on high, medium, and low ratings; coefficients are reported for low and medium risk with high-risk the omitted category. Lower risk companies may be perceived as more attractive tenants, *ceteris paribus*, and for that reason be better fits for high floors. In addition, a tenant's low-risk status may also contribute to signaling incentives when choosing where to locate in a tall building.

It is important to note that employing these site-specific characteristics in the estimation requires that we address the issue of multi-establishment firms. For multi-establishment firms the attribution of sales to sites is uncertain. It is for that reason that we work primarily with single establishment firms. Multi-establishment firms are interesting, however, so we do consider them in a limited way by estimating a model of headquarter establishments. We obviously cannot employ the establishment-level

sales-worker ratio in these models. We instead work with the sales-per-worker ratio at the firm level along with employment at both the firm and establishment levels. The employment variables speak to productivity, as above.

Consider now column (1) of Table 5 which reports the results for headquarter establishments. The strongest results are for firm-level sale-per-worker and employment. Larger firms have headquarters located on higher floors, with an elasticity of 3.5%. Conditional on firm size and the other model controls, the elasticity associated with sales-per-worker is 2.6 percent. Both of these estimates are also highly significant (with t-ratios of 5.8 and 5.6, respectively). Other coefficient estimates in the model are notable but not as dramatic: employment at the site has a small, negative and not significant effect; publicly traded firms locate 10.6 percent higher (with a t-ratio of 3.18), and lower risk companies are also higher. Subsidiary status has a negative and marginally significant coefficient of 0.049 (the t-ratio is 1.92), indicating that headquarters of subsidiaries are on somewhat lower floors after controlling for other factors. Taken as a whole, the estimates in column (1) provide compelling evidence that headquarters of higher performing companies are located higher up off the ground. It is worth emphasizing that this result is obtained even after conditioning on the 5-digit zipcode in which a headquarter is located. This pattern is also echoed in the single-site regressions.

Columns (2) and (3) of Table 5 report results for single-establishment firms pooling data from the five industries noted above. The model in column (2) controls for both 2-digit industry and 5-digit zipcode fixed effects while the model in column (3) replaces the zipcode fixed effects with building fixed effects. The results are similar for the sales-per-worker ratio and for employment at the site. Both are positively related to floor. The elasticities of floor number with respect to sales-per-worker are 1.4 percent in the zipcode fixed effect model and 1.5 percent in the building fixed effect model with t-ratios of 2.0 in both cases. For employment at the site the elasticities are 3.0 in the zipcode fixed effect model and 1.7 in the building fixed effect model (with t-ratios of 6.5 and 5.0, respectively). These results further reinforce the idea that view amenities raise profit by making it easier to attract productive workers which should result in lower wages.

Several other patterns in column (2) also suggest that higher performing establishments locate in higher offices. In particular, the publicly traded dummy is positive and significant in column (2) as are the coefficients on low and medium risk ratings. These results largely disappear, however, when we shift from the zipcode fixed effect model in column (2) to the building fixed effect model in column (3). We will comment further on these differences in the context of Table 6 to follow. First, however, we comment on the industry-stratified models in columns 4-9 of Table 5.

As noted in Table 1, Panel B, law offices account for a significant fraction of office tenants in tall buildings. Results for law offices are presented in columns (4) and (5) and are qualitatively similar to the

estimates for the pooled samples just described. The primary difference between the two sets of models is that the magnitude of the sales-per-worker coefficients in the law-office models are larger: 4.6 percent in the zipcode fixed effect model in column (4) and 2.3 percent in the building fixed effect model in column (5). These estimates are clearly significant with t-ratios of 4.6 and 2.2, respectively. In the law office sector, higher productivity companies as proxied by sales-per-worker and number of employees locate higher up in their immediate zipcode and building.

Estimates for the other industries highlighted above are presented in columns (6) – (9). For these industries only zipcode fixed effect models are presented given the much smaller sample sizes. Looking across the columns it is evident that the results are mixed and point to differences in location and sorting patterns across industries. The results for brokerage offices reported in column (7) are closest to those for law offices (consistent with patterns in Table 4 and Figure 1). In column (7), notice that the elasticity of floor number with respect to employment is 4 percent with a t-ratio of 4.6. Agents and Brokers in column (9) display a similar though more muted result. The other coefficients on sales-per-worker and employment across the remaining industries are not significant and often rather small in magnitude. On the other hand, the coefficients on publicly traded companies are revealing. In the case of law offices this variable is omitted as no law offices are publicly traded. Of the remaining industries, notice that the coefficient on publicly traded is -0.22 for advertising with a t-ratio of 2.88, and then positive 4.2, 1.3, and 0.6 for the remaining three industries with t-ratios ranging from 2.5 to 45. We do not have a good explanation for why publicly traded advertising establishments are located on lower floors. Nevertheless, for the other industries the large positive, significant elasticities are consistent with the view that publicly traded companies are higher end (higher productivity) and locate higher up in tall buildings for reasons described earlier.

Table 6 revisits the models for the pooled industries and law offices. In each case models are presented for OLS specifications, MSA fixed effects, zipcode fixed effects, and building fixed effects. This allows us to highlight systematic differences in patterns as the geographic nature of the controls becomes more refined. The coefficients on sales-per-worker and employment at the site diminish in magnitude as the geographic scope of the fixed effects narrow to that of individual buildings. A similar pattern is present for the other model controls (e.g. publicly traded, risk). It is worth recalling that the fixed effects capture the influence of unobserved factors common to the observations associated with the fixed effect. Accordingly, the patterns in Table 6 suggest that establishments tend to sort across locations down to the building level in a manner that is correlated with sales-per-worker and the other model controls. This indicates that high productivity companies concentrate in select zipcodes and buildings, although the models in Table 6 do not highlight which attributes of a zipcode or building tend to attract productive companies.

VI. Conclusion

This paper departs from fifty years of conventional urban economic analysis by explicitly modeling *vertical* spatial structure in the tall commercial buildings that dominate city skylines. Standard urban models, in contrast, have emphasized *horizontal* patterns of economic activity without attention to within-building patterns. In doing so, the previous literature has implicitly treated tall commercial buildings as if they were flat, with all activity in these buildings taking place at ground level. We show that this approach misses important and interesting vertical variation within a building.

The vertical variation has two key dimensions: rent and occupancy. The paper shows that the vertical rent gradient is non-monotonic. Rents fall initially as one moves up off the ground floor, but then rise above the second floor at a modest rate that increases with height. The magnitude of vertical variation in rent rivals that of horizontal variation: adding 100,000 workers to a building's zipcode has roughly the same impact on commercial rent as moving up 30 floors. This vertical rent gradient is largely independent of the level of nearby employment and employment within the tall commercial building itself. The level of rent depends on employment within and outside the building, both of which positively affect commercial rent. The impact of within-building employment is notably larger, a result that reinforces previous evidence from wage and other related studies that productivity spillovers from agglomeration attenuate rapidly with distance (e.g. Rosenthal and Strange (2001, 2003, 2005, 2008), Arzaghi and Henderson (2008), and Baum-Snow (2011)). The agglomeration literature has pointed to knowledge spillovers, input sharing and opportunities to draw from a common pool of skilled labor as the key determinants of productivity spillovers from nearby activity. Our finding that vertical rent gradients are independent of the level of within-building and nearby employment suggests that vertical rent patterns are driven by a different set of mechanisms.

The patterns of occupancy within buildings shed light on these mechanisms. The paper's theoretical model shows that vertical spatial structure is determined by a tension between access costs (rising as one moves up) and various sorts of amenities associated with an increase in profits for a commercial tenant (also rising as one moves up). The paper's empirical analysis shows that retail tenants, who are strongly access-oriented, locate on low floors, while office tenants, with varying degrees of amenity orientation, locate higher. Among office tenants, those who can be characterized as "trophy" or "anchor" tenants – based on indicators of productivity – locate nearer the top of the building.

In addition to explicating vertical rent and spatial structure, the unique data and vertical perspective employed in this paper open up a number of avenues for future research. Some deal with commercial real estate, as with the management of a building's composition. Others deal with organizational issues, such as executive compensation in the form of corner office perquisites. Many deal with agglomeration. Most research on this topic has considered manufacturing rather than the sorts of

service industries we consider here. This leaves important gaps in knowledge, since the service sector is fundamental for commercial real estate, for cities, and, in fact, for the entire economy. In considering these office activities, researchers should make use of actual commercial rents, since the seminal paper by Roback (1982) has the clear implication that agglomerative productivity advantages will be capitalized into these rents. This contrasts with prior research that has either ignored rents entirely or has proxied for commercial rents with residential rents. Finally, there is an opportunity here to examine whether the identity of neighbors on nearby floors impacts productivity. Thus, looking inside the black boxes of tall buildings sheds light on the attenuation of agglomeration economies at a highly refined spatial scale.

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Table 1: Summary Measures**Panel A: Three Data Sources**

	Offering Memo (OM)	CompStak (CS)	Dun and Bradstreet Merged with OM Data	Dun and Bradstreet For 5 Industries Not Merged with OM or CS Data ^a
Number of Buildings	93	1,922	93	19,721
Number of Tenant-Suite Obs	5,750	37,007	5,472	57,748
Number of MSAs	18	8	18	12
Time Period for Data	2003 - 2014	1999 - 2015	2014	2015

Panel B: Industry Composition in Offering Memo Tall Buildings in Percent^b

	All Floors	Ground Floor and Concourse	Floor > 2 and < 40	Floor >= 40
Retail (SIC 52-59)	6.79	32.71	2.34	3.45
FIRE (SIC 60-67)	23.43	10.12	25.74	25.43
Business Services (SIC 73)	8.43	7.76	8.62	8.19
Law Offices (SIC 81)	20.31	8.24	20.65	43.10
Eng, Acc, Man (SIC 87)	12.13	2.59	14.00	11.64
All Other Industries	28.91	38.58	28.65	8.19

Panel C: Commercial Rents Per Square Foot (\$2014)

	Average	25 th percentile	50 th percentile	75 th percentile
Offering Memo Data	38	22	33	51
CompStak Data	36	17	33	49

Panel D: Building Height in Number of Floors

	Average Floor	Median Floor	% Over Floor 30	% Over Floor 60	Minimum Floor	Maximum Floor
By Building						
Offering Memo (93)	32.7	28	47.3%	4.3%	16	109
CompStak (1,922)	21.5	17	21.2%	1.3%	10	109
By Tenant Suite						
Offering Memo Data (5,750)	39.5	34	59.9%	10.5%	16	109
CompStak Data (37,007)	30.5	27	46.9%	3.9%	10	109

Panel E: Zipcode Employment in Which CompStak Buildings are Located (in 1,000 units)

	Average	1 st Pctl	25 th Pctl	50 th Pctl	75 th Pctl	99 Pctl
By Zipcode (193 zipcodes)	36.21	0.96	18.66	28.72	44.83	142.45
By Tenant Suite (36,963 suites)	85.11	11.72	42.72	78.38	134.99	146.22

^a The metropolitan areas include New York, Chicago, San Francisco, Los Angeles, Atlanta, Washington DC, Cleveland, Detroit, Dallas, Denver, Houston, and Seattle. The industries include law offices (SIC 81), advertising offices (SIC 7311), brokerage offices (SIC 62), insurance carriers (SIC 63), and agents, brokers and services (SIC 64).

^b Based on the OM data merged with D&B.

Table 2a: Rent Gradients with Building Fixed Effects^a
(t-ratios based on standard errors clustered at the building level)

	Offering Memo Data		CompStak Data	
Below ground floor	-0.0425 (-0.25)	-0.3398 (-2.73)	- -	- -
Ground floor	0.5148 (4.99)	0.3160 (2.16)	0.1156 (3.16)	0.0295 (0.81)
Ground Floor X Bldg Height	0.0070 (1.89)	0.0113 (1.91)	0.0070 (3.96)	0.0073 (4.15)
Log(Floor number + k) ^b	0.2854 (2.52)	- -	0.0858 (16.89)	- -
Floor number	- -	0.0173 (2.73)	- -	0.0058 (17.31)
Observations	5,510	5,510	37,007	37,007
Lease quarter Fixed Effects	-	-	Yes	Yes
Building Fixed Effects	93	93	1,922	1,922
R-sq within	0.065	0.106	0.247	0.254

^a Dependent variable for the OM regressions is gross rent per square foot in \$2014. Dependent variable for the CS regressions is in \$2014 and is net rent which adjusts gross rent for months of free rent at the start of the lease and other accommodations.

^b k is set to a value 1 unit larger in absolute value than the lowest basement floor in the data, -5 for the offering memo data and -1 for the CompStak data.

Table 2b: Convex Rent Gradients^a
(t-ratios based on standard errors clustered at the building level)

	Offering Memo Data			CompStak Data		
	(1)	(2)	(3)	(4)	(5)	(6)
	Floors 3 through 29	Floors 30 through 59	Floors 60 and above	Floors 3 through 29	Floors 30 through 59	Floors 60 and above
<u>PANEL A: Double Log</u>						
Log(Floor number + k) ^b	0.1447 (4.31)	0.1352 (0.81)	5.40 (649.37)	0.0760 (16.55)	0.2873 (7.29)	1.274 (4.20)
Observations	3,537	775	146	29,360	4,602	116
Lease quarter Fixed Effects	No	No	No	Yes	Yes	Yes
Building Fixed Effects	93	44	4	1,862	369	18
R-sq within	0.019	0.003	0.090	0.257	0.295	0.710
<u>PANEL B: Log-Linear</u>						
Floor number	0.0082 (4.30)	0.0033 (0.89)	0.0620 (362.06)	0.0058 (17.41)	0.0068 (7.30)	0.0161 (4.95)
Observations	3,537	775	146	29,360	4,602	116
Lease quarter Fixed Effects	No	No	No	Yes	Yes	Yes
Building Fixed Effects	93	44	4	1,862	369	18
R-sq within	0.019	0.003	0.090	0.259	0.295	0.708

^aDependent variable for the OM regressions is gross rent per square foot in \$2014. Dependent variable for the CS regressions is in \$2014 and is net rent which adjusts gross rent for months of free rent at the start of the lease and other accommodations.

^b k is set to a value 1 unit larger in absolute value than the lowest basement floor in the data, -5 for the offering memo data and -1 for the CompStak data.

Table 3a: Vertical Versus Horizontal Rent Gradients Using CompStak Data^a
(t-ratios based on standard errors clustered at the building level)

	Double-Log Models				Log-Linear Models			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	MSA FE	MSA FE	MSA FE	Bldg FE	MSA FE	MSA FE	MSA FE	Bldg FE
Building height (floors)	-	0.0024 (2.68)	0.0021 (2.25)	-	-	0.0018 (2.00)	0.0011 (1.30)	-
Ground floor	-	0.1787 (4.55)	0.1813 (4.48)	0.1156 (3.16)	-	0.0537 (1.36)	0.0556 (1.37)	0.0295 (0.81)
Ground Floor X Bldg Height	-	0.0072 (3.86)	0.0072 (3.70)	0.0070 (3.96)	-	0.0075 (4.09)	0.0076 (3.99)	0.0073 (4.15)
Log(Floor number + k) ^b	-	0.1165 (12.98)	0.1157 (13.14)	0.0858 (16.89)	-	-	-	-
Floor number	-	-	-	-	-	0.0074 (12.90)	0.0073 (13.75)	0.0058 (17.31)
Log(Zipcode emp in 1,000)	0.1068 (5.42)	-	0.0931 (4.93)	-	-	-	-	-
Zipcode emp (1,000s)	-	-	-	-	0.0023 (7.62)	-	0.0020 (6.96)	-
Observations	36,963	37,007	36,963	37,007	36,963	37,007	36,963	37,007
Lease quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MSA Fixed Effects	8	8	8	No	8	8	8	No
Building Fixed Effects	No	No	No	1,922	No	No	No	1,922
R-sq within	-	-	-	0.247	-	-	-	0.254
R-sq total	0.881	0.887	0.889	0.945	0.884	0.887	0.891	0.945

^a Dependent variable is in \$2014 and is net rent which adjusts gross rent for months of free rent at the start of the lease and other accommodations.

^b k is set to a value 1 unit larger in absolute value than the lowest basement floor in the data, -5 for the offering memo data and -1 for the CompStak data.

Table 3b: New York City, Chicago, and San Francisco Rent Gradients Controlling for Building-Level Employment^a
(t-ratios based on standard errors clustered at the building level)

	(1)	(2)	(3)	(4)	(5)	(6)
Building height (floors)	-	-	0.0021	0.0115	0.0009	-
	-	-	(2.00)	(1.44)	(0.89)	-
Ground floor	-	-	0.1875	0.1996	0.1969	0.1407
	-	-	(2.61)	(2.76)	(2.71)	(2.14)
Ground Floor X Bldg Height	-	-	0.0056	0.0052	0.0051	0.0055
	-	-	(2.09)	(1.96)	(1.92)	(2.26)
Floor number	-	-	0.0087	0.0085	0.0084	0.0064
	-	-	(14.45)	(15.28)	(15.44)	(18.42)
Zipcode emp (1,000s)	0.0024	-	-	0.0022	-	-
	(7.63)	-	-	(6.94)	-	-
Zipcode – Bldg emp (1,000s)	-	0.0023	-	-	0.0021	-
	-	(7.19)	-	-	(6.76)	-
Building employment (1,000s)	-	0.0113	-	-	0.0073	-
	-	(3.87)	-	-	(2.75)	-
Chicago	-0.904	-0.9004	-0.1.026	-0.9460	-0.9395	-
	(-28.93)	(-28.92)	(-33.50)	(-28.17)	(-27.96)	-
San Francisco	-0.0546	-0.0489	-0.1442	-0.0354	-0.0344	
	(-1.99)	(-1.81)	(-7.01)	(-1.40)	(-1.36)	
Observations	28,324	28,324	28,324	28,324	28,324	28,324
Lease quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Building Fixed Effects	No	No	No	No	No	1,192
R-sq within	-	-	-	-	-	0.294
R-sq total	0.565	0.573	0.584	0.604	0.607	0.798

^aDependent variable is net rent which adjusts gross rent for months of free rent at the start of the lease and other accommodations.

Table 4: Vertical Location By Industry^a

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All Industries	Retail (Sic2 52-59)	Not Retail (Not Sic2 52-59)	Business Services (Sic2 73)	Law Offices (Sic2 81)	Brokerage Offices 12 MSAs (SIC 62)	Insurance Carriers 12 MSAs (SIC 63)	Insurance Agents, Brokers & Services (SIC 64)
1 st Pctl	-2	-2	-2	-2	-1	-2	-1	-1
25 th Pctl	4	1	7	5	14	12	7	9
50 th Pctl	14	1	16	15	21	23	13	18
75 th Pctl	25	5	26	25	33	31	26	26
99 th Pctl	97	90	66	93	72	55	61	43
# Obs	5,750	226	2,940	267	643	277	63	76

^a Offering memo data for 93 buildings for tenants matched to D&B records.

**Table 5: Location by Sales per Worker
(Dependent Variable: Log Floor Number)^a**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Head Quarters 12 MSAs	Single Site 12 MSAs ^b	Single Site 12 MSAs ^b	Law Offices 12 MSAs (SIC 81)	Law Offices 12 MSAs (SIC 81)	Advertising Offices 12 MSAs (SIC 7311)	Brokerage Offices 12 MSAs (SIC 62)	Insurance Carriers 12 MSAs (SIC 63)	Insurance Agents, Brokers & Services 12 MSAs (SIC 64)
Log sales/worker at site	- -	0.0139 (2.01)	0.0149 (2.00)	0.0463 (4.61)	0.0225 (2.21)	-0.0353 (-1.28)	0.0040 (0.26)	-0.0227 (-1.24)	-0.0064 (-0.43)
Log employment at site	-0.0110 (-1.40)	0.0304 (6.47)	0.0169 (5.03)	0.0372 (6.03)	0.0134 (3.37)	0.0065 (0.47)	0.0406 (4.56)	-0.0112 (-0.58)	0.0160 (2.35)
Log sales/worker – Firm	0.0262 (5.64)	- -	- -	- -	- -	- -	- -	- -	- -
Log employment – Firm	0.0352 (5.84)	- -	- -	- -	- -	- -	- -	- -	- -
Publicly traded	0.1061 (3.18)	0.5371 (1.84)	0.2265 (0.89)	- -	- -	-0.2242 (-2.88)	0.4196 (2.49)	1.3266 (7.13)	0.6150 (45.89)
Subsidiary	-0.0488 (-1.92)	0.0029 (0.11)	-0.0819 (-2.38)	0.0523 (0.38)	-0.0244 (-0.18)	0.0741 (0.85)	-0.0184 (-0.45)	0.0599 (0.66)	0.0501 (1.06)
Risk Rating: Low	0.0286 (1.69)	0.0284 (2.73)	0.0003 (0.04)	0.0331 (2.47)	-0.0046 (-0.45)	0.0364 (0.67)	0.0450 (1.30)	-0.0216 (-0.23)	0.0058 (0.35)
Risk Rating: Medium	0.0680 (2.37)	0.0432 (2.41)	-0.0225 (-1.76)	0.0372 (1.26)	-0.0315 (-1.96)	0.0547 (0.83)	0.0300 (0.86)	0.0982 (0.86)	0.0456 (1.78)
Observations	16,335	58,389	58,389	36,980	36,980	1,700	6,884	1,268	10,916
Within R-squared	0.013	0.010	-	0.004	-	0.003	0.005	0.014	0.002
Total R-squared	-	-	0.8141	-	0.8207	-	-	-	-
2-digit Industry FE	-	5	5	-	-	-	-	-	-
5-Digit Zipcode FE	640	1,767	-	1,493	-	428	1,001	574	1,460
Building FE	-	-	19,721	-	11,955	-	-	-	-

^b Data are from Dun and Bradstreet. T-ratios in parentheses based on standard errors clustered at the level of the geographic fixed effects (zipcode or building).

^b Includes SIC 62, 63, 64, 7311, 81..

**Table 6: Alternate Geographic Fixed Effects
(Dependent Variable: Log Floor Number)^a**

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pooled Data for Five 2-Digit Single Site Industries in 12 MSAs ^b				Law Offices in 12 MSAs (SIC 81)			
	OLS	MSA Fixed Effects	5-Digit Zip Fixed Effects	Building Fixed Effects	OLS	MSA Fixed Effects	5-Digit Zip Fixed Effects	Building Fixed Effects
Log sales/worker at site	0.0977 (12.11)	0.0635 (7.42)	0.0139 (2.01)	0.0149 (2.00)	0.1635 (11.35)	0.1238 (10.02)	0.0463 (4.61)	0.0225 (2.21)
Log employment at site	0.0860 (22.88)	0.0842 (9.22)	0.0304 (6.47)	0.0169 (5.03)	0.0873 (17.34)	0.0909 (7.36)	0.0372 (6.03)	0.0134 (3.37)
Publicly traded	0.7563 (2.90)	0.6450 (19.53)	0.5371 (1.84)	0.2265 (0.89)	- -	- -	- -	- -
Subsidiary	0.2242 (6.84)	0.1673 (2.96)	0.0029 (0.11)	-0.0819 (-2.38)	0.1712 (1.29)	0.0631 (0.50)	0.0523 (0.38)	-0.0244 (-0.18)
Risk Rating: Low	0.0566 (5.47)	0.0679 (5.93)	0.0284 (2.73)	0.0003 (0.04)	0.0835 (6.21)	0.0902 (5.48)	0.0331 (2.47)	-0.0046 (-0.45)
Risk Rating: Medium	0.1455 (10.19)	0.1076 (4.37)	0.0432 (2.41)	-0.0225 (-1.76)	0.1595 (7.95)	0.1178 (3.14)	0.0372 (1.26)	-0.0315 (-1.96)
Observations	58,389	58,389	58,389	58,389	36,980	36,980	36,980	36,980
Within R-squared	0.081	0.071	0.010	-	0.014	0.013	0.004	-
Total R-squared	-	-	-	0.814	-	-	-	0.821
2-digit Industry FE	5	5	5	5	-	-	-	-
MSA FE	-	12	-	-	-	12	-	-
5-Digit Zipcode FE	215	-	1,749	-	-	-	1,493	-
Building FE	-	-	-	19,721	-	-	-	11,955

^a Data are from Dun and Bradstreet. T-ratios in parentheses based on standard errors clustered at the level of the fixed effects.

^b Includes SIC 62, 63, 64, 7311, 81.

Appendix A: Offering Memo Example
JP Morgan Chase Commercial Mortgage Securities Trust 2006-LDP²⁷

One Prudential Plaza Stacking Plan

Flr	Tenant	SqFt	Lease Ends	Tenant	SqFt	Lease Ends
41	Plaza Club	7,798	06/06			
40M	AM/FM Ohio, Inc	100	09/06			
40	Vacant	1,860		Multi-Tenant	8,254	
39	Baker & McKenzie LLP	22,503	11/12			
38	Schuyler, Roche & Zwirner	24,082	04/15			
37	Baker & McKenzie LLP	24,017	11/12			
36	Baker & McKenzie LLP	24,068	11/12			
35	Baker & McKenzie LLP	24,148	11/12			
34	Vacant	14,274		Baker & McKenzie LLP	8,917	12/08
33	Baker & McKenzie LLP	23,026	11/12			
32	Baker & McKenzie LLP	22,411	11/12			
31	Baker & McKenzie LLP	22,990	11/12			
30	Baker & McKenzie LLP	21,191	11/12			
29	McGraw-Hill Inc	22,647	11/16			
28	Baker & McKenzie LLP	9,747	11/12	BDO Seidman, LLP	12186	09/11
27	Bonneville International	21,913	05/18			
26	Multi-Tenant	21,742				
25	Baker & McKenzie LLP	22,862	11/12			
24	Peoples Gas Light & Coke	21,803	05/14			
23	Peoples Gas Light & Coke	21,803	05/14			
22	Peoples Gas Light & Coke	21,803	05/14			
21	Peoples Gas Light & Coke	22,862	05/14			
20	Peoples Gas Light & Coke	23,264	05/14			
19	Peoples Gas Light & Coke	21,321	05/14			
18	Peoples Gas Light & Coke	19,917	05/14			
17	Peoples Gas Light & Coke	23,203	05/14			
16	Peoples Gas Light & Coke	23,126	05/14			
15	Atty Regis & Disciplinary Commission	23,125	05/15			
14	Vacant	1,208		McGraw-Hill, Inc	23,199	11/16
13	Vacant	22,398		BDO Seidman, LLP	383	09/06
12	Vacant	1,991		Multi-Tenant	21,375	
11	Multi-Tenant	22,397				
10	Vacant	1,009		Multi-Tenant	47,600	
9	McGraw-Hill, Inc	49,998	11/16			
8	Vacant	48,818				
7	Vacant	19,655		Kirkland & Ellis LLP	28,154	12/11
6	Kirkland & Ellis LLP	52,224	21/11			
5	BCE Nexxia Corp	49,144	08/15			
4	McGraw-Hill, Inc	49,252	11/16			
3	Peoples Gas Light & Coke	48,784	05/14			

²⁷<http://www.secinfo.com/dsvrn.v4Mq.htm>

Appendix A (continued)
JP Morgan Chase Commercial Mortgage Securities Trust 2006-LDP7²⁸

One Prudential Plaza Stacking Plan

Flr	Tenant	SqFt	Lease Ends	Tenant	SqFt	Lease Ends
2	Vacant	5		Multi-Tenant	36,763	
1	Vacant	19,239		Multi-Tenant	22,151	
Entr	Vacant	2,011		Multi-Tenant	34,148	
B2	Peoples Gas Light & Coke	267	05/14			
B1	Vacant	8,005		Multi-Tenant	9,662	

Two Prudential Plaza Stacking Plan

Flr	Tenant	SqFt	Lease Ends	Tenant	SqFt	Lease Ends
58	Taipei Econ/ Cultural Ofc	12,994	06/11			
57	Taipei Econ/ Cultural Ofc	10,267	06/11	Advisory Research Inc.	2,943	05/14
58	Taipei Econ/ Cultural Ofc	12,994	06/11			
56	Prudential Insurance Co.	13,717	07/08			
55	Multi-Tenant	14,000				
54	Prudential Insurance Co.	14,082	07/08			
53	Multi-Tenant	12,822		Vacant	1,325	
52	Vacant	14,038				
51	Centraxcorp	14,932	03/16			
50	Leydig, Voit & Mayer Ltd	15,164	08/10			
49	Leydig, Voit & Mayer Ltd	16,000	08/10			
48	Leydig, Voit & Mayer Ltd	16,000	08/10			
47	Leydig, Voit & Mayer Ltd	9,704	08/10	Prudential Insurance Co.	7,540	07/08
46	Prophet Brand Strategy	17,950	03/12			
45	Multi-Tenant	17,950				
44	International Food Svc	9,747	11/13	Vacant	8,203	
43	Black Entertainment TV	9,647	08/07	BDO Seidman, LLP	8,303	
42	Aleri, Inc	18,726	10/07			
41	Aleri, Inc	19,000	10/07			
40	Aleri, Inc	19,565	10/07			
39	Mechanical Room					
38	Bowman, Barrett & Assoc	162	11/06	Mechanical Room	1,313	38
37	Leboeuf, Lamb, Greene & Macrae	20,184	09/10			
36	Norgren, Inc	6,560	09/12	Vacant	13,555	
35	Vacant	20,174				
34	Vacant	20,743				
33	Vacant	20,219				
32	Multi-Tenant	18,223		Vacant	2,007	

Appendix B (continued)
JP Morgan Chase Commercial Mortgage Securities Trust 2006-LDP7²⁹

²⁸<http://www.secinfo.com/dsvrn.v4Mq.htm>

²⁹<http://www.secinfo.com/dsvrn.v4Mq.htm>

Two Prudential Plaza Stacking Plan (continued)

Flr	Tenant	SqFt	Lease Ends	Tenant	SqFt	Lease Ends
31	Multi-Tenant	19,865				
30	Multi-Tenant	19,893				
29	Aon Corporation	20,966	09/09			
28	Aon Corporation	20,966	09/09			
27	Aon Corporation	20,992	09/09			
26	Multi-Tenant	20,447				
25	Multi-Tenant	20,059				
24	Multi-Tenant	18,174		Vacant	1,731	
23	Vacant	19,922				
22	Vacant	19,936				
21	Michael Best&Friedric LLP	20,157	01/17			
20	Michael Best&Friedric LLP	20,655	01/17			
19	Michael Best&Friedric LLP	3,599	01/17	Vacant	17,052	
18	Amsted Industries, Inc	17,040	11/18	Singapore Econ Dev	3,578	03/09
17	SAS Institute, Inc.	20,611	12/15			
16	SAS Institute, Inc.	8,504	12/15	Vacant	12,089	
15	Vacant	20,571				
14	Vacant	20,571				
13	Multi-Tenant	10,256		Vacant	9,702	
12	Vacant	20,762				
11	Infinity Holdings Corp.	21,548	04/18	Vacant	316	
10	Infinity Holdings Corp.	20,580	04/18			
9	Infinity Holdings Corp.	21,145	04/18			
8	Multi-Tenant	15,718		Vacant	5,344	
7	Doubleclick, Inc.	9,801	07/10	Vacant	11,590	
6	Kirkland & Ellis LLP	21,420	12/11			
5	Multi-Tenant	4,034				
4	Multi-Tenant	5,885		Vacant	1,375	
2	Las Vegas Convention Visitors Authority	2,380	08/15	Mechanical Room		
1	Multi-Tenant	9,230		Vacant	1,841	
Entr	Schermerhorn	300	10/09	Vacant	1,608	
B1	Multi-Tenant	900		Vacant	600	

**Appendix B: Rent Roll Example
A Portion of the Rent Roll for 999 Peachtree (2/28/2013)³⁰**

Database: PRODUCTION Bldg Status: Active only JAMESTOWN 999 PEACHTREE, L.P.										Rent Roll 999 PEACHTREE 2/28/2013			Page: 1 Date: 3/8/2013 Time: 01:50 PM	
Bldg Id	-Suit Id	Occupant Name	Rent Start	Expiration	RSF Sqft	Monthly Base Rent	Annual Rate PSF	Monthly Cost Recovery	Expense Stop	Monthly Other Income	Future Rent Increases			
											Cat	Date	Monthly Amount	PSF
Vacant Suites														
4507	-0520	Vacant			8,543									
4507	-0840	Vacant			1,567									
4507	-0920	Vacant			190									
4507	-1300	Vacant			22,520									
Occupied Suites														
4507	-0100	Wells Fargo Bank, N.A.	1/1/1988	3/31/2015	4,872	10,767.12	26.52				RTL	4/1/2013	11,091.92	27.32
4507	-0110	Stephanie Hyde / En Paris	4/20/2011	5/31/2012	1,973			250.00			RTL	4/1/2014	11,424.84	28.14
4507	-0120	Clothing Warehouse (Temp)	6/1/2012	12/31/2013	3,439			250.00						
4507	-0130	Fitness Center	3/1/2010	3/31/2015	2,395									
4507	-0140	Empire State South	9/1/2010	8/31/2020	4,300	11,183.53	31.21	1,896.98			RTL	1/1/2014	11,409.33	31.84
											RTL	1/1/2015	12,548.83	35.02
4507	-0155	Michael K. Kim / City News Stand	5/1/2004	1/31/2015	407	760.00	22.41				RTL	1/9/2014	780.00	23.00
4507	-0165	Metro Cleaners / 999 Cleaners	1/1/2006	6/30/2015	228	629.09	33.11				RTL	7/1/2013	648.09	34.11
											RTL	7/1/2014	667.47	35.13
4507	-0170	Cross Cuts / Bobby Cross	5/1/1990	4/30/2015	464	929.55	24.04				RTL	5/1/2013	464.77	12.02
											RTL	6/1/2013	957.43	24.76
											RTL	5/1/2014	478.72	12.38
											RTL	6/1/2014	986.16	25.50
4507	-0190	Eco-Denizen	4/1/2012	7/31/2017	1,336	2,783.33	25.00	592.84			RTL	4/1/2013	2,894.67	26.00
											RTL	4/1/2014	3,006.00	27.00
											RTL	4/1/2015	3,117.33	28.00
											RTL	4/1/2016	3,228.67	29.00
											RTL	4/1/2017	3,340.00	30.00
4507	-0300	Heery International, Inc.	10/1/1987	9/30/2017	26,310	79,859.20	12.75	64,083.69			OFC	10/1/2013	81,456.38	13.01
											OFC	10/1/2014	83,085.31	13.27
											OFC	10/1/2015	84,747.22	13.53
											OFC	10/1/2016	86,442.16	13.80
		Additional Space 4507 -0200	10/1/1987	9/30/2017	21,614									
		Additional Space 4507 -0400	10/1/1987	9/30/2017	22,873									
		Additional Space 4507 -BST05	10/1/1987	9/30/2017	4,358					4,358.00				
		Total			75,155	79,859.20		64,083.69		4,358.00			4,358.00	
4507	-0540	Real Estate Management Services Gr	9/1/2011	5/31/2017	2,862	3,269.83	13.71	50.59			OFC	9/1/2013	6,704.24	28.11

³⁰<http://www.sec.gov/Archives/edgar/data/1031316/000117152013000210/ex10-1.htm>

**Appendix B (continued): Rent Roll Example
A Portion of the Rent Roll for 999 Peachtree (2/28/2013)**

Database: PRODUCTION Bldg Status: Active only JAMESTOWN 999 PEACHTREE, L.P.											Rent Roll 999 PEACHTREE 2/28/2013			Page: 5 Date: 3/8/2013 Time: 01:50 PM	
Bldg Id	-Suit Id	Occupant Name	Rent Start	Expiration	RSF Soft	Monthly Base Rent	Annual Rate PSF	Monthly Cost Recovery	Expense Stop	Monthly Other Income	Future Rent Increases				
											Cat	Date	Monthly Amount	PSF	
4507	-1120A	Robbins Ross Alloy Belinfante & Little	12/1/2008	11/30/2019	3,322	8,540.31	30.85				OFC	12/1/2013	8,711.95	31.47	
4507	-1200	Flad & Associates, Inc.	3/1/2009	12/31/2014	11,310	29,867.83	31.69				OFC	3/1/2013	30,763.20	32.64	
											OFC	3/1/2014	31,686.85	33.62	
4507	-1225	Mazursky Constantine, LLC	9/1/2009	8/31/2020	2,669	5,503.11	24.74				FRR	9/1/2013	-623.72	-2.80	
											FRR	9/1/2014	-4,454.45	-20.03	
											FRR	9/1/2015	-1,947.32	-8.76	
											FRR	9/1/2016	-1,986.14	-8.93	
											OFC	9/1/2013	6,861.55	30.85	
											OFC	9/1/2014	6,999.45	31.47	
											OFC	9/1/2015	7,139.58	32.10	
											OFC	9/1/2016	7,281.92	32.74	
											OFC	9/1/2017	7,426.49	33.39	
											OFC	9/1/2018	7,575.51	34.06	
											OFC	9/1/2019	7,726.76	34.74	
4507	-1234	Raising the Bar, LLC	4/1/2011	10/31/2016	955	2,295.18	28.84	16.32			OFC	4/1/2013	2,364.42	29.71	
											OFC	4/1/2014	2,434.25	30.59	
											OFC	4/1/2015	2,508.47	31.52	
											OFC	4/1/2016	2,584.07	32.47	
4507	-1245	The Hishon Firm, LLC	4/1/2011	6/30/2014	1,077	2,588.39	28.84	18.04			OFC	4/1/2013	2,666.47	29.71	
											OFC	4/1/2014	2,746.35	30.60	
4507	-1400	Genster	1/1/2012	6/30/2023	21,136	22,655.34	12.86	547.56			FRR	1/1/2014	-15,893.96	-9.02	
											FRR	1/1/2015	-4,410.00	-2.50	
											OFC	1/1/2014	50,638.33	28.75	
											OFC	1/1/2015	51,783.20	29.40	
											OFC	1/1/2016	52,945.68	30.06	
											OFC	1/1/2017	54,143.39	30.74	
											OFC	1/1/2018	55,358.71	31.43	
											OFC	1/1/2019	56,609.25	32.14	
											OFC	1/1/2020	57,877.41	32.86	
											OFC	1/1/2021	59,180.80	33.60	
											OFC	1/1/2022	60,519.41	34.36	
											OFC	1/1/2023	61,875.64	35.13	
4507	-1500	Mazursky Constantine, LLC	9/1/2009	8/31/2020	21,136	53,262.72	30.24				OFC	9/1/2013	54,337.13	30.85	
											OFC	9/1/2014	55,429.16	31.47	
											OFC	9/1/2015	56,538.80	32.10	
											OFC	9/1/2016	57,666.05	32.74	
											OFC	9/1/2017	58,810.92	33.39	
											OFC	9/1/2018	59,981.01	34.06	
											OFC	9/1/2019	61,188.72	34.74	
4507	-1600	Sutherland Asbill & Brennan	3/1/2003	4/30/2020	21,137										
		Additional Space 4507 -1700	3/1/2003	4/30/2020	21,417										
		Additional Space 4507 -1800	3/1/2003	4/30/2020	21,417										
		Additional Space 4507 -1900	3/1/2003	4/30/2020	21,417										