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The Vertical City: Rent Gradients, Spatial Structure, and Agglomeration Economies

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Abstract

Tall commercial buildings dominate city skylines. Nevertheless, despite decades of research on commercial real estate and *horizontal* patterns of urban development, *vertical* patterns have been largely ignored. We document that high productivity companies locate higher up, with less productive offices lower down and retail at ground level. These patterns reflect tradeoffs between street access and vertical amenities. Vertical rent gradients are non-monotonic, independent of nearby employment, and large. Doubling zipcode employment is associated with a 10.7% increase in rent, consistent with the presence of agglomeration economies. Moving up one floor has the same effect on rent as adding roughly 3,500 workers to a zipcode.

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I. Introduction

Tall commercial buildings define city skylines and are equivalent in scale to small cities. To take one famous example, the World Trade Center's twin towers together had roughly 50,000 workers in 10 million square feet of space, making each equivalent in size to a small town.[1] The twin towers were part of the vast commercial real estate industry. As of 2009, the aggregate value of commercial real estate in the United States was in excess of 11 trillion dollars (Florance *et al.*, 2010). Nevertheless, despite decades of research on commercial real estate and on *horizontal* patterns of urban development, *vertical* patterns within cities have been largely ignored.[2] As a consequence, the extent to which different types of companies sort into different vertical locations, analogous to extensively studied horizontal sorting, is poorly understood. Are the most productive law offices, for example, high up off the ground, consistent with industry folklore that suites up high are prestigious? If so, what may drive such sorting outcomes and how does vertical sorting affect rent? The answers to these questions are not obvious because higher commercial rents must be offset in equilibrium by higher revenue or reduced operating costs, given the profit motive of commercial tenants.

Systematic vertical variation in rents must also be reconciled with previous estimates of spatial variation in productivity in urban areas. The agglomeration literature has emphasized that proximity to nearby employment often increases productivity by enhancing the ability of businesses to draw on pools of skilled labor, share intermediate inputs and learn from their neighbors (e.g. Rosenthal and Strange, 2004; Combes and Gobillon, 2015; Behrens and Robert-Nicoud, 2015). Again though, studies of this sort have been carried out exclusively in a horizontal context, even those taking a microgeographic approach (e.g. Rosenthal and Strange, 2003; Arzaghi and Henderson, 2008). Moreover, while a large literature has considered the relationship of agglomeration to wage (e.g. Rosenthal and Strange, 2004, 2008; Combes and Gobillon, 2015), the agglomeration literature has largely ignored commercial rent. By how much does the scale of nearby employment boost rent and how does that relationship compare to estimated wage elasticities? Are estimates of the rent-agglomeration elasticity sensitive to the vertical location of establishments, and conversely are estimates of vertical rent gradients sensitive to the scale of nearby employment? As will become apparent, answers to these questions can illuminate the nature of the underlying drivers of vertical and horizontal patterns of sorting and productivity, as well as whether those mechanisms are similar or different.

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[1] See https://www.nysm.nysed.gov/wtc/about/facts.html.

[2] The focus on horizontal patterns of spatial sorting in urban areas is evident in literature reviews by Brueckner (1987) and Duranton and Puga (2015). In addition, as discussed in greater detail below, the few recent papers on tall buildings (e.g, Barr, 2012, Koster *et al*, 2014a, Ahlfeldt and McMillen, 2015) have focused on building height rather than internal structure.

For at least two reasons, the need to know more about these issues will grow over time. The first is that the number of skyscrapers worldwide is growing at a dramatic rate.[3] Thus, an increasing amount of aggregate employment is housed in tall buildings, and failing to allow for the vertical organization of economic activity risks missing much of what may contribute to urban productivity. Second, the business service sector continues to grow relative to the rest of the economy but most of the agglomeration literature has focused on manufacturing that is declining in employment share and tends to operate in low-rise buildings outside of city centers. The business services sector, in contrast, increasingly dominates city centers and operates disproportionately in tall buildings.[4] As economies continue to evolve in this direction, the need to understand more about the vertical organization of urban areas and the office sector will grow.

This paper addresses the questions highlighted above, and in doing so it makes a number of contributions to the literature. We begin by adapting the standard monocentric model of urban spatial structure of Alonso (1964), Mills (1967), and Muth (1969) to activity inside tall buildings. This yields new insights into spatial sorting in a manner that points to a series of sharp testable predictions. These predictions are then tested using three unique databases, two of which have only just become available. Data sources include confidential offering memoranda that lay out the tenant stack (tenant locations) and rents by floor for 93 tall buildings spread across 18 metropolitan areas, a new commercial rent dataset produced by CompStak Inc., and establishment-level data on employment, sales and more from Dun and Bradstreet (D&B). Details of these data are provided later in the paper. For now, it is sufficient to emphasize that these data allow us to examine features of commercial buildings that have not been feasible to study in the past.

Our theory treats each building as a "long narrow city" in the sense of Solow and Vickrey (1971). At the core of the model is a tension between vertical transportation costs – the cost of accessing the street – and vertical amenities, both of which increase moving up within a building. Vertical transportation costs are large. Evidence from an IBM (2010) survey of office tenants, for example, suggests that a typical tenant spends 22.36 minutes waiting for or riding in elevators in a business day. This is close to the average one way home to work commute of 24 minutes as reported in the Census (Rosenthal and

[3] The burst in skyscraper 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] In 1950, for example, manufacturing accounted for roughly 30 percent of U.S. nonfarm employment while professional and business services accounted for just 6.5 percent. In 2016 those shares had shifted to 8.5 percent and 14.1 percent, respectively (U.S. Bureau of Labor Statistics, www.bls.gov). Adding health and education services to professional and business service employment counts, the combined employment shares of these segments of the service sector accounted for just 11.4 percent of employment in 1950 but 29.8 percent in 2016.

Strange, 2012).[5] Vertical amenities matter to commercial tenants only to the extent that they raise profits.[6] We discuss below that this may be because views or simply the status associated with height can impact value both by acting as perquisites for employees and by signaling productivity to potential customers. In both cases, a high location will be worth more to a high-productivity tenant. These modeling features imply that high productivity amenity-oriented office establishments should sort into suites higher up off the ground with less productive offices lower down and access-oriented establishments like retail concentrated at ground level. We show that these patterns should also support a non-monotonic, nonlinear vertical rent pattern: ground floor rents should be high relative to the third floor because of easy street access, but should then rise gradually and at an increasing rate with additional height as amenities become more dramatic. It is important to recognize that the mechanisms in our model that drive vertical sorting are quite different from the micro-foundations that are thought to generate productivity spillovers from nearby employment. If our modeling structure is correct, a further prediction therefore is that the vertical rent gradient should be independent of the scale of nearby employment and the influence of nearby employment on commercial rent should be unaffected by a company's vertical location.

Empirical results support the model's predictions, in addition to yielding the first ever estimates of the vertical rent gradient and a robust estimate of the elasticity of commercial rent with respect to the scale of nearby employment. For a typical tall building (over 30 floors), moving up from the ground floor to the second floor, rents drop by up to 50 percent. 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). Adding controls for the scale of nearby employment allows for both vertical and horizontal drivers of rent. In these models, doubling employment in an establishment's zipcode is associated with an increase in commercial rent by roughly 10.7 percent. This estimate is robust to controls for building height, which proxies, in part, for nearby amenities and other unobserved factors that could affect rent. Furthermore, adding 3,500 workers to a building's zipcode is associated with an increase in rent by an amount about equal to moving up one floor. Consistent with wage and other agglomeration studies, we also find that within-building employment has a much stronger relationship with commercial rent than does zipcode employment outside of the building (i.e., coefficients in the rent model are four times

[5] Glaeser (2011) and Bernard (2014) argue that prior to the elevator, residential buildings were typically under six stories, with the top occupied by the lowest income tenants. Elevators dramatically reduced the cost of vertical travel which, along with steel and other technology, was crucial for making tall buildings viable.

[6] The situation is different for residential buildings where view and height enter directly into tenant utility functions. Deng et al (2016) document that views increase condominium values in tall residential buildings in Vancouver. See also Pollard (1980, 1982), Sirmans et al (2005), and Rodriguez and Sirmans (1994) for related evidence that scenic views increase residential property values. Horizontal bid-rent curves may also be non-monotonic, as in DeBartolome and Ross (2007).

larger). This echoes findings in Rosenthal and Strange (2003, 2004, 2005, 2008, and 2012) and Arzaghi and Henderson (2008) that agglomeration economies attenuate sharply with distance. As also predicted, estimates of the vertical rent gradient are unaffected by controls for nearby employment while estimates of the elasticity of nearby employment on commercial rent are unaffected by controls for the vertical pattern of rents. Our findings, therefore, confirm that both horizontal and vertical attributes are strongly related to commercial rent, with effects that are largely independent of each other.

The paper's final set of empirical results pertain to sorting and again support the theory's predictions. Using the D&B data, we proxy for establishment productivity for single-site establishments using sales per worker and the number of workers at the site. For headquarter establishments we also control for employment at the firm level and replace establishment-level sales per worker with its firm-level analogue. Results from these and other models confirm that access-oriented establishments like retail are concentrated at the ground level, while amenity-oriented establishments like law offices tend to be higher up. Moreover, compelling evidence confirms that the most productive offices disproportionately occupy suites in the upper portions of tall buildings while less productive offices tend to be lower down. As with the rent models, these estimates are extremely robust and persist regardless of controls for fixed effects at the MSA, zipcode, or building level.

The patterns above extend several distinct lines of research. As noted previously, the paper builds directly on the literatures on urban spatial structure and on agglomeration economies. The paper also builds on extensive previous work on commercial real estate. Studies in this area have considered the return on investment in commercial real estate using REITS and cap rates (e.g. Kalberg et al, 2008, Plazzi et al, 2010), the influence of vacancy rates on office rents (Wheaton and Torto, 1988, Glascock et al, 1990), and retail malls including the role of anchor tenants.[7] These sorts of studies, however, have only lightly touched on spatial issues and have overlooked vertical issues entirely.[8]

Our work builds most directly on research that considers building height and the effect of building height on building value and rent. Sullivan (1991) considers the economics of tall buildings, with vertical transportation costs playing an important role. 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. Ahlfeldt and McMillen (2015) document a robust positive relationship between building heights and land rents using Chicago microdata that spans more than a century. They also show that

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[7] This includes theoretical work by Brueckner (1993) and Konishi and Sandfort (2003) and empirical studies by Pashigian and Gould (1998) and Gould, Pashigian, and Pendergast (2005).

[8] There is also a tendency in the commercial real estate 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). This paper differs in that we explicitly model the determinants of rent based on underlying sorting outcomes.

spatial dispersion of tall buildings can be explained in part by the dissipative competition for height modeled by Helsley and Strange. Barr (2010, 2012) carefully documents patterns of building heights in Manhattan. Colwell et al (1988) and Shilton and Zaccaria (1994) provide evidence that commercial building values increase with building height for Chicago and Manhattan, respectively, while Koster et al (2014a) use data from the Netherlands to show that commercial rents are higher in taller office buildings. Koster et al argue that their rent patterns can reflect scenic views from tall buildings or the landmark nature of the structures themselves. Dericks and Koster (2016) examine current day neighborhoods in London that were bombed during the blitz in World War II. They argue that previously demolished areas were rebuilt to higher density and provide evidence that commercial rents are higher in such locations. Jennen and Brounen (2009) examine the Amsterdam office market and report evidence that doubling the number of buildings in an office cluster increases commercial rent by 4.5 percent. The fundamental difference between our paper and the existing literature on building height is that we observe and evaluate what happens inside of tall buildings including vertical spatial patterns of sorting, employment, productivity, and rent.[9,10]

The remainder of the paper is organized as follows. Section II presents our theoretical model and highlights predictions that will be examined in the data. Section III describes the unique data that make the paper's analysis possible. Section IV computes and compares vertical and horizontal rent gradients, while Section V presents estimates of vertical sorting patterns among office establishments. 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 profits and thus rents depending on two factors: access to the ground floor and amenities that rise 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. In this "open" model, rents will depend on what tenants value. Retail 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 of tenants

[9] The data used by Koster et al (2014a) include a small number of observations for which it is possible to observe the floor on which an office suite is located, but there are too few for the sort of analysis here.
[10] We have written two papers that extend the present paper. Liu et al (2017a) considers the vertical pattern of density (employment/space) within buildings, while Liu et al (2017b) considers the tendency of buildings to specialize and more generally the idea that buildings are fundamental spatial units.

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 as well as 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.[11] 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 of the building. Let the retailer be located on floor z.[12] 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.[13]

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

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

[11] Supposing that customers are matched with particular tenants is a convenient way to capture this. 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.
[12] 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.
[13] We take vertical transportation costs as exogenous throughout the paper. In fact, these costs are determined by the costs that the building owner chooses to incur, a choice that may be impacted by agency problems.

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) = ηM. 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,

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

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

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

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

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

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.[14] 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.

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[14] Yet another explanation for a negatively sloped bid rent is that moving inputs to a higher floor is costly, impacting profit and bid-rent. For retailers, the key cost of this sort is the cost of moving goods.

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

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

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, $p^O \leq v - \tau^O z$.[15]

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 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.[16]

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

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[15] 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.

[16] 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.

patterns discussed in the Introduction and that will be explicated in detail below. An alternative 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.[17] 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.[18]

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 perquisite, 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.[19] Alternatively, a high floor might attract better workers at a given price. This would have parallel effects on firm profits and rents.

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

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

where w^O 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:

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

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

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

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[17] Miller and Rock, (1985) is a seminal reference on dividends as signals.
[18] We are arguing here that signaling may lead some tenants to buy high floors. We are not claiming that signaling must exist.
[19] See for example, Rajan and Wulf (2006) for a discussion of 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.

Absent a strong enough amenity effect of some sort, bid-rent will fall as floor height rises, as with retailers. Vertical transportation costs are likely to be low in the office sector, however, implying that the amenity effect is likely to dominate. The presence of a positively sloped bid-rent – as discussed in the Introduction – suggests that this is the case.

C. Equilibrium rent and 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. 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 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

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

and

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

(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 give sorting, with a given building divided into retailers below and office tenants above. Equilibrium rents for the retail zone will be given by (II.3), while for the office zone, rent is given by (II.7).

In reality, there is obviously a much finer gradation of tenants according to their access and amenities orientation. In this case, sorting can also arise within categories of tenant. Suppose that there are two sorts of office employers, with some having a stronger amenity orientation. This could potentially manifest itself in either $\alpha^H > \alpha^L$ or $\omega^H > \omega^L$. From (II.8), the stronger the amenity-orientation in either sense, the steeper the bid rent curve. This, of course, generates a convex equilibrium rent function and sorting even within tenant categories.[20]

The vertical sorting that arises in this model 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.

In addition, 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. In a signaling equilibrium, high type firms signal their type by locating high. In the case of workers and amenities, and assuming that dramatic views are normal goods, high productivity establishments that rely on highly paid workers will outbid others for office suites up high. Accordingly, a third prediction of our theory is:

(iii) Among amenity-oriented establishments, higher productivity companies will sort into higher floors with lower productivity companies lower down.

Taken as a group, the predictions above all mean that verticality matters, both in pricing and spatial structure.

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[20] Convexity may also arise even without sorting. For instance, a one floor increase might improve the view more near the top of a building. This is parallel to the treatment of amenities in a horizontal setting by Brueckner et al (1999).

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 extension 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 a greater share of the space at or close to street level. 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 both contribute to higher ground floor rent premia in central cities.

The second extension concerns the supply of space. We have thus far taken the supply of space as fixed in our analysis. In this case, rents depend on tenant demand for space, with the tenant zero-profit condition determining the level and slope of the equilibrium bid-rent curves. Of course, supply is approximately fixed in the short run. Furthermore, even if supply were not fixed, (II.3) and (II.7) would still hold in equilibrium, with rents adjusting by floor to make tenants indifferent among locations. In addition, equilibrium rents would also need to satisfy a supply condition. With free entry of builders, this condition would set profits of builders to zero. The presence of both demand and supply indifference conditions in equilibrium is a version of the "double envelope" that determines hedonic prices (Rosen, 1974).

In order to understand supply better, consider the following example. Buildings can have at most two floors, each of fixed size. The cost of building floor z equals a constant c_z, with $c_1 < c_2$. Builders enter freely. In this polar case, the equilibrium rents must equal these constant marginal costs, so that both rent levels and the vertical rent gradient are determined by construction costs. To satisfy the hedonic double envelope condition, equilibrium rents must also adjust so that rents adjust vertically to compensate for tenant perceptions of view amenities net of vertical travel costs, as modeled above. For this to occur, in a setting where supply is not fixed, the intensity of competition must increase with the scale of activity (or some sort of congestion externality must be present) so that tenant profit declines with tenant entry (at least locally). This would ensure that both the equilibrium condition for builders and the equilibrium condition for tenants are satisfied. The key point here is that tenant zero-profit conditions must support the vertical pattern of equilibrium rents outlined earlier even when supply is not fixed.

It is worth noting that there are further complications in considering supply that this simple example does not include. First, the construction cost specification above implicitly assumes that office space is built on stilts for higher floors. While this is essentially true for structures like Toronto's CN

Tower, it is clearly not true for an office building, where supplying 20^{th} floor space requires suppling space at all of the lower floors. While this does not change the tenant zero-profit equilibrium conditions, it obviously complicates the supply conditions. Second, in the case of the downtown office sector considered here, an increase in the supply of space can lead to an increase in the demand for office services nearby. A neighboring building's bankers, for example, may demand legal services from the lawyers next door. Or the neighboring building's lawyers may compete away clients from the lawyers next door. This means that having more activity nearby has a theoretically ambiguous effect on rent in a given building. Again, the tenant indifference conditions remain, but in a form that reflects the complicated relationship of the neighboring environment on tenant profits.

The third extension concerns the horizontal structure of cities. This is the subject of traditional monocentric analysis. Our model extends easily to incorporate horizontal factors that affect commercial rent. Suppose that x gives the distance to the predetermined center of the city. At greater distances, employment declines along with the number of companies seeking space for retail and office activities. The decline in employment density also lowers productivity by reducing spillovers from nearby employment. Together these forces lower demand for space in commercial buildings and can be captured by making the demand variables functions of x. If M(x) and N(x) decline in x, then we have the result that bid rents for both retail and office tenants decline with horizontal distance. Equivalently, if N and M capture nearby employment density, these arguments imply that bid-rents for retail and office tenants decline with density.

The fourth extension concerns the frictions that would arise in a non-Walrasian alternative to the standard bid rent analysis that the model employs. 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. In a search model, the tenant who occupies a given location is not necessarily the agent who would be the highest bidder from the universe of potential tenants. Instead, the occupant will be the highest bidder from those matched with the location in the search process. This will introduce noise into the assignment of tenants to locations, making it more difficult to identify vertical spatial patterns. Another 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 may not be preferred to one who offers almost as much rent but has a low default probability. This sort of calculation is likely to be most important at the top of a tall building, where rents are especially high.

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

(iv) The ground floor rent premium will increase with building height.

(v) Rents will be higher in dense central locations.

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

The next section will describe the data that will be employed in the paper's empirical analysis.

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. After dropping a small number of outliers that could not be reliably coded and also antennae on the roofs of very tall buildings, in total we use 5,445 tenant-suite observations spread across 93 buildings.

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. 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 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.

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). In addition, not all of the CompStak records indicate floor or suite number, and other observations contain other types of missing information. Thus, while the raw CompStak data cover over 100,000 office suites, the cleaned sample with all of the key variables present for buildings ten floors or higher includes 37,007 suites spread across 1,922 buildings.[21]

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 because in many instances it was necessary 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).[22] 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.[23] 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, but do not include the full tenant stack for the buildings in the sample.

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[21] To reduce the incidence of missing variables, for some of the leases in Chicago we were able to fill in missing information using data from CoStar which also markets proprietary data on commercial real estate leases. This was done by matching some of the Chicago buildings in the CS and CoStar data files.

[22] http://www.secinfo.com/dsvrn.v4Mq.htm

[23] http://www.sec.gov/Archives/edgar/data/1031316/000117152013000210/ex10-1.htm

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 level. Syracuse University has 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 is the establishment's 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.[24]

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 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

[24] 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.

as 2003.[25] 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-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. In all instances we report summary measures based only on the cleaned data used in the regressions to follow. Note that in the OM data 5,445 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 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 single-site firm 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 58,389 tenant-suite observations spread across 20,215 buildings based on the street addresses reported in the data. An analogous sample over the same set of cities was also collected for headquarter establishments of multi-site firms.

Panel B summarizes the composition of tenants in the 93 OM buildings in the cleaned data. 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). In each

[25] 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.

instance, measures are reported based on the share of establishments by industry and the share of space occupied by industry.

As seen in the first two columns, FIRE and Law offices account for 15.9 percent and 11.2 percent, respectively of all establishments while Engineering-Accounting-Management makes up 6.87 percent. Retail is just 3.84 percent of establishments in tall commercial buildings. Similar values are evident based on the share of space occupied (in column 2). 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 14.2 percent of establishments while law offices just 3.87 percent. From floors 3 up to 40, retail is just 1.38 percent of establishments while FIRE is 17.2 percent and law offices are 11.9 percent. Above floor 40, retail is 1.68 percent – all of which are restaurants – and FIRE is 17.9 percent. Law offices dominate, however, and make up 24.3 percent of establishments above floor 40 and occupy 34.8 percent of the space (in the far right column). 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 monthly rent per square foot across the OM data is $44 per square foot while for the CS data average monthly 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.[26]

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 $23, $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 bottom 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,

[26]See http://www.millersamuel.com/files/2013/02/Rental_0113.pdf .

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 38.7 floors for the OM sample and 30.5 floors for the CS sample. In the OM data, 59.5% of observations are at or above floor 30, and 9.5% 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 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

This section presents estimates of the vertical rent gradient. The general structure of the rent function in the regression models to follow is given by,

$$r_i = \exp[h(z_i, \beta_z)]\cdot\exp[\theta_1 z_{concourse} + \theta_2 z_{ground} + \theta_3 z_{ground} X_{buildingheight} + \theta_4 X_j + \varepsilon_i] \qquad \text{(IV.1)}$$

where r_i and z_i are the rent and floor number for suite *i*, respectively, as denoted earlier in the paper. Specified in this fashion, the vertical rent gradient is given by $h(z_i, \beta_z)$, with rent levels shifted multiplicatively by concourse and ground floor premia (represented by the coefficients θ_1 and θ_3), by building height which proxies for within building demand ($X_{buildingheight}$), and by other attributes of the building that are common to suites in the building. These latter terms are captured by X_j (for buildings j = 1, … J) and include physical attributes of the building as well as employment in the building and in the surrounding area.

Taking logs, our estimating equation becomes,

$$\log(r_i) = h(z_i, \beta_z) + \theta_1 z_{concourse} + \theta_2 z_{ground} + \theta_3 z_{ground} X_{buildingheight} + \theta_4 X_j + \varepsilon_i \qquad \text{(IV.2)}$$

In some of the specifications to follow, we assume a log function for h with $h(z_i, \beta_z) = \beta_z \log(z_i)$, so that β_z is an elasticity.[27] In other models, a semi-log function is imposed with $h(z_i, \beta_z) = \beta_z z_i$. In these models, β_z approximates the percentage change in rent for a one floor change in height. As a robustness check, we also estimate a non-parametric model of vertical rents. For reasons that will become clear, the semi-log model is our preferred specification.

A final challenge in estimating (IV.2) is to specify X. In principle, many building and location-specific attributes could affect rent and belong in the X_j vector. For this reason, in most of our models we replace $\theta_4 X_j$ with building fixed effects that sweep out all unobserved elements common to suites in the building. In these models, identification is based on within-building variation in rents. In other models, we instead control for the level of within-building employment and also nearby employment. Finally, in all cases, rent is reported in 2014 dollars and ε_i is assumed to be correlated within buildings so that we cluster the standard errors at the building level.[28]

We begin in Table 2a which displays regression results for the OM data (in columns (1) and (2)) and the CS data (in columns (3) and (4)). 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 60 percent (equal to 30*0.0046 + 0.4661) while in the CS data the corresponding premium is roughly 33 percent. The below-ground coefficient for the OM data in column (1) is negative and significant (the t-ratio implied by the standard errors is -2.53). Estimates for the semi-log models in columns (2) and (4) are mostly similar. The ground floor premium for a 30 story building here is 52 percent for the OM sample and 25 percent for the CS sample. On the other hand, the below ground discount is now 75 percent larger 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

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[27] More precisely, in the double-log models we control for 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. This is necessary to ensure that floor number + k is positive and its log defined.

[28] In the CS rent regressions, lease quarter fixed effects were also included to control for possible effects of macroeconomic conditions common to leases originated in the same quarter. The issue is that that business cycles could affect rent differently for floors close to the ground versus higher up. This would occur if retail was more (or less) sensitive to business cycle effects than the business service sector. Lease year fixed effects were not included in the OM regressions because in some instances there were few offering memos from a given year, in which case year effects are largely captured by the building fixed effect. Given the similarity between CS and OM results and the fact that commercial leases are long (and thus designed to span entire business cycles), we believe that business cycle effects are likely small in comparison to the primary drivers of the vertical rent gradient as modeled above.

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 18.8 percent in the OM data and 8.6 percent in the CS data. In the semi-log models (columns (2) and (4)), a one floor increase in height above the ground level increases rent by 0.87 percent in the OM data and 0.58 percent in the CS data. Both estimates are significant. 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 non-monotonic.

As a robustness check, we also estimate a nonparametric specification for the OM sample using local polynomial regression (lpoly).[29] This approach does not impose any restrictions on the shape of the vertical rent gradient, and so provides an opportunity to verify the structure imposed on the parametric models in Table 2a. The lpoly approach, however, suffers from the fact that the distribution of OM building heights is highly skewed, with a median building height of 28 floors and only four buildings at or above 60 floors (see Table 1, Panel D). This means that the number of suites in the sample shrinks sharply as one moves up above the thirtieth floor and also that the set of buildings that contribute to the sample changes with floor height. To address these issues, we restrict the sample used to estimate the lpoly model to just those buildings over thirty floors in height, and we estimate the model only up to floor 30. This ensures a thick sample of suites over all floors, drawn from the same set of buildings at all levels. This approach, in turn, helps to ensure a sufficient and similar level of precision over the range of floors considered in the model. The sample design also reduces possible confounding effects of building-specific attributes in X since the distribution of building specific attributes in the sample is alike for each floor included in the estimation.

Estimates of the vertical rent gradient based on the lpoly model are plotted in Figure 1 along with the corresponding 95 percent confidence band. Although the non-parametric approach is less efficient, the estimated pattern is the same as for the parametric models in Table 2a. Once again, the vertical rent gradient is non-monotonic with a sharp ground floor premium (for buildings over 30 floors in height) and gently rising rents above the third floor.[30]

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[29] In the CS data, many buildings contribute only a small number of suite observations, and suite observations are spread across a large number of buildings with very different values for X. The OM sample, in contrast, includes the full tenant stack for each building. Because of this, the CS sample is not as well suited to a nonparametric model of the vertical rent gradient, and is not used for that reason.

[30] The plot in Figure 1 was obtained using a Gaussian kernel function with 3 degrees of power. The bandwidth and pwidth were chosen by the default optimization routine in Stata as 1.49 floors and 2.23 floors, respectively.

It is also interesting to determine whether the vertical rent gradient is steeper higher up off the ground. This could occur if, for example, views increase at an increasing rate with height. It would also arise if bidders with different willingness to pay for height-based amenities sort into different parts of a building.[31] To address this question, we return to a parametric model for reasons noted above. In Table 2b, Panel A presents results for the double log specification, while Panel B presents results for the semi-log 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 0.1334, 0.1810, and 1.036, respectively (with t-statistics of 4.14, 1.15, and 52.82). For the CS data, the corresponding coefficients are 0.0760, 0.2873, and 1.274 (with t-statistics of 16.52, 7.29 and 4.20). Estimates for the semi-log model display a similar pattern. In the OM sample, the gradients for the three bins are 0.75 percent, 0.45 percent, and 1.24 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.[32]

It is worth emphasizing that the OM and CS samples both exhibit similar non-monotonic rent gradients in Tables 2a and 2b, both qualitatively and with respect to the magnitude of the point estimates. That similarity reinforces the robustness of the patterns and also validates the veracity of the CompStak sample in comparison to the offering memos which report the full tenant stack. This is important because the CS data are easily obtained as they are commercially available and provide a new resource for future real estate research. In addition, some of the extensions to follow are only possible to estimate using the much larger sample of buildings in the CS data.

The estimates in Tables 2a, 2b and Figure 1 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

[31] As an example, with linear bid-functions and two types of tenants A and B, if type-A companies outbid type-B establishments for space up high, higher floors will be dominated by A and the equilibrium vertical rent function within the building will be convex.

[32] An unrestricted developer will set building height so that the marginal rent from the last floor is greater than or equal to marginal construction cost, while the marginal rent from the next floor would be smaller. Since buildings have finite heights, the result that rents increase rapidly near the top of tall buildings implies that the cost of adding additional floors high up off the ground increases even more rapidly than rent or that regulation restricts building heights.

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 we consider more direct evidence of vertical sorting patterns. Before doing this, however, it is useful to characterize the relationship between nearby agglomeration of economic activity, the level of commercial rents and the vertical rent gradient.

B. Vertical vs. horizontal rent patterns allowing for spillovers from agglomeration

As noted earlier, standard models of urban spatial structure and productivity spillovers have solved for spatial equilibrium patterns 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 document the elasticity of commercial rent with respect to nearby employment, a measure that is largely unknown despite being fundamental to urban theory. The models to follow will also allow us to compare the relative magnitudes of vertical and horizontal rent effects while shedding light on the nature of vertical versus horizontal drivers of commercial rent.

We begin with Table 3a, which 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 semi-log 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, of course, also control for unobserved attributes of the buildings themselves.

In columns (1) and (5), zipcode employment has a positive and highly significant relationship with rent. In the elasticity model (column (1)), doubling zipcode employment is associated with an increase in rent of roughly 10.7 percent while the gradient in the semi-log model (column (5)) indicates that adding 1,000 workers to a zipcode increases rent by 0.23 percent (the corresponding t-ratios implied by the standard errors are 5.4 and 7.7, respectively).

These estimates confirm a core stylized fact: densely developed locations have higher commercial rents, resulting in sharp horizontal spatial variation in office rents across business districts and cities. It is possible that this result comes from local amenities of some sort that both raise the willingness to pay of commercial tenants and also attract more tenants. The estimates are also consistent with the large literature on agglomeration economies that has established that spatial concentration contributes to productivity. Most often, this literature has focused on wage effects from agglomeration. 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 agglomeration literature have used commercial rent as the outcome measure, and no previous paper has looked at agglomeration economies arising from highly localized (e.g. zipcode level) concentrations of employment using commercial rents.[33] Our estimates of the rent-employment relationship are, therefore, new to the literature. 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).

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[33] The closest paper in this regard that we are aware of is the work by Jennen and Brounen (2009). As noted earlier, using data for commercial buildings in Amsterdam, they find that doubling the square footage of office space in a local office cluster increases commercial rent by 4.5 percent. Drennan and Kelly (2011) and Koster et al (2014b) also provide evidence that local agglomeration economies are capitalized into higher rent. Kelly's analysis, however, is an MSA-level study and in that sense focuses on much larger geographic units than used in this paper. Koster et al (2014b) measures agglomeration at the municipality level which is smaller than an MSA but still much larger than our geographic units. Koster et al use 1870 population density to instrument for current values of employment density as a strategy to help address possible concerns that municipal level employment density could be endogenous. All of these papers provide valuable evidence that commercial rents are higher in densely developed areas. They do not, however, offer the sort of detailed within building analysis as in this paper or the ability to measure geographic attenuation effects from nearby employment as we do in Table 3b to follow.

Columns (2) and (6) of Table 3a revisit the vertical rent regressions from Table 2a with the primary difference that building fixed effects, which are included in Table 2a, 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 quite similar, both qualitatively and in magnitude, to those in columns (4) and (8) which repeat the specifications from Table 2a.

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: 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 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 semi-log 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 + 0.0556). This is roughly equivalent to the estimated increase in rent associated with moving up 37 floors (0.0073 * 37). 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.[34]

[34] 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.

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 be more strongly related to 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 complications 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 28,648 suite observations spread across 1,220 buildings, roughly 64 percent of which are in New York, 20 percent in Chicago and 16 percent in San Francisco.

Six different models are presented in Table 3b, each of which utilizes a semi-log 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 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.[35] Second, in column (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 roughly 4 times larger. This echoes results from Rosenthal and Strange (2003, 2004, 2005, 2008, and 2012) and Arzaghi and Henderson (2008) that

[35] The coefficient on zipcode-level employment in column (1), for example, is 0.0024 compared to the corresponding estimate of 0.0023 in column (5) 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.

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.

Summarizing, estimates from this section yield several novel results. First, there is 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. These patterns are quantitatively important. Second, we estimate the elasticity of commercial rent with respect to the level of employment in a building's zipcode to be roughly 10.7. That estimate is roughly two to five times larger than analogous estimates that examine the impact of agglomeration on wage rates. Spillover effects are also much larger when considering the scale of employment inside of a building as compared to nearby employment just outside, consistent with previous evidence that agglomeration economies attenuate sharply with distance. What is unique here is that we obtain this evidence using rent as an outcome measure and based on a spatial organization of activity that specifies an establishment's building as the focal point. Third, the vertical and horizontal forces that impact commercial rent are largely independent from each other. This is consistent with our model, which is based on underlying mechanisms that differ from those used to explain horizontal variation in productivity and rent.

V. Vertical spatial structure

This section addresses two additional 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 further evidence of the underlying mechanisms that drive vertical rent gradients.

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 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. Also, as noted in Section II, there are likely to be differences in the degree of amenity-orientation, and these will be manifested in sorting within the office sector.

Tables 5 and 6 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 (SIC 81), Advertising (SIC 7311), Brokerage (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, with establishments drawn from all industries.

The regression models in Tables 5 and 6 are of the following general form,

$$\log(z_i) = \delta_1 T_i + \delta_2 X_{Bldg,j} + \delta_3 X_{Location,m} + \varepsilon_i \qquad \text{(V.1)}$$

where z_i is the floor number on which tenant *i* is located, T_i is a vector of tenant characteristics, $X_{Bldg,j}$ is a vector of building-specific attributes (for buildings j = 1, … J), and $X_{Location,m}$ is a vector of location specific attributes (m = 1, … L). In some of the models we include building fixed effects to control for both $\delta_2 X_{Bldg}$ and $\delta_3 X_{Location}$. In other models, 5-digit zipcode or MSA fixed effects are used without any direct controls for building-specific features, implicitly setting δ_2 to zero. Differences in estimates of δ_1 across the alternate specifications suggest that elements of T are correlated with different levels of geographically defined attributes. Partly for these reasons, in each of the models to follow the error term ε_i is assumed be correlated at the level of the geographic fixed effects, and the standard errors are clustered at that same level.

Central to the models in Tables 5 and 6 are controls that proxy for individual tenant productivity and other attributes that may play a role in vertical sorting. In the single-site firm models, this includes 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 tenant 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 expensive 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. Finally, in some models we include 2-digit level fixed effects for a tenant's SIC industry classification.

It is important to note that employing these tenant-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 we control for the sales-per-worker ratio at the firm level while also controlling for 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 employment 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 implied by the standard errors of 5.8 and 5.7, respectively). Other coefficient estimates in row (1) 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 implied by the standard error 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 implied by standard errors of 2.01 and 2.04. 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 6.46 and 4.97, 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 large fraction of office tenants in tall buildings. For that reason, we are able to re-run the zipcode and building fixed effects models in columns (2) and (3) separately for just the law offices, results from which are presented in columns (4) and (5). Estimates from those models 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 2.2 percent in the building fixed effect model in column (5). These estimates are clearly significant, with standard errors giving t-ratios of 4.63 and 2.20, 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), the elasticity of floor number with respect to employment is 4 percent with a t-ratio of 4.56 implied by the standard errors. 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 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, the coefficient on publicly traded is -0.22 for advertising (with a t-ratio of 2.88), and then positive 0.42, 1.3, and 0.6 for the remaining three industries, with all coefficients significant. 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 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 fixed effects 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 in X_{Bldg} and $X_{Location}$ in (V.1) 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 (see Liu et al (2017b) for related analysis of sorting of establishments into select neighborhoods and buildings).

VI. Conclusion

This paper departs from conventional urban economic analysis by modeling *vertical* patterns of rent and productivity in tall commercial buildings that dominate city skylines. This contrasts with a vast previous literature that has focused almost exclusively on horizontal patterns in cities, including papers on urban spatial structure and agglomeration economies. Nevertheless, the number of skyscrapers worldwide is growing rapidly and business services – which are naturally suited to tall commercial buildings – have replaced manufacturing as the dominant source of central city employment.

The paper's theory predicts systematic vertical sorting based on the tension between vertical access costs and amenities, both of which increase with height off of the ground. Consistent with the theory, empirical analysis confirms that high productivity amenity-oriented office companies locate high up, with less productive offices lower down. Retail tenants, who are strongly access-oriented, concentrate at ground level. These sorting patterns support a non-monotonic, nonlinear vertical rent gradient, with rents falling initially as one moves up off the ground floor, but then rising above the second floor at a modest rate that increases with height.

The magnitude of vertical variation in rent rivals that of horizontal variation associated with the scale of nearby employment. Doubling employment in a building's zipcode increases commercial rent by roughly 10.7 percent, on average. The impact of within-building employment is even 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)). In comparison, adding 100,000 workers to a building's zipcode has roughly the same impact on commercial rent as moving up 30 floors.

Finally, we find that the vertical rent gradient is independent of the scale of nearby employment. This includes the level of employment in the building itself as well as nearby employment outside of the building. The agglomeration literature has pointed to opportunities to share skilled labor, intermediate inputs and knowledge as key determinants of productivity spillovers from nearby activity. Our finding that vertical rent gradients are independent of the scale of nearby employment confirms that vertical rent patterns are driven by a different set of mechanisms, consistent with our model.

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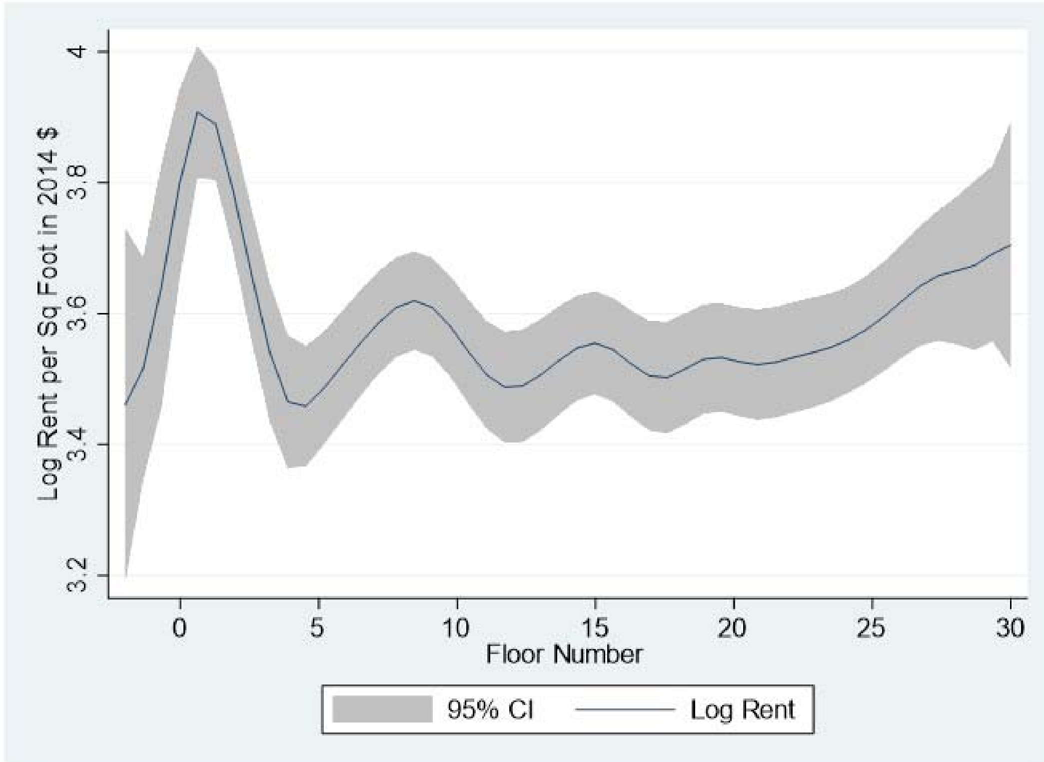
Figure 1: Non-parametric Estimates of Offering Memo Rent Function[1]



[1]Estimated using local polynomial (lpoly) regression with a Gaussian kernel function, 3 degrees of power and a bandwidth optimally chosen at 1.49 floors (using Stata's lpoly routine). The sample includes only suites from offering memo (OM) buildings over 30 floors in height and is restricted to suites from 2 floors below ground level up to floor 30.

Table 1: Summary Measures

Panel A: Three Data Sources

	Offering Memo (OM)	CompStak (CS)	Dun & Bradstreet For 5 Industries Not Merged with OM or CS Data[a]
Number of Buildings	93	1,922	20,215
Number of Tenant-Suite Obs	5,445	37,007	58,389
Number of MSAs	18	8	12
Time Period for Data	2003 - 2014	1999 - 2015	2015

Panel B: Shares of Establishments and Space in Offering Memo Buildings[b]

	All Floors		Ground Floor and Concourse		Floors > 2 and < 40		Floors >= 40	
	Estab	Space	Estab	Space	Estab	Space	Estab	Space
Retail (SIC 52-59)	3.84	2.20	14.2	9.86	1.38	1.50	1.68	1.43
FIRE (SIC 60-67)	15.9	22.3	10.2	20.2	17.2	22.8	17.9	19.5
Business Services (SIC 73)	4.68	4.18	3.39	2.42	5.01	4.45	4.75	3.20
Law Offices (SIC 81)	11.2	13.0	3.87	2.52	11.9	12.1	24.3	34.8
Eng, Acc, Man (SIC 87)	6.87	7.64	1.45	2.68	8.19	8.12	7.54	7.77
All Other Industries	57.4	50.6	66.9	62.3	56.3	51.1	43.9	33.3

Panel C: Commercial Rents Per Square Foot ($2014)[b]

	Average	25th percentile	50th percentile	75th percentile
Offering Memo Data	44	23	33	51
CompStak Data	36	17	33	49

Panel D: Building Height in Number of Floors[b]

	Average Floor	Median Floor	% Over Floor 29	% Over Floor 59	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 (5,445)	38.7	34	59.5%	9.5%	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)[c]

	Average	1st Pctl	25th Pctl	50th Pctl	75th 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] This sample is used in Tables 5 and 6 and includes data from the cities of New York, Chicago, San Francisco, Los Angeles, Atlanta, Washington DC, Cleveland, Detroit, Dallas, Denver, Houston, and Seattle. Industries include law (SIC 81), advertising (SIC 7311), brokerages (SIC 62), insurance (SIC 63), and agents, brokers and services (SIC 64).
[b] Summary measures are based on the regression sample used in Table 2a. See Section III for details.
[c] Summary measures are based on the regression sample used in Table 3a. See Section IIII for details.

Table 2a: Rent Gradients with Building Fixed Effects[a]

	Offering Memo Data		CompStak Data	
	Double Log	Semi-Log	Double Log	Semi-Log
Below ground floor	-0.2621	-0.4596	-	-
	(0.1035)	(.0987)	-	-
Ground floor	0.4661	0.3448	0.1156	0.0295
	(0.0952)	(0.1002)	(0.0357)	(0.0354)
Ground Floor X Bldg Height	0.0046	0.0059	0.0070	0.0073
	(0.0017)	(0.0018)	(0.0017)	(0.0017)
Log(Floor number + k)[b]	0.1883	-	0.0858	-
	(0.0355)	-	(0.0049)	-
Floor number	-	0.0087	-	0.0058
	-	(0.0012)	-	(0.0003)
Observations	5,445	5,445	37,007	37,007
Lease quarter Fixed Effects	-	-	Yes	Yes
Building Fixed Effects	93	93	1,922	1,922
R-sq within	0.162	0.177	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. Standard errors clustered at the building level are in parentheses.

[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]

	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
PANEL A: Double Log						
Log(Floor number + *k*)[b]	0.1334	0.1810	1.036	0.0760	0.2873	1.274
	(0.0322)	(0.1571)	(0.0196)	(0.0046)	(0.0394)	(0.3036)
Observations	3,524	774	115	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	0.029	0.008	0.112	0.257	0.295	0.710
PANEL B: Semi-Log						
Floor number	0.0075	0.0045	0.0124	0.0058	0.0068	0.0161
	(0.0018)	(0.0034)	(0.0002)	(0.0003)	(0.0009)	(0.0032)
Observations	3,524	774	115	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	0.030	0.010	0.117	0.259	0.295	0.708

[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. Standard errors clustered at the building level are in parentheses.

[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]

	Double-Log Models				Semi-Log 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	0.0021	-	-	0.0018	0.0011	-
	-	(0.0009)	(0.0009)	-	-	(0.0009)	(0.0009)	-
Ground floor	-	0.1787	0.1813	0.1156	-	0.0537	0.0556	0.0295
	-	(0.0393)	(0.0405)	(0.0357)	-	(0.0396)	(0.0407)	(0.0354)
Ground Floor X Bldg Height	-	0.0072	0.0072	0.0070	-	0.0075	0.0076	0.0073
	-	(0.0019)	(0.0019)	(0.0017)	-	(0.0018)	(0.0019)	(0.0017)
Log(Floor number + *k*)[b]	-	0.1165	0.1157	0.0858	-	-	-	-
	-	(0.0090)	(0.0088)	(0.0049)	-	-	-	-
Floor number	-	-	-	-	-	0.0074	0.0073	0.0058
	-	-	-	-	-	(0.0006)	(0.0005)	(0.0003)
Log(Zipcode emp in 1,000)	0.1068	-	0.0931	-	-	-	-	-
	(0.0197)	-	(0.0189)	-	-	-	-	-
Zipcode emp (1,000s)	-	-	-	-	0.0023	-	0.0020	-
	-	-	-	-	(0.0003)	-	(0.0003)	-
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	0.889	0.889	0.942	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. Standard errors clustered at the building level are in parentheses.
[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]

	(1)	(2)	(3)	(4)	(5)	(6)
Building height (floors)	-	-	0.0022	0.0015	0.0009	-
	-	-	(0.0010)	(0.0010)	(0.0010)	-
Ground floor	-	-	0.1919	0.2019	0.1987	0.1420
	-	-	(0.0723)	(0.0721)	(0.0723)	(0.0654)
Ground Floor X Bldg Height	-	-	0.0055	0.0052	0.0050	0.0055
	-	-	(0.0027)	(0.0027)	(0.0027)	(0.0024)
Floor number	-	-	0.0087	0.0085	0.0083	0.0064
	-	-	(0.0006)	(0.0006)	(0.0005)	(0.0003)
Zipcode emp (1,000s)	0.0024	-	-	0.0022	-	-
	(0.0003)	-	-	(0.0003)	-	-
Zipcode emp - Bldg emp (1,000s)	-	0.0023	-	-	0.0021	-
	-	(0.0003)	-	-	(0.0003)	-
Building employment (1,000s)	-	0.0122	-	-	0.0080	-
	-	(0.0028)	-	-	(0.0026)	-
Observations	28,648	28,648	28,648	28,648	28,648	28,648
Lease quarter Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
City Fixed Effects	3	3	3	3	3	No
Building Fixed Effects	No	No	No	No	No	1,220
R-sq within	-	-	-	-	-	0.295
R-sq total	0.563	0.573	0.583	0.604	0.607	0.799

[a] Dependent variable is log of net rent which adjusts gross rent for months of free rent at the start of the lease and other accommodations. The sample includes lease data from New York City, Chicago (Cook County), and San Francisco (San Francisco County). In all models, standard errors clustered at the building level are in parentheses.

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)
1st Pctl	-2	-3	-2	-2	-2	-3	-3	-1
25th Pctl	5	1	7	5	14	12	7	9
50th Pctl	14	1	16	15	21	23	13	18
75th Pctl	24	5	26	24	32	31	26	24
99th Pctl	93	90	62	93	71	55	61	43
# Obs	5,445	209	2,829	255	611	268	64	74

[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	0.0153	0.0463	0.0224	-0.0353	0.0040	-0.0227	-0.0064
	-	(0.0069)	(0.0075)	(0.0100)	(0.0102)	(0.0276)	(0.0156)	(0.0183)	(0.0148)
Log employment at site	-0.0110	0.0304	0.0169	0.0372	0.0134	0.0065	0.0406	-0.0112	0.0160
	(0.0078)	(0.0047)	(0.0034)	(0.0062)	(0.0040)	(0.0140)	(0.0089)	(0.0193)	(0.0068)
Log sales/worker – Firm	0.0262	-	-	-	-	-	-	-	-
	(0.0046)	-	-	-	-	-	-	-	-
Log employment – Firm	0.0352	-	-	-	-	-	-	-	-
	(0.0060)	-	-	-	-	-	-	-	-
Publicly traded	0.1061	0.5371	0.2245	-	-	-0.2242	0.4196	1.3266	0.6150
	(0.0334)	(0.2926)	(0.2544)	-	-	(0.0779)	(0.1687)	(0.1862)	(0.0134)
Subsidiary	-0.0488	0.0029	-0.0811	0.0523	-0.0243	0.0741	-0.0184	0.0599	0.0501
	(0.0254)	(0.0255)	(0.0345)	(0.1392)	(0.1321)	(0.0868)	(0.0412)	(0.0902)	(0.0475)
Risk Rating: Low	0.0286	0.0284	0.0003	0.0331	-0.0046	0.0364	0.0450	-0.0216	0.0058
	(0.0169)	(0.0104)	(0.0086)	(0.0134)	(0.0101)	(0.0544)	(0.0346)	(0.0953)	(0.0167)
Risk Rating: Medium	0.0680	0.0432	-0.0225	0.0372	-0.0316	0.0547	0.0300	0.0982	0.0456
	(0.0287)	(0.0179)	(0.0128)	(0.0296)	(0.0161)	(0.0655)	(0.0348)	(0.1145)	(0.0257)
Observations	16,335	58,389	58,389	36,980	36,980	1,700	6,884	1,268	10,916
Within R-squared	0.013	0.011	-	0.004	-	0.003	0.005	0.014	0.002
Total (Adj) R-squared	0.308	0.458	0.716	0.454	0.735	0.253	0.403	0.293	0.353
2-digit Industry FE	-	5	5	-	-	-	-	-	-
5-Digit Zipcode FE	640	1,767	-	1,493	-	428	1,001	574	1,460
Building FE	-	-	20,215	-	11,963	-	-	-	-

[a] Data are from Dun and Bradstreet. Standard errors in parentheses are 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	0.0635	0.0139	0.0153	0.1635	0.1238	0.0463	0.0224
	(0.0081)	(0.0086)	(0.0069)	(0.0075)	(0.0144)	(0.0124)	(0.010)	(0.0102)
Log employment at site	0.0860	0.0842	0.0304	0.0169	0.0873	0.0909	0.0372	0.0134
	(0.0038)	(0.0091)	(0.0047)	(0.0034)	(0.0050)	(0.0123)	(0.0062)	(0.0040)
Publicly traded	0.7563	0.6450	0.5371	0.2245	-	-	-	-
	(0.2608)	(0.0330)	(0.2926)	(0.2544)	-	-	-	-
Subsidiary	0.2242	0.1673	0.0029	-0.0811	0.1712	0.0631	0.0523	-0.0243
	(0.0328)	(0.0565)	(0.0255)	(0.0345)	(0.1329)	(0.1257)	(0.1392)	(0.1321)
Risk Rating: Low	0.0566	0.0679	0.0284	0.0003	0.0835	0.0902	0.0331	-0.0046
	(0.0103)	(0.0114)	(0.0104)	(0.0086)	(0.0134)	(0.0165)	(0.0134)	(0.0101)
Risk Rating: Medium	0.1455	0.1076	0.0432	-0.0225	0.1595	0.1178	0.0372	-0.0316
	(0.0143)	(0.0246)	(0.0179)	(0.0128)	(0.0201)	(0.0375)	(0.0296)	(0.0161)
Observations	58,389	58,389	58,389	58,389	36,980	36,980	36,980	36,980
Within R-squared	-	0.071	0.011	-	-	0.013	0.004	-
Total (Adj) R-squared	0.081	0.130	0.458	0.716	0.014	0.066	0.454	0.735
2-digit Industry FE	5	5	5	5	-	-	-	-
MSA FE	-	12	-	-	-	12	-	-
5-Digit Zipcode FE	-	-	1,767	-	-	-	1,493	-
Building FE	-	-	-	20,215	-	-	-	11,963

[a] Data are from Dun and Bradstreet. Standard errors in parentheses are 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-LDP7[36]

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			

[36] http://www.secinfo.com/dsvrn.v4Mq.htm

Appendix A (continued)
JP Morgan Chase Commercial Mortgage Securities Trust 2006-LDP7[37]

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-LDP7[38]

[37] http://www.secinfo.com/dsvrn.v4Mq.htm
[38] 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	Schermerhorm	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)[39]

Database: PRODUCTION						Rent Roll							Page 1	
Bldg Status: Active only						999 PEACHTREE							Date: 3/8/2013	
JAMESTOWN 999 PEACHTREE, L.P.						2/28/2013							Time: 01/50 PM	
											Future Rent Increases			
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	Cat	Date	Monthly Amount	PSF
Vacant Suites														
4507	0520	Vacant			8,543									
4507	0520	Vacant			1,557									
4507	0520	Vacant			190									
4507	0520	Vacant			22,520									
4507	0520	Vacant												
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
											RTL	4/1/2014	11,424.84	28.14
4507	0100	Stephanie Hyde/En Paris	4/20/2011	5/31/2012	1,973			250.00						
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
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	0180	Eco-Deizen	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	4/1/206	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				
					75,155	79,859.20		64,083.69		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
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

Continued next page

[39] http://www.sec.gov/Archives/edgar/data/1031316/000117152013000210/ex10-1.htm

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

Database: PRODUCTION						Rent Roll							Page 1	
Bldg Status: Active only						999 PEACHTREE							Date: 3/8/2013	
JAMESTOWN 999 PEACHTREE, L.P.						2/28/2013							Time: 01/50 PM	
											Future Rent Increases			
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	Cat	Date	Monthly Amount	PSF
4507	1225	Maxursky 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	Gensler	1/1/2012	6/30/2023	21,136	22,655.34	12.86	547.56			FRR	1/1/2014	15,983.96	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	32.75
											OFC	9/1/2017	58,810.92	33.39
											OFC	9/1/2018	59,991.01	34.06
											OFC	9/1/2019	61,188.72	34.74
4507	1600	Sutherland Asbill & Brenan	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									