This article reports empirical evidence on the nature and magnitude of real depreciation in commercial and multifamily investment properties in the United States. The article is based on a much larger and more comprehensive database than prior studies of depreciation in such properties, and it is based on actual transaction prices rather than appraisal estimates of property or building structure values. The article puts forth an “investment perspective” on depreciation, which differs from the tax policy perspective that has dominated the previous literature in the United States. From the perspective of the fundamentals of investment performance, depreciation is measured as a fraction of total property value, not just structure value, and it is oriented toward cash flow and market value metrics of investment performance such as internal rate of return and holding period return. Depreciation from this perspective includes all three age-related sources of long-term secular decline in real value: physical, functional and economic obsolescence of the building structure. The analysis based on 107,805 transaction price observations finds an overall average depreciation rate of 1.5%/year, ranging from 1.82%/year for properties with new buildings to 1.12%/year for properties with 50-year-old buildings. Apartment properties depreciate slightly faster than nonresidential commercial properties. Depreciation is caused almost entirely by decline in the property’s current real income, only secondarily by increase in the capitalization rate (“cap rate creep”). Depreciation rates vary considerably across metropolitan areas, with areas characterized by space market supply constraints exhibiting notably less depreciation. This is particularly true when the supply constraints are caused by physical land scarcity as distinct from regulatory constraints. Commercial real estate asset market pricing, as indicated by transaction cap rates, is importantly related to depreciation differences across metro areas.

Introduction

This article reports empirical evidence on the nature and magnitude of real depreciation in commercial and multifamily investment properties in the United

*Massachusetts Institute of Technology, Center for Real Estate, 77 Massachusetts Avenue, Cambridge, MA 02139 or dgeltner@mit.edu.
**Massachusetts Institute of Technology Center for Real Estate, 77 Massachusetts Avenue, Cambridge, MA 02139 or sbokhari@mit.edu.

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States. By the term “real depreciation” (or simply, “depreciation”) we are referring to the long-term or secular decline in property value, after netting out inflation, due to the aging and obsolescence of the building structure, apart from temporary cyclical downturns in market values, and even after routine capital maintenance. Such depreciation is sometimes referred to as “net depreciation,” to distinguish it from “gross depreciation” (or total “capital consumption”), which would also include the cost of capital improvement expenditures on the property. Net depreciation is measured empirically by an essentially cross-sectional comparison of the transaction prices of properties with building structures of different ages, controlling for other non–age-related differences among the properties and the transactions. In the United States, most prior studies of depreciation in income-producing structures have been made from the perspective of income tax policy, given that asset value in accrual income accounting in the United States is based on historical cost and allows for depreciation to be deducted from taxable income. But considering basic economics, depreciation is important from an investment perspective apart from tax policy, as depreciation is ubiquitous and significantly affects the nature of property investment performance. Though tax policy considerations certainly are important (including from an after-tax investment perspective for taxable investors), we leave such considerations for other papers.

This investment perspective is the major focus of this article, though we will also make some observations relevant to the tax policy perspective. From the investment perspective depreciation constrains how much capital growth the investor can expect over the long run, and from this perspective depreciation is measured with respect to total property value not just structure value, and is measured on a cash flow and current market value basis rather than a historical cost accrual accounting basis. In this article, we explore how such depreciation varies with several correlates including metropolitan location, building type and structure age. We also explore the role of income versus capitalization as the source of depreciation.

**Literature Review**

Most of the prior literature on structure depreciation has focused on owner-occupied housing, and as noted, most of the U.S. literature that has focused on depreciation in commercial real estate (income property) has done so from the perspective of taxation policy. An early and influential example is Taubman and Rasche (1969), which used limited data on building operating expenses to quantify a theoretical model of profit-maximizing behavior on the part of building owners to estimate the optimal lifetime of structures and the age and value profile of office buildings, assuming rental revenues decline.
with building age while operating costs remain constant. The result was a model in which the building structure (excluding land) becomes completely worthless (fit for redevelopment) after generally 65 to 85 years of life, with the rate of depreciation growing with the age of the structure.\footnote{This is where the depreciation rate is measured as a percent per year of the remaining value of the structure alone, excluding the land component of the property value. Of course, any model in which the structure becomes completely worthless at a finite age (such as straight-line depreciation) will necessarily tend to have increasing depreciation rates as the structure ages measured as a fraction of the structure value alone excluding land, at least after some point of age. (For example, in the last year of building life, the depreciation rate is by definition 100\% of the remaining structure value.)} The focus of the analysis was on what sort of depreciation allowances would be fair from an income tax policy perspective.

By the mid-1990s, subsequent research led to a consensus that the balance of empirical evidence supported the view that commercial structures tend to decline in value in a somewhat geometric pattern (roughly constant rate over time), averaging about 3\% per year (of remaining structure value), though there was some evidence for faster depreciation rates in the earlier years of structure life. (See most influentially Hulten and Wyckoff, 1981, 1996.) In the paper that most influenced subsequent tax policy, Hulten and Wyckoff (1981) estimated average depreciation rates of approximately 3\% per year of remaining structure value. With the 1986 tax reform, income tax policy settled on straight-line depreciation methods (which imply an increasing rate of depreciation for older buildings), with the depreciation rate based on 27.5 years for apartments and 31 (subsequently increased to 39) years for nonresidential commercial buildings. This has remained a relatively constant and noncontroversial aspect of the income tax code since then.\footnote{Straight-line methods are easy to understand and administer, and can be designed in principle so that the present value of the depreciation is the same as that of an actual geometric profile of declining building value, which might better represent the economic reality. By completely exhausting the book value of the structure at a finite point in time (and hence, exhausting the depreciation tax shields), straight-line methods may tend to stimulate sale of older buildings (so as to re-set the depreciable basis and begin generating tax shields again).}

Gravelle (1999) reviewed the evidence on depreciation rates for the Congressional Research Service and found that rates allowed in current tax law are not too far off from economic reality, if one uses as the benchmark the present value of the allowed depreciation (recognizing that the straight-line pattern is only a simplification). An industry white paper produced in 2000 by Deloitte–Touche studied 3,144 acquisition prices of properties held by Real Estate Investment Trusts (REITs) for which data existed on the structure and land value components separately as of the time of acquisition Sanders and
Randall (2000). That study found approximately constant depreciation rates for acquisition prices as a function of structure age, measured as a percent of remaining structure value, ranging from 2.1%/year for industrial buildings to 4.5%/year for retail buildings (with office at 3.5% and apartments at 4%). However, the study was limited to only buildings less than 20 years old. The Deloitte study also separately estimated depreciation rates for gross rental income, finding rates ranging from 1.7% for office to 2.5% for retail (with industrial at 1.9%, and apartments omitted). Note that, as fractions of preexisting rent, these rent depreciation rates would be more comparable to rates based on total property value than just on structure value as, like property value, rents reflect land and location value as well as just structure value. The working consensus apparently persists that, at least for tax policy considerations, commercial structures tend to depreciate in a roughly geometric pattern at typically a rate of 2–4% of the remaining structure value per year, with apartment structures depreciating slightly faster than commercial.3

More recent literature is sparse and primarily focused on new empirical data. Fisher et al. (2005) used sales of some 1,500 NCREIF apartment properties to examine depreciation in institutional quality multifamily property.4 They conclude that a constant rate of 2.7% per year of property value including land, or 3.25% of structure value alone, well represents the depreciation profile for NCREIF apartments.5

There have also been a number of studies of commercial property depreciation in Europe, particularly in the United Kingdom. Many of these studies focus on the investment perspective rather than the tax policy perspective, and they tend to be very applied, industry sponsored reports that use less sophisticated methodologies. In one of the more academic studies, Baum and McElhinney (1997) studied a sample of 128 office buildings in the city of London and estimated a capital value depreciation rate averaging 2.9%/year as a fraction of total property value (including land), with older buildings (over age 22 years) depreciating less than new or middle-aged buildings. Their study was based on appraised values. More recently, a 2011 study by the Investment Property Forum (IPF), a British industry group, examined 729 buildings

3See United States Treasury (2000).
4NCREIF properties are owned by tax-exempt investors and tend to be at the upper end of the asset market. The average initial property cost in the Fisher et al. sample was $17 million.
5NCREIF records indicate that on average almost 20% of apartment property net operating income (NOI) is plowed back into the properties as capital improvement expenditures, and this is mostly routine maintenance and upgrades, not major renovations. The depreciation occurs absent (or between) major renovations in spite of such substantial upkeep.
in the United Kingdom that were held continuously over the period 1993–2009. Office buildings were found to experience the highest rate of rental depreciation at 0.8%/year followed by industrial at 0.5% and retail at 0.3%, all as a fraction of total property value. A comparable IPF (2010) article on office properties in select European cities, estimated depreciation rates that ranged up to almost 5%/year in Frankfurt to no depreciation at all in some cities (such as Stockholm). The IPF studies were based on comparing the rental growth (based on appraisal valuation estimates) of the held properties with that of a benchmark based on a new property held in the same location. However, problems with using valuations and in benchmark selection led Crosby, Devaney and Law (2011) to conclude that these findings are not a good indication of the rates of depreciation in Europe.

Investment Perspective on Depreciation

Although tax policy is clearly important, the previous literature’s focus on it may have complicated or omitted some considerations that are more important from a before-tax investment perspective. What we are referring to as the investment perspective on depreciation is the perspective that reflects the fundamental economic performance of investments. This perspective is the basis on which capital allocation decisions derive their economic value and opportunity cost. In the investment industry, profit or performance is measured by financial return metrics such as (most prominently) the internal rate of return and the total holding period return. These metrics are based on market value and cash flow, not on historical cost accrual accounting principles. This opportunity cost perspective may lead investors to be less directly concerned than accountants are about distinguishing (inevitably somewhat arbitrarily) between structure value and land value in investments in viable existing buildings. At the most fundamental level, real economic depreciation directly and importantly affects investment returns before, and apart from, income tax effects. Therefore, investors care (or should care) about the granular characteristics and determinants or correlates of property depreciation, in order to make better property investment and management decisions.

It is worth noting, as well, that many major investment institutions are tax-exempt (such as pension and endowment funds). Furthermore, the United States is fairly unique in having financial accounting rules based on historical cost asset valuation. In most other countries the type of tax policy considerations that have dominated the U.S. literature on commercial property depreciation are not relevant.
Figure 1  ■ A framework for analyzing depreciation.

The component of total property value (P) attributed to the building structure equals the component not attributed to land value. There are two ways to conceptually define land value: “U” is the legal/appraisal definition (value of comparable vacant lot); “C” is the economic definition (value of the redevelopment call option). In the graph below, S = P - C. But most practical applications use the legal definition of land value, and S = P - L. Depreciation results from any/all of three forms of obsolescence: (i) Physical (wearing out, more expensive maintenance), (ii) Functional (components & design no longer optimal for the intended use) and (iii) Economic (intended use no longer optimal for the site).

A Conceptual Framework for Analyzing Depreciation

A careful and complete view of depreciation from the investment perspective must consider the causes and correlates of differences in depreciation rates across different types or locations of properties. Such an investment perspective on depreciation must strive in particular to recognize differences and patterns in the urban economic dynamics of locations of commercial properties. The fundamental economic framework from which to view depreciation from the investment perspective is presented in Figure 1.

Figure 1 depicts a single urban site or property parcel over time, with the horizontal axis representing a long period of time, and the vertical axis representing the money value of the property asset on the site. The top (thin) line connecting the U values reflects the evolution of the location value of the site as represented by the value of the “highest and best use” (HBU).

\[ U = \text{Usage value at highest and best use at time of reconstruction} \]
\[ P = \text{Property value} \]
\[ S = \text{Structure value} \]
\[ L = \text{Land appraisal value (legal value)} \]
\[ C = \text{Land redevelopment call option value (economic value)} \]
\[ K = \text{Construction (redevelopment) cost excl. acquisition cost} \]

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7A very long span of time must be represented, because depreciation is, by definition, a long-term secular phenomenon, reflecting permanent decrease in building value, and buildings are long-lived, transcending medium-term or transient changes in the supply/demand balance in the real estate asset market.
development of the site whenever it is optimally (re)developed (new structure built), an event that occurs at the points in time labeled R. This location value of the site fundamentally underpins the potential long-run appreciation of the property value and the capital return to the investor in the property asset. But the actual market value of the property over time is traced out by the thick solid line labeled P, which represents the opportunity cost or price at which the property asset would sell at any given time. P declines relative to U due to the net depreciation of the building structure on the site. Based on standard cash flow (opportunity cost)-based investment return metrics such as IRR or total HPR, it is the combination of the change in location value (U) and the occurrence of structure depreciation which determines the price path of P and hence the capital return possibility for the investor over the long run.\(^8\)

From an investment perspective, one can define the “land value” component of the property value in either of two alternative and mutually exclusive ways as indicated in Figure 1. The more traditional conception of land value is labeled L and reflects what the parcel would sell for if it were vacant, that is, with no preexisting structure on it. The second, newer conception of land value comes from financial and urban economics and views the land (as distinct from the building on it) as consisting of nothing more (or less) than the call option right (without obligation) to develop or redevelop the site by constructing a new building on it.\(^9\) This value, labeled C, generally differs from L. The redevelopment call option is nearly worthless just after a (re)development of the site, because the site now has a new structure on it.

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\(^8\)Although it is the total investment return that matters most, including current income (cash flow) plus change in capital value, there is also interest in breaking out the total return into components, one of which is the current income return or yield rate (net cash flow as a fraction of current asset market value). In such breakout, current routine capital improvement expenditures, which are financed internally as plow-back of property earnings are a cash outflow from the property owner, netted out of the income return (i.e., not taken out of the capital return component, from a cash flow perspective). Thus, the investment capital return indicated by the change in P between R points reflects the growth in total property value including (after) the effect of such routine capital improvement expenditures. In the Figure 1 model, major externally financed capital improvement expenditures would be considered redevelopments associated with the R points on the horizontal axis, resetting the building age to zero at those points.

\(^9\)The exercise cost (or “strike price”) of the call option consists not only of the construction cost of the new building plus any demolition costs of the old building, but also includes the opportunity cost of the foregone present value of the net income that the old building could still continue to earn (if any). Thus, for it to make sense to exercise the redevelopment option either the old building must be pretty completely obsolete or the new HBU of the site must be considerably greater than the old HBU to which the previous structure was built. Formal mathematical models of call option value typically assume frictionless transactions, though such assumption is not necessary for the general conceptual applicability of the model.
built to its HBU. But at the time when it is optimal (value maximizing) to tear down the old structure and build a new one, the entire value of the property is just this call option value, the land value. Out-of-the-money call options are highly risky, meaning they have very high OCC (high required investment returns), and the investment returns of options must be achieved entirely by capital appreciation as options themselves pay no dividends. Thus, the call option value of the site tends to grow very rapidly over time between the R points, ultimately catching up with the traditional (“L”) value of the land.

At the reconstruction points (R) all three measures and components of property value, P, L and C are the same; the old building is no longer worthwhile to maintain (at least, given the redevelopment opportunity), so the property value entirely equals its land value. At that point new capital (cash infusion) in an amount of K is added to the site, as depicted in Figure 1, and this value of K (construction costs including demolition costs and normal profit for the developer) adds to the site-acquisition cost (the preexisting property value, Old P = L = C) to create the newly redeveloped property value (the new P value = Old P + K) upon completion of the development. The net present value (NPV) of the redevelopment project investment is: NPV = New P − Old P − K. In an efficient capital market super-normal profits will be competed away and this NPV will equal zero, providing just the opportunity cost of its invested capital as the expected return on the investment.

The investor’s capital return is represented by the change in the property value P between the reconstruction points in time. The change in P across a reconstruction point R includes new external capital investment (K), not purely return to preexisting invested financial capital. By definition, property value, P, is the sum of land value plus building structure value. The path

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10It makes sense for functional and economic obsolescence to detract from the value of the structure, not from the value of the land. “Functional obsolescence” refers to the structure becoming less suited to its intended use or relatively less desirable for its users/tenants compared to newer competing structures, for example, due to technological developments or changes in preferences, such as need for fiber-optic instead of copper wiring or need for sustainable energy-efficient design. “Economic obsolescence” refers to the phenomenon of the HBU of the site evolving away from the intended use of the structure, the type and scale of the building becoming no longer the HBU for the site as if it were vacant, as for example, if commercial use would be more profitable than the preexisting residential, or high-rise residential would be more profitable than the preexisting low-rise.

11Note that this zero NPV assumption is consistent with the classical “residual theory of land value,” in which any windfall in location value accrues to the preexisting landowner (thus adding to the “acquisition cost” of the redevelopment site, the value of C or L or Old P at the time of redevelopment). However, if the redevelopment is particularly entrepreneurial or innovative, perhaps there will be some super-normal Schumpeterian profits for the new developer.
of \( P \) between reconstruction points therefore reflects the sum of the change in the building structure value plus the change in the land value. The latter reflects the underlying usage value of the location and site as represented by its HBU as if vacant, the U line at the top in Figure 1. Thus, the land value component does not tend to decline over time in real terms in most urban locations, although there certainly are exceptions to this rule. However, the building structure component of the property value will almost always tend to decline over the long run, at least in real terms (net of inflation), reflecting building depreciation. In any case, the extent to which the property value path falls below the location value of the site (U), causing a reduction in the investor's capital return below the trend rate in U, is due largely and ubiquitously to building structure depreciation. This is the fundamental reason why, and manner in which, the investor cares about depreciation.

Note that from this perspective the rate at which the building structure itself declines in value due to depreciation is fundamentally ambiguous. This is because building value equals the total property value minus the land value. But there are two very different yet fundamentally equally valid ways to define and measure land value, the traditional perspective (L) and the economic or functional call option perspective (C). The structure value component (labeled S in Figure 1), can be defined either as \( P - L \) or \( P - C \). Thus, the rate of depreciation expressed as a fraction of building structure value is ambiguous from the investment perspective. However, depreciation measured as a fraction of total property value, \( P \), is not ambiguous.\(^{12}\) Therefore, from the investment perspective, it is more appropriate to focus on depreciation relative to total property value including land value (P) rather than only relative to remaining structure value (S). We will adopt this approach for the remainder of this article.

Finally, given that land generally does not depreciate, an implication of this framework is that we should expect newer properties to depreciate at a faster rate because land value is a smaller proportion of the total property value of a new building. This also suggests that depreciation rates may vary across

\(^{12}\)It is worth noting that, apart from the conceptual problem, measuring depreciation as a fraction of structure value (S) is also difficult to estimate empirically. This is because, compared to quantifying the total property value, \( P \), it is usually relatively difficult to quantify either L or C for a given property at a given time. While appraisers or assessors sometimes estimate the value of L, such valuations are only estimates, and are often crude and formulaic. In built-up areas there is often little good empirical evidence about the actual transaction prices of comparable land parcels recently sold vacant. And land value estimates can be circular from the perspective of quantifying structure depreciation, as the land value may be backed out from property value minus an estimate of depreciated structure value, meaning that for purposes of empirically estimating structure depreciation we get an estimate of depreciation based on an estimate of depreciation.
metropolitan areas as different cities have different scarcity of land, and therefore, different land value proportions of total property value. We test both these hypotheses in our subsequent empirical analysis.

**Source of Depreciation: Income or Capitalization?**

It is of interest from an investment perspective to delve deeper into the depreciation phenomenon and explore how much depreciation is due to changes in the current net cash flow the property can generate as it ages versus how much is due to the property asset market’s reduction in the present value it is willing to pay for the same current cash flow as the building ages. This latter phenomenon is sometimes referred to as “cap rate creep.” Such an understanding could improve the accuracy of investment return forecasts, and possibly improve the management and operation of investment properties.  

By way of clarification and background, consider the fundamental present value model of an income property asset:

\[
P_{i,t} = \sum_{s=t+1}^{\infty} \frac{E_t[CF_s]}{(1 + r_{i,t})^{s-t}},
\]

where \(P_{i,t}\) is the price of property \(i\) at time \(t\); \(E_t[CF_s]\) is the expectation as of \(t\) of the net cash flow generated by the property in future period \(s\); and \(r_{i,t}\) is the property asset market opportunity cost of capital (OCC, the investor’s required expected total return) for property \(i\) as of time \(t\). With the simplifying assumption that the expected growth rate in the future cash flows is constant (at rate \(g_{i,t}\)) and the property resale price remains a constant multiple of the current cash flow, (1) simplifies to the classic “Gordon Growth Model” of asset value (GGM), which is a widely used valuation model in both the stock market and the property market:

\[
P_{i,t} = \frac{E_t[CF_s]}{r_{i,t} - g_{i,t}}.
\]

With the slight further simplification that the NOI approximately equals the net cash flow \((NOI_{i,t} \approx E_t[CF_s])\), this formula provides the so-called...

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13For example, there might be things the investor could do to mitigate the decline in net cash flow, whereas there might be less that can be done to influence cap rates.

14Clearly the GGM is a simplification of the actual long-term cash flow stream as modeled in Figure 1. But the GGM is widely used and its simplification is relatively benign for our purpose, which is only to explicate the basic roles in property depreciation of the two factors, current net cash flow and asset market capitalization.

15The difference between NOI and CF is the routine capital improvement expenditures: \(CF_i = NOI_i - CI_i\). Although this difference does not matter for our purpose in this article, it is of interest to note that among properties in the NCREIF Property...
“direct capitalization” model of property value which is widely used in real estate investment:

\[ P_{i,t} = \frac{NOI_{i,t}}{k_{i,t}} \]  

(3)

where \( k_{i,t} = r_{i,t} - g_{i,t} \) is the capitalization rate (“cap rate” for short) for property \( i \) as of time \( t \). The property value equals its NOI divided by its cap rate.

Thus, if the property real value tends to decline over time with depreciation, due to the aging of the building, then such value decline may be (with slight simplification) attributed to some combination of (i) a decline over time in the real NOI that the property can generate or (ii) an increase over time in the cap rate that the property asset market applies to the property as it ages. To the extent depreciation results from an increase in the cap rate with building age (“cap rate creep”), this could result either from an increase in the OCC or from a decrease in the expected future growth rate, \( g_{i,t} \), or a combination of those two. In this article we will not attempt to parse out this OCC versus growth expectations breakout. We content ourselves with exploring the question of how much of the depreciation in \( P \) is due to the NOI and how much is due to \( k \). To answer this question, we will estimate the effects of depreciation on both property value and on cap rates. The difference between the total depreciation and effect of the cap rate creep will be attributable to NOI depreciation. We now turn to outlining our empirical model.

**The Hedonic Price and Cap Rate Models**

In this section, we outline our approach for estimating the effects of depreciation on both total property value and the property cap rate. Following in the tradition of depreciation estimation modeling, the approach known as “used asset price vintage year” analysis is applied to quantify real depreciation. This involves an essentially cross-sectional analysis of the prices at which properties of different ages (defined as the time since the building was constructed) are transacted, controlling for other variables that could affect price.

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Index, the historical average capital expenditure \((CI)\) is over 2% of property value (including land value) per year. This reflects essentially just routine capital expenditures, not major renovations. Sanders and Randall (2000) reports that U.S. Census data indicate overall postconstruction capital improvement expenditures on buildings is approximately 40% of the cost of new construction. (If the average building is somewhat more than 20 years old, this would be roughly consistent with the NCREIF 2%/year rate.) The Sanders and Randall study also conducted a survey that suggested that capital expenditures may often exceed 5% of structure value per year. (If structure value is on average halfway between 80% and 0% of total property value, then this too would be roughly consistent with the NCREIF data.) However, the Sanders and Randall survey was very limited.
either cross-sectionally or longitudinally. This is estimated via the hedonic price model given in Equation (4):

\[
\ln(p_{i,t}) = \sum_{h=1}^{H} \beta_A A_{h,i,t} + \sum_{j=1}^{J} \beta_X X_{j,i,t} + \sum_{m=1}^{M} \beta_M M_{m,i,t} + \sum_{s=1}^{T} \beta_T T_{s,i,t} + \epsilon_{i,t}, \tag{4}
\]

where

- \( p_{i,t} \) is the price of property sale transaction \( i \) occurring in year \( t \).
- \( A_{h,i,t} \) is a vector of \( H \) property and location characteristics attributes for property sale transaction \( i \) as of year \( t \).
- \( X_{j,i,t} \) is a vector of \( J \) transaction characteristics attributes for property sale transaction \( i \) as of year \( t \).
- \( M_{m,i,t} \) is a vector of fixed-effects dummy variables representing \( M \) metropolitan markets for property sale transaction \( i \) as of year \( t \).
- \( T_{s,i,t} \) is a vector of \( s = 1, 2, \ldots, T \) time-dummy variables equaling one if \( s = t \) and zero otherwise (for property sale transaction \( i \) as of year \( t \)).

The \( A_h \) property and location characteristics in the model include, most importantly, the property age in years since the building was constructed and age-squared, but also include the natural log of the property size in square feet, dummy variables for property usage type sector (office, industrial, retail or apartment) and a dummy variable flagging whether the property is in the central business district (CBD) of its metro area. The \( X_j \) includes several transaction characteristics. If a property has a distress indicator, we include that in the regression as it suggests that it will likely sell at a discount.\(^{16}\) We include an indicator if the property has excess land potential, which implies that the option to expand the space might enable the property to fetch a higher price. We also include seller-type dummies to capture any differences in institutional and behavioral differences across investors that may affect their market experiences. Previous research has shown that different types of investors reflect different degrees of loss aversion and the subsequent price they are able to get (Bokhari and Geltner 2011). Finally, we also include a dummy variable to indicate if the buyer had a loan that was part of a Commercial Mortgage Backed Securities (CMBS) pool, as cheaper financing can facilitate a higher priced purchase.

The hedonic price model in Equation (4) is relatively sparse in terms of property characteristics, compared with many such models of housing prices.

\(^{16}\)The data provider, Real Capital Analytics (RCA), flags properties as being in “distress” if the property owner or a major tenant is in bankruptcy or certain other criteria are met.
in the academic literature. In reality, hedonic data for commercial property transactions is much scarcer than that for housing. Commercial properties are not covered by the U.S. Census. For example, we do not have data on the type or quality of construction. To test whether the parsimony of the Equation (4) model could importantly affect our depreciation estimates, we test an alternative panel regression specification on only properties that have repeat sales, effectively a repeat-sales model of depreciation. This effectively controls for most unobservable property characteristic variables that are omitted in Equation (4). The results of this panel regression analysis are reported in the Appendix, which indicates very little difference in the depreciation results from the Equation (4) model, suggesting that for our purposes the Equation (4) model is sufficiently complete and does not suffer from important omitted variable bias.

Censored Sample Bias and Correction

As pointed out by Hulten and Wyckoff (1981), any estimation of the depreciation rate would need to take into account the experience of torn-down buildings in order to avoid introducing a survivorship bias. Because buildings that have been demolished have already depreciated to a point that their structure has no value, omission of such data is likely going to result in a depreciation estimate that is smaller than it should be. Hulten and Wyckoff (1981) correct for this censored sample bias by noting that the average price of a building (of a given age) is the price of surviving buildings, multiplied by the survival probability (having survived until that age), plus the zero value of torn-down buildings (of that vintage) times the probability of being torn-down (having not survived by that age).\(^\text{17}\) Using this approach, we can re-write the left-hand side of Equation (4) as

\[
\ln(P_i \ast p_{i,t}) = \sum_{h=1}^{H} \beta_h A_{h,i,t} + \sum_{j=1}^{J} \beta_X X_{j,i,t} + \sum_{m=1}^{M} \beta_M M_{m,i,t} + \sum_{s=1}^{T} \beta_T T_{s,i,t} + \epsilon_{i,t},
\]

where \(P_i\) is the probability of survival until the age of building \(i\).

This expected price formulation of Equation (5) will be the focal regression for the remainder of this study. In order to estimate a survival probability for

\(^{17}\text{An alternative approach to dealing with the censored sample problem is proposed by Francke and van de Minne (2017), who specify land and structure quantities separately in the price model regressors, enabling them to specify a structure quantity of zero in any transaction of land or of development sites.}\)
our sample properties, we will employ data on demolished buildings (along with surviving buildings) and use the Kaplan–Meier estimator to calculate the survival probability at each building age.

**Cap Rate Model**

We also estimate a hedonic model of the cap rate that can, similar to the analysis of property price, quantify how the cap rate is a function of the age of the property’s building structure (holding other characteristics constant). This cap rate model can then be combined with the hedonic price model to derive how much of the overall depreciation in the property value is due to depreciation in the property NOI and how much is due to change in the cap rate.

Our hedonic cap rate model is very similar to our hedonic model of property price in Equation (4) except that we replace the dependent variable with a normalized construct of the property’s cap rate at the time of sale instead of the property price. The normalized cap rate is the difference between the property’s cap rate minus the average cap rate prevailing in the property’s metropolitan market (for the type of property) during the year of the transaction. This normalization controls for systematic differences in cap rates across metropolitan areas, as well as for cyclical and market effects on the cap rate.\(^{18}\) The normalized cap rate thus allows the individual property differences in cap rates that could be caused by the age of the buildings to be estimated in the model below:

\[
\text{CapRate}_{i,t} = \sum_{h=1}^{H} \beta_{A_h} A_{h,i,t} + \sum_{j=1}^{J} \beta_{X_j} X_{j,i,t} + \sum_{m=1}^{M} \beta_{M_m} M_{m,i,t} + \sum_{s=1}^{T} \beta_{T_s} T_{s,i,t} + \epsilon_{i,t},
\]

\(^6\)

**Data**

This study is based on the RCA Inc. database of commercial property transactions in the United States.\(^{19}\) RCA collects all property transactions greater than $2,500,000, and reports a capture rate in excess of 90%. Properties

\(^{18}\)Alternatively, cap rates on the left hand side and interacted dummies between Metropolitan Statistical Area (MSA) and time would also capture the between market variation in cap rate over time. This alternative specification gives nearly identical results, not surprisingly.

\(^{19}\)In general from here on, unless specified otherwise or it is clear from the context, we will use the term “commercial” property to refer to all income-producing property including multifamily apartments.
smaller than $2.5M are often owner-occupied or effectively out of the main professional real estate investment industry. We believe the data represent a much larger and more comprehensive set of investment property transactions than prior studies of depreciation. The present analysis is limited to the four major core property sectors of office, industrial, retail and apartment. The study data set consists of all such transactions in the RCA database from 2001 through the second quarter of 2014 and which pass the data quality control filters and for which there is sufficient hedonic information in the RCA database, 107,805 transactions in all.\textsuperscript{20} This includes 80,431 nonresidential commercial property sales and 27,374 apartment property sales. A subsample of 81,310 transactions are located in the top 25 metropolitan area markets, which are studied separately.\textsuperscript{21} A total of 49,634 transactions are repeat-sales, which are used in the panel regression analysis in the Appendix. Thirty-two thousand four hundred and eighty-one sales have, in addition to sufficient hedonic data, also reliable information about the cap rate (as defined in the section “Investment Perspective on Depreciation”). This cap rate subsample will be used in our analysis of the cap rate creep per Equation (6). Table 1 presents the summary statistics for the overall data set. The average age of the properties in our sample is 32 years and the median age is 25 years. The data are fairly equally distributed across the four core property types. The seller types are broadly categorized as Equity, Institutional, Public, Private, User and CMBS Financed, of which Private constitutes about 69\% of the data. Figure 2 shows the number of observations in each of the top 25 RCA Metro Markets. The sample sizes range from 15,380 transactions in Metro Los Angeles down to only 288 in Pittsburgh.

\textit{Torn-Down Building Data, Multiple Imputation of Age-at-Demolition and Survival Probabilities}

In addition to the above described data, which will serve as the basis of our analysis, we have a sample of 12,903 transaction price observations in which the building on the property was either demolished or acquired with the intention to demolish. Unfortunately, of these, only 2,109 observations have nonmissing building age information. In order to calculate survival

\textsuperscript{20}We drop sales that were part of a portfolio sale to avoid an uncertain sale price for a property within the portfolio. We also drop properties for which the sale price was not classified as confirmed by RCA’s standards and if they were older than 150 years. RCA’s standards include checks to make sure the sale was an arm’s-length transaction (and this excludes foreclosure sales).

\textsuperscript{21}RCA has their own definition of metropolitan areas which differ slightly from the U.S. Census definitions and conform better to actual commercial property markets. We refer to these as “RCA metros” or “Metro Markets.”
Table 1  ■  Summary statistics.

| Variable                        | Mean   | Std. Dev. | N    |
|---------------------------------|--------|-----------|------|
| Age                             | 32     | 26        | 107,805 |
| Age squared                     | 1706   | 2726      | 107,805 |
| Price                           | $15,176,605 | $47,556,544 | 107,805 |
| Square feet                     | 116,694 | 178,773   | 107,805 |
| Cap Rate                        | 0.07   | 0.017     | 32,481  |
| Normalized cap rate             | 0      | 0.013     | 32,481  |
| CBD                             | 0.153  | 0.36      | 107,805 |
| Distress flag                   | 0.067  | 0.25      | 107,805 |
| CMBS financed                   | 0.109  | 0.311     | 107,805 |
| Excess land potential flag      | 0.023  | 0.151     | 107,805 |
| Apartments                      | 0.254  | 0.435     | 107,805 |
| Industrial                      | 0.259  | 0.438     | 107,805 |
| Office                          | 0.234  | 0.423     | 107,805 |
| Retail                          | 0.253  | 0.435     | 107,805 |
| Seller type—user/other          | 0.037  | 0.189     | 107,805 |
| Seller type—CMBS financed       | 0.003  | 0.05      | 107,805 |
| Seller type—equity fund         | 0.032  | 0.175     | 107,805 |
| Seller type—institutional       | 0.105  | 0.307     | 107,805 |
| Seller type—private             | 0.689  | 0.463     | 107,805 |
| Seller type—public              | 0.048  | 0.215     | 107,805 |

probabilities at each building age, we first need to impute the missing age-at-demolition data. We choose a multiple imputation approach where each missing age is imputed 20 times. The method of imputation outlined by Royston (2007) is particularly suited for imputing censored variables. Its main feature is that the researcher can specify an interval of the normal distribution from which the imputed values will be simulated. In our case, we specified that interval to be between ages 10 and 150 years, the assumption being that buildings with age less than 10 years are very unlikely to be demolished. An added advantage of this approach is that our imputed values are always going to be nonnegative and within a sensible range. As recommended by the multiple imputation literature, the model for the conditional distribution of Age contains all covariates, including price and a dummy variable for surviving properties. Upon obtaining 20 imputations of age-at-demolition, we construct 20 separate sets of survival probabilities using the Kaplan–Meier estimator. Figure 3 shows all 20 sets; they all exhibit a very similar shape. Finally, we construct a single set of survival probabilities \( P_i \) in (5)) by taking an average over the 20 sets (shown in bold in Figure 3). The thus obtained survival probabilities are then multiplied by the price of the surviving buildings (107,805 transactions) to create the left-hand side (in logs) of the regression equation (5).
Figure 2: Transactions by RCA metro area.

Transactions Observations Counts by RCA Metro Market
Total: 81,310 obs 2001-14 in top 25 metros with sufficient hedonic data
Empirical Analysis

Depreciation Magnitude and Value/Age Profile

The first set of results is based on the bias-corrected hedonic price model in Equation (5), run on the entire 107,805 U.S. transaction sample, and focuses on the overall rate of depreciation and its profile over time. Column (1) in Table 2 presents the regression results. The variables of interest, both Age and Age-squared, are highly significant, with the coefficient on Age being negative and that on Age-squared being positive; a convex quadratic function. Thus, the property value tends to decline in real terms with building age, but at a declining rate. Also shown in column (2) of Table 2 is the regression from Equation (4), reflecting an estimate that does not correct for censored sample bias caused by torn-down buildings whose structures have already fully depreciated. There are two points worthy of note when comparing the Age and Age-squared coefficients between columns (1) and (2). First, the coefficients are less precise in the bias-corrected estimates of column (1). The standard errors are greater due to the uncertainty introduced by the multiple imputation (of age-at-demolition) step in the estimation of the survival probabilities. Nevertheless, the results are still statistically significant. Second, the biased estimates of column (2) do indeed underestimate the rate of depreciation. This
Table 2  Effect of depreciation on property value.

|                           | (1) Log Expected Price | (2) Log Price |
|---------------------------|------------------------|---------------|
| Age                      | −0.01845               | −0.02110      |
|                           | (75.12)**              | (88.27)**     |
| Age squared               | 0.00007                | 0.00016       |
|                           | (26.52)**              | (62.37)**     |
| Ln Sqft                   | 0.69647                | 0.69709       |
|                           | (318.60)**             | (319.45)**    |
| CBD                       | 0.41110                | 0.40685       |
|                           | (52.55)**              | (53.33)**     |
| Industrial                | −0.34602               | −0.34429      |
|                           | (73.75)**              | (73.49)**     |
| Office                    | 0.26328                | 0.26551       |
|                           | (50.46)**              | (51.00)**     |
| Retail                    | 0.29279                | 0.29383       |
|                           | (52.99)**              | (53.26)**     |
| Distress flag             | −0.58159               | −0.58180      |
|                           | (60.84)**              | (60.91)**     |
| CMBS financed             | 0.25262                | 0.25220       |
|                           | (47.89)**              | (47.89)**     |
| Excess land potential flag| 0.20432                | 0.20389       |
|                           | (15.67)**              | (15.66)**     |
| Seller type—CMBS financed | 0.00262                | 0.00355       |
|                           | (0.08)                 | (0.10)        |
| Seller type—equity fund   | 0.35121                | 0.35172       |
|                           | (27.66)**              | (27.73)**     |
| Seller type—institutional | 0.23632                | 0.23696       |
|                           | (28.44)**              | (28.54)**     |
| Seller type—private       | 0.09399                | 0.09358       |
|                           | (16.85)**              | (16.82)**     |
| Seller type—public        | 0.19405                | 0.19503       |
|                           | (19.37)**              | (19.49)**     |
| Constant                  | 7.64135                | 7.64808       |
|                           | (108.58)**             | (108.94)**    |
| $R^2$                     | 0.72                   | 0.70          |
| $N$                       | 107,805                | 107,805       |

Notes: MSA and Year dummies not shown.  
*p < 0.05; **p < 0.01.

is best seen in Figure 4, where the two quadratic specifications are compared in an implied Value/Age profile (constructed using both Age and Age-squared coefficients). It is clear that while the biased and unbiased profiles closely agree up until the first 40 years of building age, the biased quadratic specification fails to capture the continued decay in property value much beyond that point. Also shown in Figure 4 is an alternate bias-corrected age dummy
We also show a two standard error bound around this specification to depict the noise in these estimates, which is quite large in the range beyond 110 years, a point where the data start to get thin. The age dummy specification suggests that the bias-corrected quadratic approach is a very good approximation to a more flexible but noisier alternative. As noted, we further examine the robustness of the results in the Appendix, by estimating a panel regression using only the subset of the data that has sold more than once (repeat sales), thereby controlling for any omitted variable bias. We find that the depreciation rate over the first 50 years of age is greater by only 0.08%/year in the panel model when compared with the current ordinary least-squares (OLS)-based hedonic model run on the same sample. We conclude that this difference is economically insignificant and thus choose to make use of the full single-sales database.

In this specification, there is a dummy for each age up until age 129, while ages 130 to 150 are lumped together into one final dummy variable.

As suggested by a referee, we also split the sample into two periods; a typical period and a bubble period (2005 to 2007). We find that the depreciation rate differs by less than 0.08%/year during the bubble period compared to the typical period. Again, this is economically insignificant. Few other studies have examined how secular depreciation varies over historical time, but a study by Smith (2004) found similarly for housing in Bloomington, Indiana, that time variation in depreciation rates was of
Using the quadratic specification as the more parsimonious model, we model the depreciation rate (using the Age and Age-squared coefficients) for all building ages from 1 to 50 years old. We then take, as our summary measure of average depreciation rate, the equally weighted average rate across the 50-year horizon. (That is, each of the 50 years’ rates counts equally. This average is normally very similar to the depreciation rate of a 25-year-old building).\(^{24}\) Thus, in effect, this is a summary depreciation metric that holds the age of the building structure constant across comparisons, at the time-weighted average depreciation rate over a 50-year building life horizon.

For the national sample, this gives an average real depreciation rate of 1.5%/year of property value (including land). The depreciation rate declines from 1.82%/year for a property with a new building down to 1.12%/year for a property with a 50-year old building (see Figure 5). At first glance, these depreciation rates appear to be smaller than what was reported in earlier studies in the United States, such as the Hulten–Wyckoff (1981) and Sanders and Randall (2000). But those studies were quoting rates as a fraction of minimal economic significance, ranging only about +/- 10 basis-points. The forces which cause depreciation are long term and secular in nature, as distinguished from real estate market movements, so one would not generally expect great variation in depreciation rates across time.

\(^{24}\)As noted earlier, the mean building age in our sample is 32 years, with a median age of 25 years.
remaining estimated structure value, not total property value which is our focus.

To compare our results with the previous U.S. depreciation literature, it may be of some interest to make some observations on what our findings suggest about depreciation as a fraction of structure value.\textsuperscript{25} Given our bias-corrected empirical model in column (1) of Table 2, we can estimate an implied average structure lifetime by finding the minimum point (over Age) at which there is no further property depreciation. The minimum point of the quadratic function $\ln(p) = -0.0185 \times \text{Age} + 0.00007 \times \text{Age}^2$ is at age 128 years (see also Figure 4).\textsuperscript{26} When a building is no longer depreciating, it is worthless and hence it is time for redevelopment. At that point, the entire property value is land value. As a fraction of value of newly built property value, this pure land value component can be found by plugging the building lifetime age (i.e., age when structure becomes worthless as indicated by no further depreciation) back into our hedonic price equation $\exp(-0.0185 \times 128 + 0.00007 \times (128)^2 = 0.31)$, which indicates a land value fraction of 31% (for newly developed property). Thus, the corresponding structure value fraction of newly built property value would be 69%. Given this initial structure value fraction and our property value depreciation profile, we back out that the rate of structure depreciation (per annum) is 2.7% at the median building age of 25 years.\textsuperscript{27} This estimate is roughly consistent with previous studies’ findings as summarized in the section “Literature Review.”

In Table 3, we run separate regressions for the four core property types. We find (consistent with the national aggregate results) signs and significance for the Age and Age-squared variables across all property types.\textsuperscript{28} In the case of

\textsuperscript{25}For more depth and detail on this topic, see Geltner and Bokhari (2015).

\textsuperscript{26}This is also similar to the half-life of 107 years found in our estimated Kaplan–Meier building survival probability function.

\textsuperscript{27}Due to the essentially cross-sectional nature of our empirical estimation of depreciation, the average land value as a fraction of newly built property value is essentially constant across all building ages in the property value/age profile, by definition. We are essentially comparing the prices of properties with different age buildings, as of the same point in time. Thus, for example, if a newly built property has a value of 100 including 31 land and 69 structure, and a property with a 50-year-old building has a value of 50 (implying geometric depreciation of 0.50/(50−1) = 1.4%/year in the property value/age profile, which is approximately what our findings suggest, in aggregate), then the 50-year-old structure has an implied value of 50 − 31 = 19, or only 19/69 = 28% of that of a new building (and this implies a structure geometric depreciation rate of 0.281/(50−1) = 2.5%/year). With our log-quadratic value/age profile, the instantaneous depreciation rate varies by age, and is more rapid for younger buildings, resulting in 2.7%/year for the median-age building.

\textsuperscript{28}The one exception is the quadratic term for industrial property, which is not statistically significant.
Table 3  Effect of depreciation on expected property value, by property type.

| Log Expected Price | Apartments  | Industrial | Office   | Retail   |
|-------------------|------------|------------|----------|----------|
| Age               | −0.02699   | −0.01133   | −0.01759 | −0.01739 |
|                   | (56.08)**  | (23.03)**  | (33.25)**| (34.21)**|
| Age squared       | 0.00015    | 0.00001    | 0.00006  | 0.00009  |
|                   | (29.83)**  | (1.37)     | (11.16)**| (14.95)**|
| Ln Sqft           | 0.80033    | 0.59403    | 0.83244  | 0.59855  |
|                   | (167.64)** | (144.12)** | (194.53)**| (129.36)**|
| CBD               | 0.27821    | 0.38906    | 0.42497  | 0.34850  |
|                   | (17.46)**  | (22.04)**  | (36.66)**| (17.82)**|
| Distress flag     | −0.46068   | −0.44758   | −0.67668 | −0.61466 |
|                   | (28.00)**  | (24.21)**  | (36.12)**| (29.05)**|
| CMBS financed     | 0.13760    | 0.34349    | 0.22706  | 0.29982  |
|                   | (14.20)**  | (23.53)**  | (23.71)**| (33.39)**|
| Excess land potential flag | 0.31029 | 0.16883 | 0.17500 | 0.18751 |
|                   | (7.81)**   | (7.98)**   | (8.34)** | (6.74)** |
| Seller type—CMBS financed | 0.08695 | 0.11973 | 0.08416 | 0.01474 |
|                   | (1.20)     | (1.95)     | (1.44)   | (0.25)   |
| Seller type—equity fund | 0.14889 | 0.33638 | 0.31126 | 0.37409 |
|                   | (6.21)**   | (14.22)**  | (15.96)**| (10.44)**|
| Seller type—institutional | 0.20924 | 0.17049 | 0.18319 | 0.25393 |
|                   | (11.71)**  | (12.25)**  | (12.08)**| (12.36)**|
| Seller type—private | 0.10168 | 0.06406 | 0.06786 | 0.15205 |
|                   | (7.29)**   | (8.15)**   | (5.62)** | (12.37)**|
| Seller type—public | 0.30655 | 0.19398 | 0.13518 | 0.14470 |
|                   | (16.17)**  | (12.24)**  | (6.63)** | (6.72)** |
| Constant          | 6.32318    | 8.77162    | 6.12840  | 9.11602  |
|                   | (51.93)**  | (57.60)**  | (51.50)**| (67.83)**|
| R²                | 0.79       | 0.63       | 0.80     | 0.62     |
| N                 | 27,374     | 27,959     | 25,231   | 27,241   |

Notes: MSA and Year dummies not shown.  
*p < 0.05; **p < 0.01.

nonresidential commercial real estate, office and retail properties depreciate the fastest at similar rates, while industrial depreciates the slowest. In Figure 6, we lump all the nonresidential commercial property sectors together and break out the analysis separately for apartments and nonresidential commercial properties. It is not clear a priori why apartment properties should depreciate at different rates than commercial property, but tax policy has long differentiated them (possibly for political reasons). In fact, we see that apartments do on average depreciate slightly faster than nonresidential commercial properties, holding age constant. In our sample, the average apartment building is 10 years older than the average nonresidential commercial property (median of
Figure 6 ■ Real depreciation: apartments versus nonresidential.

In our sample the avg apt is 10 yrs older than the avg non-resi comm property (median 35 vs 23 yrs old) and the depreciation rate of the median property is aps: 1.63% vs comm: 1.5%/yr.

35 years vs. 23 years old) and the depreciation rate of the median apartment property is 1.63% versus 1.5% per annum for commercial.

In summary, our aggregate-level findings suggest depreciation rates that average 1.5% per annum as a fraction of total property value (including land). Compared to the previous literature, our estimates are based on actual transaction prices rather than building structure value estimates, and are based on a much larger and more comprehensive property sample. Given our model’s implications for structure depreciation, the rates we find are consistent with the earlier findings. We find clear evidence that properties depreciate slower as buildings age. There is also clear evidence that apartment properties depreciate faster, but only slightly faster, than nonresidential commercial properties.

Estimation of Cap Rate and NOI Effects on Total Depreciation

In order to estimate how much property value depreciation would result purely from cap rate creep, and how much from NOI decline, we estimate the (bias-corrected) hedonic price and cap rate models (Equations (5) and (6), respectively) on the same transaction subsample for which we have cap rate data available. These regressions are shown in columns (1) and (2), respectively, of Table 4. We first compute the total depreciation in property
value from the age coefficients in the price model (column (1) of Table 4), much as described in the previous section. We next compute how much decline in property value with building age would result purely from the increase in the cap rate due to age as implied by the age coefficients in the cap rate model (column (2) of Table 4), holding the property NOI constant.
The difference between the total depreciation and the pure cap rate creep depreciation presumably is attributable to NOI depreciation.

The result of this analysis is shown in Figure 7. It can be seen that almost all of the property value real depreciation results from the decline in the real NOI and very little from cap rate creep. Using our previously defined average-age metric for the summary depreciation rate, the overall average depreciation rate in the subsample is 1.55%/year, while the average depreciation rate due solely to cap rate creep is only 0.17%/year. The implication is that the NOI source of depreciation accounts for 1.38%/year or 90% of all the depreciation. This implies, in a typical investment property pro-forma cash flow projection, that if inflation is projected to be 3% per year, for example, then NOI should be projected to grow at only some 1.62% per year.

The dominance of net income and the space market as the fundamental source of property value in real depreciation is interesting in view of the fact that changes in capitalization, in the asset market’s OCC or future growth expectations, have been found to play a major and perhaps even dominant role in short- to medium-term movements in property value. But depreciation is a very long-term secular phenomenon, and it makes sense that it would largely reflect underlying fundamentals.

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29See, for example, Geltner and Mei (1995), and Plazzi, Torous and Valkanov (2010).
Depreciation and Metropolitan Location

We noted previously that real depreciation is a phenomenon of decline in the value of the building structure on the property, as land generally does not depreciate. This probably largely accounts for why the rate of depreciation is greater in properties with newer buildings (Figure 5). This also strongly suggests that property depreciation rates may vary across metropolitan areas, as different cities have different scarcity of land and different land value proportions of total property value. To analyze this issue, we estimated the bias-corrected hedonic price model in Equation (5) separately for each of the top 25 Metro Markets (see again Figure 2 for the sample sizes in each metro).  

Figure 8 shows the resulting estimated coefficients on the Age variable in Equation (5), in terms of absolute value (higher value is faster depreciation). The Age coefficients are statistically significant in all 25 Metro Markets and Age-squared coefficients are statistically significant for all but nine

30 For this analysis, the imputation of the age-at-demolition data was computed separately for each market. At the excellent suggestion of a reviewer, we also computed depreciation separately for CBD and non-CBD properties. However, we do not find significantly different depreciation by that definition of intra-metropolitan location. This is somewhat surprising, as presumably land value fractions are higher in more central locations. However, it is possible that functional or economic obsolescence operates more powerfully in CBD locations, causing a more rapid decline in structure value, offsetting the pure effect of the higher land value fraction.
Table 5  ■ Real depreciation rates (per annum) by building age.

| Metro Market | 1 Year | 10 Years | 30 Years | 50 Years | Average |
|--------------|--------|----------|----------|----------|---------|
| Dallas       | 3.32%  | 3.17%    | 2.83%    | 2.50%    | 2.95%   |
| Houston      | 2.29%  | 2.52%    | 3.04%    | 3.56%    | 2.85%   |
| Phoenix      | 1.50%  | 1.90%    | 2.78%    | 3.66%    | 2.46%   |
| Austin       | 2.31%  | 2.35%    | 2.45%    | 2.54%    | 2.41%   |
| Atlanta      | 1.77%  | 2.03%    | 2.61%    | 3.18%    | 2.40%   |
| Charlotte    | 2.00%  | 2.10%    | 2.33%    | 2.55%    | 2.25%   |
| Denver       | 2.36%  | 2.22%    | 1.92%    | 1.62%    | 2.03%   |
| Tampa        | 1.62%  | 1.79%    | 2.16%    | 2.53%    | 2.02%   |
| Pittsburgh   | 2.10%  | 1.97%    | 1.68%    | 1.39%    | 1.78%   |
| Sacramento   | 1.74%  | 1.76%    | 1.80%    | 1.83%    | 1.78%   |
| Baltimore    | 1.59%  | 1.59%    | 1.61%    | 1.62%    | 1.60%   |
| St Louis     | 1.71%  | 1.66%    | 1.54%    | 1.43%    | 1.59%   |
| Chicago      | 1.65%  | 1.57%    | 1.38%    | 1.19%    | 1.45%   |
| Philly Metro | 1.69%  | 1.59%    | 1.36%    | 1.13%    | 1.44%   |
| Minneapolis | 1.36%  | 1.38%    | 1.43%    | 1.48%    | 1.41%   |
| So Fla       | 1.54%  | 1.49%    | 1.37%    | 1.25%    | 1.41%   |
| Detroit      | 1.61%  | 1.52%    | 1.31%    | 1.11%    | 1.39%   |
| Portland     | 1.24%  | 1.21%    | 1.15%    | 1.08%    | 1.17%   |
| DC Metro     | 1.17%  | 1.16%    | 1.12%    | 1.09%    | 1.14%   |
| San Diego    | 0.70%  | 0.81%    | 1.06%    | 1.31%    | 0.97%   |
| Seattle      | 0.76%  | 0.83%    | 0.99%    | 1.15%    | 0.93%   |
| NYC Metro    | 1.19%  | 1.06%    | 0.78%    | 0.49%    | 0.88%   |
| SF Metro     | 1.09%  | 1.03%    | 0.79%    | 0.59%    | 0.87%   |
| Boston       | 0.69%  | 0.70%    | 0.73%    | 0.76%    | 0.72%   |
| LA Metro     | 0.25%  | 0.32%    | 0.47%    | 0.63%    | 0.42%   |
| Average      | 1.57%  | 1.59%    | 1.63%    | 1.67%    | 1.61%   |

Notes: Estimated rates are statistically significant.

Metro Markets. The figure ranks the metros from greatest (fastest) to lowest (slowest) depreciation (based on the Age coefficient) and shows the two-standard-deviation confidence bounds around the Age coefficient estimate in each metro. However, recall that the Age coefficient by itself is not the complete story about depreciation, as the effect of the Age-squared coefficient must also be considered, which makes the property depreciation rate a function of building age. Table 5 therefore shows for each metro the implied depreciation rates as a function of building age, as well as the time-weighted average summary metric for each metro (which effectively compares across metro holding building age constant). Finally, Figure 9 depicts the value/age profiles for three representative major metropolitan areas, providing a visual
impression of how both the average depreciation rate and the age profile of the depreciation can vary across select metropolitan areas.\textsuperscript{31}

The extent of variation across metropolitan areas is striking. For the age-constant summary metric, the average depreciation rate for all income-producing commercial property ranges from 2.95\%/year in Dallas down to 0.42\%/year in Los Angeles, roughly a 250 basis-point range. The value/age profile (see Figure 9) also can vary greatly, with New York City apparently exhausting the property depreciation just prior to 85 years of building age. This probably does not generally reflect an historic building or “vintage effect” as has been sometimes found for single-family houses.\textsuperscript{32} Income-producing properties, essentially capital assets traded in the investments industry, are probably not very susceptible to architectural style vintage year preference effects like houses may be. Rather, the exhaustion of property depreciation probably suggests rapid economic obsolescence in a high land value, dynamic

\textsuperscript{31}The value/age profile is noisy for many metro areas at that level of granularity introduces more noise in the imputation and survival probability estimations.

\textsuperscript{32}See Clapp and Giacotto (1998), who document that home buyers may develop preferences for certain vintages of housing construction.
The Saiz elasticity measure is based on both regulatory and physical land supply constraints on real estate development, which Saiz (2010) has shown are major determinants of overall real estate development supply elasticity. Thus, the Saiz elasticity measure should be highly correlated (negatively) with land value and the land value fraction of total development costs (and therefore, with the average land value fraction of total property value). Metro Markets with higher Saiz elasticity measures probably tend to have lower land values. Figure 10 indeed reveals a strong positive relationship between depreciation and the Saiz elasticity. Metro areas that tend to have more elastic supply of real estate by the Saiz measure...
(which probably have lower land costs resulting in building value being a larger share of total property value) are associated with faster depreciation, especially in the early years of building life.\(^\text{34}\) We see the opposite in metros that have the lowest Saiz elasticities.\(^\text{35}\)

In Figure 11, we regress MSA depreciation rates against the physical land constraint component of Saiz’s elasticity measure. The physical land constraint measure is a sum of various geographical constraints within a 50-km radius from the center of an MSA. These constraints include the share of land area that’s at more than a 15% slope, or if it is under open water or wetlands, or generally not available for development. The figure shows that depreciation rates are lower in MSAs where there are greater (higher value) physical constraints to development. This again is consistent with the view that land

\(^{34}\)Lower depreciation as a fraction of property value in later years (older buildings) in metro areas with rapid initial depreciation rates could reflect exhaustion of building value due to widespread economic obsolescence of structures reflecting very dynamic metropolitan growth. Ex.s. include Dallas, Denver, Phoenix, Atlanta.

\(^{35}\)Most notably the West Coast metros (LA, SF, SD, Seattle, Portland) and major North Atlantic metros (NY, Bos, DC).
value proportions of total property value would be higher in such MSAs and therefore, depreciation in the structure would be a smaller percentage of total property value.

In Figure 12, we regress MSA depreciation rates against the Wharton Land Regulation Index (WLRI, also a component of Saiz’s elasticity measure). In the figure, higher values reflect greater regulatory constraints and we see a negative relationship between average depreciation rates and the WLRI. However, the relationship between depreciation and regulatory constraints in Figure 12 is weaker than the relationship between depreciation and physical land constraints in Figure 11. Onerous regulations constrain development without adding to land value (they do not cause land scarcity per se but merely an increase in development costs), while physical land constraints should cause land scarcity and higher land costs. In a simple regression of average MSA depreciation rates onto the Saiz physical land constraints measure and the WLRI, we find that the physical land constraints measure has greater explanatory power than the WLRI measure. The physical land constraint measure has a bigger coefficient (−0.71) and higher statistical significance (at 1% level) than WRLI, which has a coefficient of −0.37 and is only statistically significant at the 10% level. Physical land constraints
alone can explain over 40% of the variation in average depreciation rates across MSAs while adding WRLI only marginally increases the explained variation to 50%. Thus, low depreciation is more associated with physical land constraint than with regulatory constraints.

The analysis in Figures 10, 11 and 12 explores a major cause of the cross-section of metropolitan depreciation rates in commercial property. On the other hand, the analysis in Figure 13 explores a major effect of this variation in depreciation rates. Figure 13 regresses the average cap rates of property sale transactions onto the average depreciation rates across the Metro Markets. As noted in our derivation of the direct capitalization formula for property value in formula (2) in Section “Investment Perspective on Depreciation,” cap rates can be viewed as reflecting essentially or primarily the current OCC (the investors’ expected total return, \( r_i \)) minus the long-term expected growth rate in property value (what we labeled \( g_{i,t} \), which fundamentally and primarily reflects the long-term growth in property net income). Clearly the long-term growth rate strongly reflects the property depreciation rate that we have been estimating. Therefore, we should expect property transaction prices, as reflected in their cap rates, to be partially and importantly determined by depreciation expectations. Thus, the dispersion in cap rates should be
Figure 13 shows that this is exactly what we find. The relationship is strongly positive and statistically significant.

However, the cap rate/depreciation relationship in Figure 13 is less than a one-to-one correspondence (slope is less than 1.00). If cap rates were completely determined by the $r_{i,t} - g_{i,t}$ relationship, and if $g_{i,t}$ were completely determined by depreciation (growth is the negative of depreciation), then we would expect the estimated slope line in Figure 13 to be closer to 1.00. Instead, the slope is 0.44. Apparently cap rates are a bit more complicated than $r_{i,t} - g_{i,t}$ and/or the growth that matters to investors is more complicated than just the long-term depreciation that characterizes the metro area. Nevertheless, Figure 13 suggests that the type of depreciation we are measuring is important for investors, as it should be.

Conclusion

In this article, we have analyzed the wealth of empirical data about U.S. commercial investment property contained in the RCA transaction price database in order to characterize the nature and magnitude of real depreciation. We introduce and explicate what we call the investment perspective for this analysis, which differs from that of the income tax policy oriented studies that have dominated most of the past literature in the United States. The investment perspective is based on before-tax cash flow and market value metrics such as the IRR and the holding period total return that are prominent in the financial economics field, instead of on the historical cost accrual accounting perspective that underlies IRS tax policy in the United States.

To briefly summarize our empirical findings about depreciation in income property viewed from the investment perspective, we see first that depreciation is significant. With average rates well over 100 basis-points per year (as a fraction of total property value including land), often over 200 bps in newer properties, depreciation has an important impact on realistic expected returns and property investment values.

And depreciation varies in interesting ways. It tends to be greater in younger properties (those with more recently constructed buildings). This probably largely reflects the relative share of land value and building structure value in overall property value, as land does not tend to depreciate. Holding building age constant, depreciation tends to be slightly greater in apartment properties than in nonresidential commercial properties. Depreciation varies importantly across metropolitan areas. Metros with lower development supply elasticity, especially places with physical land constraints such as the large East and
West Coast metropolises, have lower depreciation rates. Places with plenty of land and less development constraints (higher supply elasticity) have higher average depreciation (holding building age constant). Differences in land value fractions underlie these results.

We also confirm that investment property asset prices significantly reflect the differences in depreciation rates across metropolitan areas (as they should with rational asset pricing), though depreciation can only explain about half of the cross-sectional differences in cap rates.

Finally, real depreciation is largely caused by (or reflects) real depreciation in the NOI that the property can generate, rather than by “cap rate creep” (increasing property cap rate with building age). Depreciation is a long-term secular phenomenon, so it makes sense that it would largely reflect property value fundamentals.

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**References**

Baum, A. and A. McElhinney. 1997. The Causes and Effects of Depreciation in Office Buildings: A Ten Year Update. Working Paper of the Department of Land Management and Development, University of Reading.

Bokhari, S. and D. Geltner. 2011. Loss Aversion and Anchoring in Commercial Real Estate Pricing: Empirical Evidence and Price Index Implications. *Real Estate Economics* 39(4): 635–670.

Clapp, J.M. and C. Giaccotto. 1998. Residential Hedonic Models: A Rational Expectations Approach to Age Effects, *Journal of Urban Economics* 44: 415–437.

Crosby, N., S. Devaney and V. Law. 2011. Benchmarking and Valuation Issues in Measuring Depreciation for European Office Markets. *Journal of European Real Estate Research* 4(1): 7–28.

Fisher, J.D., B.C. Smith, J.J. Stern and R.B. Webb. 2005. Analysis of Economic Depreciation for Multi-Family Property. *Journal of Real Estate Research* 27(4): 355–369.

Francke, M. and A. van de Minne. 2017. Land, Structure and Depreciation. *Real Estate Economics* 45(2): 415–451.

Geltner, D. and S. Bokhari. 2015. Commercial Buildings Capital Consumption in the United States. MIT Center for Real Estate Report for Real Estate Roundtable.

——— and J. Mei. 1995. The Present Value Model with Time-Varying Discount Rates: Implications for Commercial Property Valuation and Investment Decisions, *Journal of Real Estate Finance and Economics* 11(2): 119–135.

Gravelle, J.G. 1999. *Depreciation and the Taxation of Real Estate*. Washington, DC: Congressional Research Service.
Appendix: Panel Regression Robustness Test

A possible source of bias in the depreciation estimates could be due to the omission of property characteristics variables that are unavailable in the RCA database. (For example, we do not know the construction material of the building, whether steel or concrete or wood.) However, for such “omitted variable bias” to be a problem for our purpose, the omitted variable has to be highly correlated with the age of a property. Of course, this is a possibility. A good way to explore this issue is to construct a so-called “panel data model” and compare it with the standard OLS hedonic model. The panel data model should be highly robust to omitted variable bias, while the OLS model should be as susceptible to such bias as our methodology that we employ in this study.

To perform this test, we use a subset of the RCA transaction price data that represents properties that have transacted more than once. Several of the properties transacted multiple times and having repeat observations on the same property allows for a model that controls for unobservable effects that are constant across time. Almost all variables that could cause a bias in our context should cancel out in such repeat-sales observations. For example, location remains constant in the same property across time, including considerations such as proximity to the CBD. Similarly, the construction quality of the structure also remains constant in our data set (where major
Table A.1 ■ Comparison of age coefficients in panel and OLS models.

| Variable          | Panel Regression | OLS Regression |
|-------------------|------------------|----------------|
| Age               | -0.0291473       | -0.0240643     |
|                   | (0.002)          | (0.000)        |
| Age squared       | 0.0002698        | 0.0001846      |
|                   | (0.000)          | (0.000)        |
| No. of obs.       | 49,634           | 49,634         |

Renovations between repeat sales of the same property are excluded. The panel data model can be written as follows:

$$\ln(p_{i,t}) = \alpha + \beta \text{Age}_{i,t} + \gamma \text{Age Squared}_{i,t} + \sum_{h=1}^{H} \delta_h A_{h,i,t} + \theta_i + \epsilon_{i,t},$$

where $A_{h,i,t}$ is a vector of $H$ observable property and transaction characteristics that are different between multiple transactions of the same property. In our data, a few properties have their square feet change in minor ways between sales (major changes are filtered out). In addition, distress status, CMBS financing by the buyer and seller types are all different between sales. All characteristics of the property that are unchanged are captured by the property fixed effect $\theta_i$ (that is akin to having a dummy variable for each property $i$). Its purpose is to capture all property-specific factors that may or may not be observable in the data but may affect the transaction price. The model is estimated using the panel data regression estimation technique with fixed effects. Note that if our data had only one pair for each property, then this model would reduce to a standard repeat sales regression. We prefer the panel specification over repeat-sales as the panel avoids the multicollinearity issues that arise for purposes of depreciation estimation in repeat sales regressions between the change in property age and the time between sales.

Table A.1 shows a side-by-side comparison of the age coefficients obtained via the panel and OLS regression methods, over the first 50 years of building age (the span for which our transaction sample is richest). Recall that the panel regression should be highly robust to omitted variable bias, while the OLS regression would be most susceptible to such bias. As seen in the table, the coefficients on Age and Age squared are slightly different between the two models that were run on the same data. Figure A.1 shows a graphical comparison of the two value/age profiles obtained from these coefficients.
Upon examining the two value-age profiles, we find that the panel regression method suggests a slightly faster rate of depreciation for the first 30 years of age. But between ages 30 and 50 years, it is the OLS model that instead suggests a faster rate of depreciation. Overall, taking the average difference in depreciation over the 50 years between the two methods, we find that the panel method gives only about 0.08%/year more depreciation than the standard OLS method. While statistically significant, this amount of difference is economically insignificant, suggesting that omitted variable bias is not an important concern. The main analysis of net depreciation in this study accordingly sticks with the classical OLS hedonic model approach, as this allows us to use the larger and arguably more representative full transaction sample of 107,805 observations.