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COMMERCIAL BUILDINGS CAPITAL CONSUMPTION AND THE UNITED STATES NATIONAL ACCOUNTS

BY SHEHARYAR BOKHARI

MIT Center for Real Estate

AND

DAVID GELTNER*

MIT Department of Urban Studies and Planning

Commercial buildings are a major asset class, over 30 percent of the value of the stock of all produced assets according to the BEA. Yet, US commercial buildings depreciation has not been comprehensively studied since the highly influential work of Hulten and Wykoff almost 40 years ago. This paper's major contributions include: (i) More flexible and precise estimation of the net depreciation value/age profile, allowing much finer characterization of the building life cycle; (ii) Explicit quantification of the land value component of commercial property value, enabling net depreciation to be quantified as a fraction of remaining structure value; (iii) Inclusion of capital improvement expenditures, allowing estimates of "gross depreciation" (total capital consumption); and (iv) Implications of the paper's findings to and for the national accounts.

JEL Codes: E01, R33 and H25

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1. INTRODUCTION AND DEFINITIONS

Commercial property, including private multi-family rental housing (apartments), is a huge asset class in the United States.[1] As of 2013 the Bureau of Economic Analysis (BEA) National Balance Sheet listed over $16 trillion net worth of nonresidential structures valued at current cost, over 30 percent of the

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*Correspondence to: David Geltner, MIT Department of Urban Studies & Planning; 77 Massachusetts Ave.; Massachusetts Institute of Technology; Cambridge, MA 02139, USA (dgeltner@mit.edu).

[1]While the present study focuses primarily on income-producing (investment) property, much so-called "corporate real estate" (owner-occupied commercial property) is physically and operationally very similar to income property, such that it is probably reasonable to believe that the structure depreciation characteristics are similar. In fact, approximately 9% of our RCA transaction price sample on which our net depreciation analysis is based, consists of owner-occupied commercial properties.

value of all the produced assets on the National Balance Sheet.[2] Commercial buildings annual depreciation is over $300 billion in the National Income & Product Accounts. In spite of this large importance, the nature and magnitude of the capital consumption of US commercial structures has not been much studied. The most influential work was done almost 40 years ago, based on a Treasury Department survey of property owners taken in 1972. That study ignored capital improvement expenditures and apartment buildings.[3]

Commercial building depreciation enters into the national accounts in three major ways. First, depreciation enters the income and product accounts directly as capital consumption, a negative item differentiating Net Domestic Product from Gross Domestic Product. Second, depreciation enters the National Balance Sheets indirectly through the Perpetual Inventory Method (PIM), in which a starting quantity of fixed assets is reduced by depreciation each year. Third, as the National Balance Sheet is completed by the addition of land value accounts, depreciation can be a useful input for the derivation of land price indices useful for updating such accounts, based on commercial property transaction price indices.

In the present paper we first update, improve and extend the previous empirical analyses of commercial property depreciation in the United States. Then we provide some discussion of the implications of our findings for the national accounts. We are able to study a combined database of over 120,000 transactions of commercial buildings and development sites, and over 17,000 property records of capital improvement expenditures, spanning 2001–14. This is over ten times larger than any previous study of commercial property capital consumption. The paper makes four major contributions to the previous published literature include. First, we are able to conduct a more flexible and precise estimation of the net depreciation value/age profile, allowing much finer characterization of the building life cycle. Second, we present an explicit quantification of the land value component of commercial property value. An interesting contribution in its own right, this also enables our net depreciation findings to be quantified as a fraction of remaining structure value (not just whole property asset value including land). Third, this is the first paper to include findings on the magnitude of capital improvement expenditures. This allows estimates of "gross depreciation" (total capital consumption), which includes the cost of capital improvements as well as "net depreciation" (which is the loss in real value as a function of structure age even after and including capital improvements). Finally, we discuss the implications of our findings for the national accounts, including BEA quantification of capital consumption and commercial structure fixed asset value in the National Balance Sheets.

The remainder of the paper is organized into eight sections. We begin with a threshold discussion of conceptual definitions, followed in Section 3 by a literature review and Section 4's description of the data. Sections 5 and 6 present our net depreciation and capital expenditure findings, in that order. Section 7 combines the

[2]Bureau of Economic Analysis (2015).
[3]Hulten and Wykoff (1981a,1981b)

two previous findings to present our overall capital consumption findings. Section 8 discusses implications for the national accounts. Section 9 concludes.

2. Definitions

The terms "capital consumption" and "depreciation" are often used interchangeably, but in the present context we must elaborate on the meaning of depreciation. This paper bridges two sub-fields of economics, seeking to bring knowledge from real estate and urban economics to bear on a problem of economic statistics in the national accounts.[4] In the case of building structures, capital consumption includes two separable components: capital improvement expenditures ("capex") and "net depreciation." The sum of these two components is what we will term, "gross depreciation." In the national accounts literature, the term "depreciation" typically refers to "gross depreciation" and it is effectively synonymous with "capital consumption." In the real estate and investments literature the term "depreciation" typically refers to "net depreciation."

Net depreciation refers to the loss in property market value attributable to the usage and aging of the structure, even after and in spite of the expenditures on capital improvements and renovations (capex). Depreciation is an essentially cross-sectional concept, comparing prices as of the same point in time of otherwise identical assets that differ by the age of the structure.

Net depreciation arises from physical, functional, and economic (or "external") obsolescence. In economic statistics, the term "obsolescence" is not always applied to physical obsolescence, which may be simply referred to as "wear and tear". Functional obsolescence refers to the loss of functionality as preferences and technology change, rendering even buildings that are fine physically less suitable or desirable for potential occupants or users. Economic or external obsolescence refers to a building becoming suboptimal for the site on which it is located, even though the structure might still be physically and functionally fine. Economic obsolescence reflects change in the highest and best use (HBU) of the site. Economic obsolescence can lead ultimately to the profitable demolition of the existing building in order to redevelop or re-purpose the site. While physical and functional obsolescence are reflected in (or reflect) loss in the productive efficiency of the asset (such as its net rental generation ability), this is not necessarily the case with economic obsolescence. The increment in profitability associated with a new HBU for the site could be sufficiently large to warrant the demolition of even a profitable and successful structure.[5] In fact, all three sources of depreciation are properly charged against the value of the existing structure, not against the value of the land site.[6]

[4]Commercial property depreciation is also of important interest to the investments industry (see Bokhari and Geltner, 2016) and for income tax policy (see PricewaterhouseCoopers, 2016). However, the present paper focuses on the fundamental economic and national accounts indications.

[5]For example, the Empire State Building was built on the site of the prestigious Waldorf Astoria Hotel, which was less than 40 years old at the time and doing fine.

[6]When the economically optimal thing to do with a building is to demolish it, then the building has no economic value as such. It makes sense for any increase in property asset value due to a changing HBU to be reflected entirely in the land value component of the property value prior to the demolition of the pre-existing structure.

Property owners spend money on the maintenance and upkeep of their buildings, typically as a matter of routine necessity. Without such capex property values would fall farther, faster, than what we observe empirically in net depreciation. Capital improvements can partially offset all three sources of net depreciation, especially physical wear and tear. When we compare the values of properties with older versus newer buildings, the older buildings have had more cumulative capex spent on them, and these costs are part of the cumulative capital consumption. This is why we must add capex to net depreciation to arrive at total capital consumption.

3. Previous Literature

While depreciation in single-family owner-occupied (SFOO) housing has been relatively well studied in the U.S. (see for example Malpezzi *et al*., 1987; Sirmans *et al*., 2006), depreciation in commercial properties has been only very little and occasionally studied. Yet SFOO housing is quite different from commercial property, both structurally and in terms of locations and the economic role and drivers of decision making affecting development, operation and demolition (retirement of the structure). In general, there would be little theoretical justification for presuming that depreciation in commercial structures should necessarily be very similar to that in SFOO housing structures. Commercial property depreciation has been recently studied in some other countries, where the most extensive studies relevant for economic statistics indicate much higher rates of depreciation than have been assumed in the U.S. national accounts.[7]

The principal and most influential previous study of commercial structure depreciation in the U.S. is that of Hulten and Wykoff (1981a,1981b,1996), hereafter, "HW". The data that HW used to arrive at their conclusions about commercial building structure depreciation consisted of 8066 observations of about 22 types of nonresidential buildings, from a survey conducted by the U.S. Treasury's Office of Industrial Economics in 1972. This was not directly a transaction price observation dataset, and it did not include any information about capex on the properties, nor did it include apartment properties. The HW data was a survey in which building owners were asked when their buildings were built, when they acquired the building, and the price they paid exclusive of the land. It is not clear how the survey respondents estimated the structure values of their buildings, in effect, how the land value component was estimated and subtracted from the purchase price of the property asset.

HW (1981a) reported depreciation rates for office, warehouse, and retail structures averaging 2.47, 2.73, and 2.02 percent respectively. These are the constant geometric rates per year of age that best fit their estimated value/age profiles which were initially estimated using a more flexible Box-Cox formulation. HW characterize their overall findings as suggesting a range of 1.5 percent to 3.5 percent for the constant geometric depreciation rate of commercial structures. The U.S. Bureau of Economic Analysis (BEA) has been applying a constant geometric rate near to 2.5 percent for many types of commercial structures.

[7]See Eurostat-OECD (2015a).

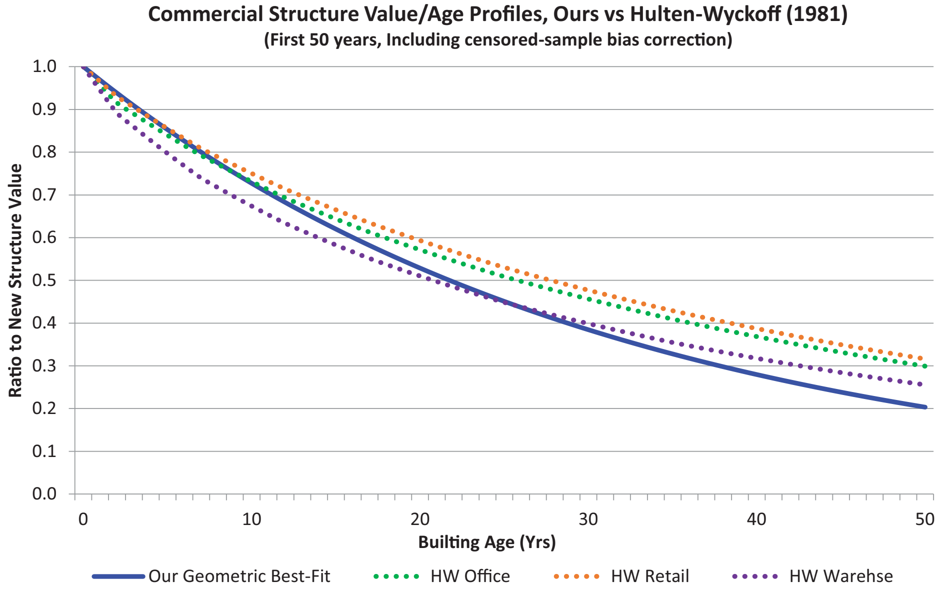

Figure 1. Commercial Value/Age Profiles: Ours vs Hulten-Wykoff [Colour figure can be viewed at wileyonlinelibrary.com]

HW argued that their value-age profile findings are well approximated by constant-rate geometric functions. However, their Box-Cox results imply depreciation rates that are much more accelerated during the early years of building life. The HW value/age profiles based on their more flexible Box-Cox specification indicate building values declining to near zero at ages somewhat in excess of 100 years. Figure 1 compares the HW Box-Cox estimate of commercial building value/age profiles with a geometric curve fit to our estimated structure value/age profile that we will present in Section 5, over the first 50 years of structure life, the age range covered by most of the data. The HW estimates based on 1972 data are effectively not very different from ours, which suggests that structure value/age profiles are likely pretty stable over time.[8]

After HW, there was no major new empirical study of commercial property depreciation in the U.S. until a 2000 study by Deloitte-Touche sponsored by a consortium of commercial property industry associations (see Sanders and Weiss, 2000). The Deloitte-Touche study (hereafter "DT"), which included apartment properties, analyzed both the value/age profile and a rent/age profile (akin to the efficiency profile in economic statistics terminology), although economic depreciation is conceptually defined on the former not the latter.

The DT study was based on a sample of acquisitions of properties by REITs.[9] Separate regressions were run on office, industrial, retail and apartment properties with sample sizes of 832, 674, 917 and 721 acquisitions, respectively.

[8]Statistics Canada (Baldwin *et al.*, 2015) also reports stable depreciation behavior over historical time.

[9]Real Estate Investment Trusts, a type of firm that is publicly-traded on the stock exchange that is essentially a pure play in commercial property investment.

The REIT data reported land and structure values separately for each acquisition, so the study was able to use structure values directly. However, as is always the case with such data, it is never clear exactly how, or how accurately, the breakout of the property asset prices between structure and land components was done in the data, since the traded good in the property market is always the combined whole property asset. DT regressed the log of the presumed structure value per square foot onto the several property and location characteristic variables, including the age of the structure at the time of the acquisition. The results indicated net depreciation rates of 3.46, 2.10, 4.48 and 3.95 percent of structure value per year of age respectively for office, industrial, retail and apartment properties, in other words, slightly higher than the rates found by HW. This compares to 3.1 percent and 3.9 percent average net depreciation rates that we find for commercial and apartment properties respectively, for the first 50 years (see Section 5).

The way DT dealt with the issue of capex was to analyze the value/age profile only for acquisitions of properties whose structures were less than 20 years old at the time of the acquisition, since DT did not have capex data. The idea was that in the first 20 years relatively little major renovations are undertaken. However, their analysis revealed that even properties younger than 20 years of age sometimes underwent major renovation and scale-expanding projects.[10] Perhaps more importantly, DT had no way of measuring or controlling within their property sample for the magnitude of routine capital improvement expenditures that occur in virtually all properties practically every year even in younger properties (the type of data that we do have for our present study).

The 20-year age limit in the DT study would have affected the nature of the value/age profile shape that they found. Constant-rate geometric depreciation is likely to be a better fit for a sample that is limited to only pretty young buildings. If the true, more complete value/age profile is actually more convex (more accelerated than constant-rate geometric) during early years (as suggested by HW and as we find in our study), then the first 20-year age range studied by DT would exhibit faster depreciation rates than would be exhibited by older properties, and this could explain why they find slightly higher depreciation rates than HW.

Finally, it should be noted that the goodness of fit of the DT regressions was not very impressive, with adjusted R-squares ranging from 0.19 (for office) to 0.43 (retail). This suggests that, although DT were correct in principle in attempting to control for property characteristics, they only succeeded marginally in doing so in practice. Many of their regressor variables had statistically insignificant t-statistics, and their lack of property or transaction-specific hedonic characteristics blunted the effectiveness of their hedonic model (shortcomings which our study addresses).

After the DT study, the next major empirical study of investment property depreciation in the U.S. was by Fisher *et al.* (2005), which examined only apartment properties in the National Council of Real Estate Investment Fiduciaries (NCREIF) database (also one of the sources of data for the present paper). The

[10]This was particularly true for retail properties where between 12% and 29% of properties 20 years old or younger experienced major renovations. For office properties the proportion was nearly 10%.

Fisher study was based on 1,516 apartment property acquisitions by NCREIF members spanning 1983–2004. The structures ranged in age from new to 83 years old. NCREIF apartments tend to be relatively large, upscale properties, possibly not completely representative of the broad cross-section of U.S. apartment properties.

The Fisher *et al*. study produced an estimated geometric depreciation rate for NCREIF apartments of 2.7 percent per year of age, as a percent of total property value including land. To address the fact that land does not depreciate, Fisher *et al*. used the 59 (of the total 1,516) acquisitions in their dataset for which a land and structure value decomposition was given. For these the land value fraction averaged 17 percent of the total property value. (It is likely that these were newly constructed development projects, as the average land value fraction would be expected to be greater than 17 percent for older properties.) Applying this 17 percent fraction to the 2.7 percent total property depreciation rate, the authors suggested that the implied rate of structure depreciation was more like: 3.25 percent = 2.70 percent/(1 – 0.17). Of course, this would understate the structure depreciation rate if the average land value fraction were in fact greater, as would be the case if the 17 percent figure really applied mostly just to new buildings. The Fisher study's result is a net depreciation rate, as no adjustment is made for capex, which was not included in the study. Their depreciation rate findings compare to ours for apartment properties of 2.4 percent of property value and 3.9 percent of structure value.

Another recent study that is relevant to the present paper is the Eurostat-OECD "Survey of National Practices in Estimating Net Stocks of Structures" (Eurostat-OECD, 2015b). This study surveyed 32 OECD member countries regarding their current practices in accounting for commercial property structure depreciation in the official national accounts. The survey revealed a considerable range of practices and assumptions. Particularly relevant for the present paper, the Eurostat-OECD Survey revealed that depreciation rate assumptions employed in the U.S. national accounts appear to be effectively substantially lower than those employed in many (though not all) other countries. Comparisons are most direct with countries that, like the U.S., apply geometric depreciation. Among these, Canada and Japan are perhaps of particular interest, because these are large, sophisticated national statistical agencies that have conducted recent surveys. Both Canada and Japan employ substantially higher (faster) gross depreciation rates than what is effectively applied in the U.S. national accounts. The Canadian and Japanese rates are much more similar to what is implied by the findings of the present study. However, the present study is able to use a much larger property transaction sample.[11]

A recently published article on U.S. commercial property depreciation has been undertaken by the present authors, based on a part of the same database used in the present paper. Bokhari and Geltner (2016), hereafter, "BG", studied

[11]The average geometric gross depreciation rates employed in the national accounts for non-residential structures are 5.9%/year in Japan (for non-wooden structures), and 6.7% in Canada (for office buildings). See Eurostat-OECD (2015b), and Baldwin *et al*. (2015).

net depreciation from an investments perspective, that is, focusing on the whole property asset including land, based on the same 120,708 observations transaction price sample from Real Capital Analytics (RCA) as we use in the current study, well over ten times the sample size of any previous study. BG applied a log-quadratic specification that is less flexible than what is employed in the present paper, did not include capital improvements, and did not consider how the structure component of the property value differs from the whole asset value including land. BG confirmed the robustness of their net depreciation value/age profile through the use of a panel regression to control for omitted variable bias. They corrected for survival bias using the same Kaplan-Meier survival probability curve as employed in the current paper to implement the traditional HW correction technique. The hedonic price model used in BG is essentially the same as that used in the present study, only with less flexibility for the value/age profile.

Unlike the present study which lumps the three major types of nonresidential commercial properties together (office, retail, and warehouse), BG examined differences in depreciation across those sectors. They found only minor differences, with the exception of industrial properties, which counter-intuitively exhibited slower depreciation. There seems little justification for such a difference in industrial property, so this finding may exhibit some sort of omitted variable bias (and is one reason for grouping all nonresidential commercial properties together in the present study).

The BG study focused on urban economic fundamentals, showing that property asset-level depreciation is slower, but may correspond to a shorter average building lifetime, in cities that have higher land values, particularly due to physically constrained supply of buildable land (as caused by water bodies, mountains, or other physical constraints). The land value component causes depreciation rates as a fraction of property value (including land) to be greater in properties with younger buildings, because the land which does not depreciate is a smaller fraction of the property asset value. BG also found that investment property pricing, as evidenced by transaction price initial income yield rates, strongly reflects the differentials in characteristic property asset depreciation rates across cities.

BG studied separately how price and capitalization rates (initial income yields) are influenced by the age of the building on the property. This revealed that the vast majority of overall price depreciation reflects depreciation in the real net operating income the property can generate (production efficiency), rather than so-called “cap rate creep” (increase in the yield rate, or reduction in the price/income multiple, with building age). In other words, initial yields are not much affected by building age.

The present paper is in part a distillation of the findings and analysis of a subsequent study undertaken by the MIT Center for Real Estate (Geltner and Bokhari, 2015), hereafter, “GB”. This study extended and enhanced BG by including capex to quantify gross depreciation, by explicitly determining land value fractions to enable quantification of structure value depreciation rates, and by exploring a more flexible and nuanced net depreciation value/age profile. The present paper also explores some implications for the U.S. national accounts.

TABLE 1
Summary Statistics, RCA Main Transaction Sample

Variable	Mean	Std Dev	Count
Age	32	26	107,805
Age - Apartment	40	28	27,374
Age - Commercial	29	25	80,431
Apartment	0.25	0.44	107,805
Industrial	0.26	0.44	107,805
Office	0.23	0.42	107,805
Retail	0.25	0.43	107,805
Price ($)	$15,200,000	$47,600,000	107,805
Square Feet	116,694	178,773	107,805
Units - Apartment	139	159	27,374
CBD	0.15	0.36	107,805
Major Markets	0.41	0.49	107,805
Seller Type - User/Other	0.04	0.19	107,805
Seller Type - CBMS Financed	0.00	0.05	107,805
Seller Type - Equity Fund	0.03	0.18	107,805
Seller Type - Institutional	0.11	0.31	107,805
Seller Type - Private	0.69	0.46	107,805
Seller Type - Public	0.05	0.21	107,805
Distressed Flag	0.07	0.25	107,805
CMBS Flag	0.11	0.31	107,805
Excess Land Potential Flag	0.02	0.15	107,805

4. Data Used in the Study

The present paper is based on three major databases: Real Capital Analytics (RCA), Green Street Advisors (GSA) and the National Council of Real Estate Investment Fiduciaries (NCREIF). The RCA database consists of market transaction prices and other information about commercial and apartment property transactions in the U.S. We use the RCA database to estimate the property value/age profile reflecting net depreciation. The RCA data does not have information about capex. RCA also provided two supplementary datasets on development sites, their purchases, and in some cases the eventual sales of the buildings developed on those sites. These data are instrumental in estimating the survival probability curve for buildings and to provide independent estimates of new development land value fractions.

The GSA and NCREIF databases allow analysis of routine capex (as distinct from major renovation projects), based on properties owned by publicly traded REITs (in the case of GSA) and privately-held by large institutional investors (NCREIF).

The RCA database is extensively described in BG, to which the reader is referred.[12] For convenience, Table 1 summarizes the RCA main transaction price sample of properties with existing buildings.

Our NCREIF data consists of 3,927 apartment properties and 11,773 non-residential properties distributed roughly evenly among office, retail and warehouse. Table 2 summarizes the data. Although the NCREIF properties are larger,

[12]Further description and discussion is in GB, Chapter 3 and Appendix B. GB is available at: https://www.dropbox.com/s/alsmsg61xk0lgyb/MITCREforRER_CREcapConsNov2015.pdf?dl=0.

TABLE 2

NCREIF Summary Statistics by Property Type

Variable	Mean	Std Dev
Commercial (11,773 Properties)		
Annualized Capex per dollar of MV	0.0157	0.0170
Annualized Capex per square feet	$2.06	$3.60
Standardized Cap Rate[13]	0.001	0.029
Mean Age	19	15
Proportion Office	0.32	0.46
Retail	0.22	0.41
Industrial	0.47	0.50
Avg Square Feet	283,158	423,089
Apartment (3,927 Properties)		
Annualized Capex per dollar of MV	0.0126	0.0143
Annualized Capex per unit	$1,506	$1,880
Mean Age	15	16
Average No. of Units Per Property	312	259

they are widely distributed among U.S. metropolitan areas, with over 90 percent correlation between our sample frequency and non-farm employment across the 50 states.

Unlike the RCA data, the NCREIF data contains detailed information about the properties while they are held by their owners (which is typically five to 20 years). This includes information on rents and operating expenses, and importantly for our study, it also separately identifies capital improvement expenditures. Unfortunately, NCREIF properties are not representative of properties that undergo major renovation projects, for example, tenant-emptying "gut rehab" or scale expansion or usage-altering projects. Hence, the capex we are able to include reflects only routine capital improvements and upkeep of the type that almost all commercial building owners must undertake on a regular basis (roof replacement, painting, carpeting, new appliances, new HVAC systems, landscaping, tenant custom fit-outs, etc.; however, we exclude leasing-broker commissions even though these are considered "capital expenditures" by financial accounting rules). Thus, our analysis is "conservatively" biased in the sense that the major renovation component of total capital consumption is omitted (this probably corresponds roughly to what the U.S. BEA refers to as "additions & alterations").[14] The distinction between "operating expenses" (which NCREIF reports but we do not include in capex) and routine "capital improvement expenditures" (which we do include) is that the latter is for items that last longer than one year.

The NCREIF properties are also regularly and frequently appraised by professional appraisers, and this value is also reported. Hence, we are able to quantify capex as a fraction of property value (recognizing that this property value is for the

[13]The "standardized cap rate" is the *difference* between the property's cap rate (defined as current annual NOI divided by market value) and the average cap rate in the NCREIF database for properties of the same type and location. It is used as an indicator of the relative quality level of the property.

[14]Our net depreciation value/age profile is based on the RCA transaction data, and that data does reflect the value enhancement of major renovations. Thus, the observed net depreciation is reduced due to major renovations, yet we are not able to reflect the cost of such renovation in the gross depreciation.

whole asset, including land, as the appraisal does not generally separate out land and structure components). This enables us to quantify a capex annual fraction of current property value as a function of structure age. This can be summed with the net depreciation rate derived from the analysis of the property value/age profile to arrive at a gross depreciation rate as a function of building age.

In addition to NCREIF data, we also have data from GSA on capital expenditures for 1,299 REIT-owned apartment properties tracked since 1997. (REITs generally hold their properties for the long term, rarely selling into the property market.) We use the GSA data primarily as a check on the NCREIF data, because there is no overlap between the two samples. We do indeed find that the GSA capex is similar to the NCREIF, except GSA lacks appraised values, so our comparison must be based on expenditures per unit (as a function of the age of the structure). Unfortunately, similar to the NCREIF data, the GSA data also does not allow a comprehensive inclusion of major renovation expenditures, and our comparison of GSA and NCREIF capex only includes routine improvements. However, for the 721 properties in the GSA sample held at least 16 years (up to a maximum of 19 years, since tracking only began in 1997), we observe that the REITs performed major renovations (not included in routine capex) that totaled in value 37 percent of the value of the routine capex over the entire "lifetime" of the holding (up to 19 years). This provides some informal indication of the likely typical magnitude of major renovation which is not included in routine capex, measured relative to the routine capex that is formally included in our study. It seems likely that the omission of major renovation costs places a non-trivial conservative bias on our estimates of gross depreciation.

5. Net Depreciation

As with depreciation studies going back at least to HW, the focus of our net depreciation analysis is what may be termed the value/age profile, based on a regression of values on ages. The term price/age profile is sometimes used, but in a national accounting context the metric of interest for depreciation is not the construction cost price but rather the quantity of structure. (Structure value equals construction cost price times structure quantity, with the latter diminishing with depreciation.) In principle, our analysis essentially compares the expected market prices as of the same point in time across properties with different age buildings, controlling for all differences other than the ages of the structures. In practice, our data consists of arms-length transaction prices and dates, as well as important other information about the properties as of the times of their transactions, such as the size, location, and age of the structures.

We do not have explicit information about capex in the transacted properties, but there is no reason to believe they do not reflect typical capital improvement histories. Therefore, our estimated value/age profile reflects the combination of the following three quantity elements: (i) The original structure quantity as diminished by cumulative gross depreciation, plus; (ii) The quantity of capital improvements added to the original structure over time as diminished by cumulative depreciation of those improvements, plus; (iii) The quantity of land on the site.

We control for differences in prices of construction and of land (the real estate market) by use of time fixed effects (time dummy variables) in the regression model. The value/age profile we estimate empirically thus reflects "net" depreciation in the sense of the cumulative reduction in quantity of structure as improved by (reflecting increases in quantity caused by) capital improvements (and assuming the quantity of land is fixed in any given property).

For example, suppose a property with a 10-year-old building has market value of \$100, and an otherwise identical 11-year-old property has market value of \$97 as of the same time.[15] Now suppose that during the previous year the owner of the 11-year-old building put \$1 of capital improvement into the building, increasing its market value to \$98. (This \$1 of capex would have to some extent mitigated the wear and tear and the functional obsolescence of the building.) Assuming such capex behavior is typical, our estimated value/age profile based on our transaction price data would show 11-year-old properties selling for only 2 percent less than 10-year-old properties, even though the total capital consumption occurring between age 10 and 11 is 3 percent of the property value.[16] Suppose furthermore that if either of these two building sites were vacant they would sell for \$30, the land value.[17] Then as a fraction of the structure value we would have net depreciation of 2/(100-30) = 2.9 percent and gross depreciation of 3/(100-30) = 4.3 percent.

This example illustrates why we need to separately estimate the cost of capital improvements and add that cost to the net depreciation that we observe in our empirically estimated value/age profile, in order to quantify total capital consumption. Furthermore, in order to express depreciation as a fraction of structure value excluding the land value component of the property value, we must subtract from the empirically observable asset value/age profile the average land value as a fraction of newly-built property value. We will address the addition of capex in Sections 5 and 6, but we will address the land value question here in Section 5.

Our specification for estimating the value/age profile follows in the tradition of hedonic price modeling that is well developed in urban economics. Though the transaction sample spans the period 2001–14, the analysis is essentially cross-sectional, as the model controls for longitudinal changes in market pricing by means of time-period fixed effects in the regressors. The model specification is as follows:

$$Log\ EP = \alpha + X\beta + A\gamma + T\delta + \varepsilon \qquad (1)$$

where for the left-hand-side (dependent variable): "*Log*" refers to the natural logarithm; and *EP* is the "expected price" per the HW bias correction, that is, the

[15]The "otherwise" adverb in the "otherwise identical" phrase is important. The older building presumably has another year's worth of physical wear and tear, as well as a year's worth of additional functional obsolescence. It's even possible that it has another year's worth of evolution in the HBU of its site. Referring back to Section 2's discussion of definitions, these three sources of depreciation are why the property with the older building is worth 3% less than that with the younger building.

[16]We invoke the common assumption that the value added by capital improvements equals their cost.

[17]By the Residual Theory of Land Value, this \$30 land value would derive from the possibility to build a new building, to the current HBU of the site as if vacant, that would be worth, say, \$150 with a construction cost of \$120 (including sufficient developer profit). Land value is then the residual: \$150 – \$120 = \$30.

actual price multiplied times the survival probability at the age of the structure at the time of the transaction.[18]

On the right hand side of the model are three sets of variables described by matrices *X*, *A* and *T*. "*X*" includes variables that effect prices cross-sectionally, such as those listed in Table 1 in Section 4 (property and transaction characteristics), as well as location characteristics such as MSA (metropolitan area) indicators. The sale year of the property is included in *T* by a set of year dummy-variables to control for longitudinal changes in the property asset market (reflecting changes in land prices and construction prices). And finally, in *A* are included a set of building age dummies from age 1 to 149.[19] These individual age dummy variables and their coefficients are the prime focus of the analysis. The age-dummy coefficients, relative to that of a new property (with a 0-year-old building), trace out our fundamental estimate of the property asset value/age profile. We apply this hedonic model separately to nonresidential and apartment buildings.

The complete regression includes almost 300 parameter estimates (including 149 age-dummies, 98 metro market and geographical location dummies, and 13 year dummies, among others). The complete results are presented in GB, but cannot be presented here given space limitations. Table 3 presents the overall regression diagnostics and the parameter estimation results for the major hedonic variables characterizing the property and the transaction. The statistical results are very robust from an econometric perspective, with extremely high t-statistics on all the age-dummy variables up to well past the 100-year age of the average structure lifetime. The regressions fit the data quite well, much better than results reported in the previous literature, with R-square values over 71 percent (commercial) and 81 percent (apartments).[20] The parameter estimates for the hedonic variables are all of the expected sign and of statistical significance.[21]

[18]This is essentially the same survival bias correction as pioneered by HW, except that we are applying it to the property values instead of structure values. This could result in an over-correction, because even when a structure has zero value the property has some value, reflecting the land value. However, this is the best we can do without imposing any further assumptions on the land value fraction of each building to convert its property value to structure value. As we will see below, other evidence suggests that over-correction is not a serious problem, particularly during the first 50 years of building age, where we will focus most of our attention onto our empirical analysis results. See BG and GB for further details and discussion. We estimate the survival probability curve using the traditional Kaplan-Meier technique with multiple imputation for missing age-at-demolition observations, as described in BG and GB.

[19]The filtered data includes building ages up to 150, but for econometric reasons one dummy-variable must be suppressed.

[20]Additional sensitivity and robustness analyses are presented in BG and GB, including tests for omitted variables bias, for stationarity during different property market regimes, and for different sizes (values) of property.

[21]The variables "LnSqft" and "LnUnits" reflect the size of the building, for Commercial and Apartments respectively. The "CBD" variable indicates that the location is in the Central Business District (downtown) of the metropolitan area. The "Distress Flag" indicates that the property was in financial distress at the time of sale (as flagged by the data provider). "CMBS Financed" indicates that the buyer used a Commercial Mortgage Backed Security loan to finance the purchase. "Excess Land" indicates that the property had buildable vacant land as well as the aged built structure on the site. The type of owner entity selling the property can affect the selling price. The suppressed property type is retail, so there are dummy variables for office and industrial (warehouse) properties. Apartment properties are modeled in a separate regression.

TABLE 3

Net Depreciation Regression Results

Net Depreciation Regression Results:

Dependent Variable: Ln Expected Price.

	(1)	(2)
Variables	Commercial	Apartment
LnSqft	0.6779105	0.4588301
	(0.003)	(0.014)
CBD	0.4373962	0.2875668
	(0.009)	(0.015)
Distress Flag	−0.6046830	−0.4554214
	(0.011)	(0.016)
CMBS Financed	0.2816792	0.1249648
	(0.006)	(0.009)
Excess Land Potential Flag	0.1855340	0.2889286
	(0.014)	(0.039)
Seller Type - CMBS Financed	0.0620878	0.0575796
	(0.038)	(0.075)
Seller Type - Equity Fund	0.4205555	0.1379578
	(0.014)	(0.023)
Seller Type - Institutional	0.2525270	0.1974685
	(0.009)	(0.017)
Seller Type - Private	0.0931112	0.0972529
	(0.006)	(0.013)
Seller Type - Public	0.1709409	0.2920396
	(0.011)	(0.018)
Office	−0.0074936	
	(0.006)	
Industrial	−0.6041451	
	(0.006)	
LnUnits		0.4008403
		(0.014)
Age Year Dummies	yes	yes
MSA Dummies	yes	yes
Year Dummies	yes	yes
Constant	5.7355828	6.1136609
	(0.080)	(0.142)
Observations	80,431	27,374
R-squared	0.713	0.814

Figure 2 shows the full non-parametric (age-dummy variables based) property asset value/age profile estimation results for both nonresidential ("commercial") and apartment properties. The chart also shows the five and ninety-five percentile confidence ranges (indicated by the thin dotted lines on either side of the main line).[22] Blue is the nonresidential commercial property, and red is the apartment property value/age profile estimate. Clearly, once we get much beyond 100 years the transaction data becomes very sparse and the coefficient estimates are no longer reliable. But 100 years is in fact the life expectancy revealed in an analysis of building structure survival probability.

[22]In other words, the 90% confidence interval is between the two dotted lines (based on Huber-White heteroscedasticity corrected standard errors).

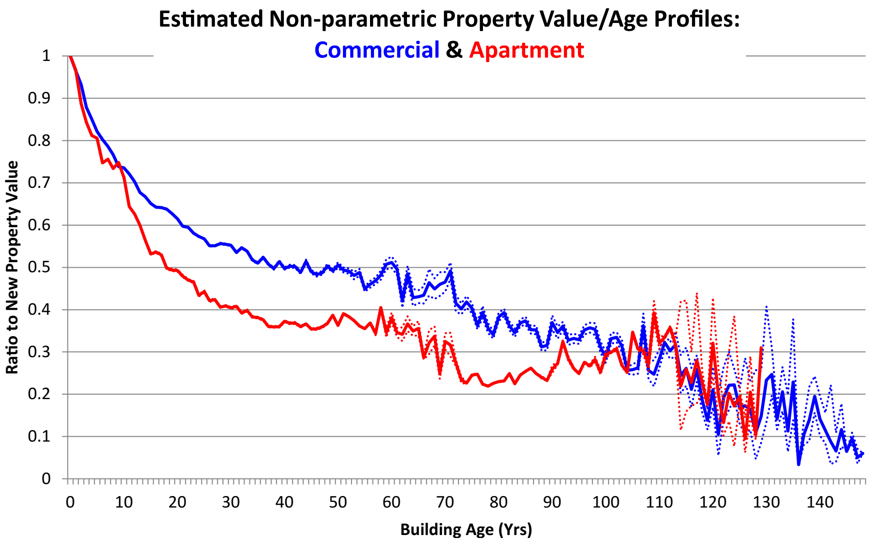

Figure 2. Non-Parametric Property Value/Age Profiles [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 3 depicts the results of the Kaplan-Meier (1958) survival analysis of the entire RCA sample of 120,708 transactions including both stabilized properties and development sites.[23] The half-life or median structure survival age is 105 years, and the mean or expected lifetime of buildings happens to be exactly 100 years. In Figure 2, we see that through about a century of age, the non-parametric value/age profile looks reasonable and reliable.[24]

With the above findings in mind, look at Figure 4, which recasts Figure 2's property value/age profiles for a canonical 100-year canonical property life cycle as suggested by the Survival Curve life expectancy, and without the clutter of the confidence bounds.

Figure 4 highlights an interesting feature of this value/age profile, which has not been able to be seen in previous studies of property depreciation. It seems that, in the U.S., income-producing buildings exhibit a somewhat anthropomorphic

[23]The survival analysis is the same as what is reported and described in BG and GB, to which the reader is referred for more depth of description.

[24]There is an interesting relatively "noisy" region in the 60–75 year age region. In our sample this corresponds to structures built during the historical period of the Great Depression and World War II, when few commercial structures were built, and therefore we have relatively sparse data for those buildings during the 2001–14 sample period of our transactions data. But the relatively precise estimates on either side of that age range provide a strong indication of what the profile is (or would be) in that range. There also appears a slight and vague tendency of the apartment value/age profile to actually rise after approximately age 80. This may reflect a preponderance of high quality structures built before the Great Depression (many in New York and other large old central cities) in the transaction sample in that age range (for example, an 80-year-old structure in 2010 was built in 1930). In fact, in our transaction sample, of 3933 apartment buildings over 80 years of age at the time of sale, 2618 (66%) are in New York City. (This excludes sales of development sites, buildings to be demolished, and thus may reflect higher than average original quality structures.)

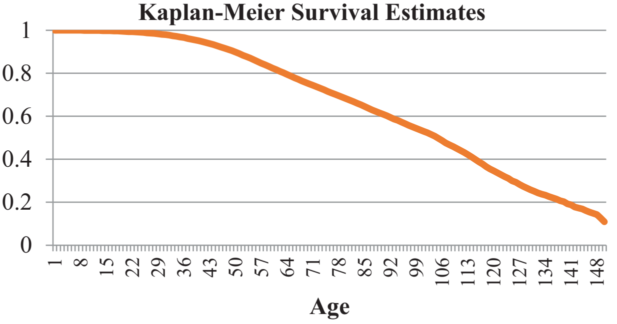

Figure 3. Kaplan-Meier Survival Curve [Colour figure can be viewed at wileyonlinelibrary.com]

value/age profile, with three stages of the lifetime. During the building's Youth phase (approximately 0–30 years), the property value declines steeply, as the structure loses its luster as a "new building". If it is in an upscale market, it will fall during this period from "Class A" to "Class B" status, with major implications for the types of tenants and the level of rents and occupancy that can be attained. But once in Middle Age (roughly 30–65 years), there is relatively little differentiation of value by age. A 40-year-old building is not perceived much differently from a 60-year-old building as far as the age of the structure is concerned ("Class B is Class B"). Of course, Middle Age buildings may absorb more capex in order to keep up their status, as we shall see in Section 6. Finally, in Old Age (over about 65 years), the building value begins to decline pretty rapidly again toward the property being reduced to essentially just land value. As the building approaches its life-expectancy it may become less worthwhile to spend money to try to keep it up ("Class C" status). The final stage may tend to drag out, as the property value/age profile seems to vacillate for several decades of age starting by around 75 to 80 years of age.

This highly flexible, non-parametric property asset value/age profile is not only interesting in its own right, but it also has a use in our estimation of the corresponding implied structure value/age profile. To derive the structure value/age profile that we need for our analysis of net depreciation, we must subtract an appropriate land value fraction from the above-described property asset value/age profile. While the property asset value/age profile is estimated directly from market price empirical data, estimating structure values (that is, property value net of land value) presents a slightly different challenge. Prior studies have sought, and contented themselves with, data that purports to directly represent structure values net of land. But such data is scarce and may be unreliable. It is not clear how such structure value data is obtained or estimated. It is particularly difficult to directly estimate commercial property land and structure value components for properties with existing, aged buildings, as opposed to for new development projects where the structure opportunity cost can be more readily observed as the construction cost of the recently-completed building. In the present study we "triangulate," using a combination of empirical indications and theoretical reasoning, resolving the land value fraction that is appropriate to subtract from our property asset value/age profile estimated in Figure 2.

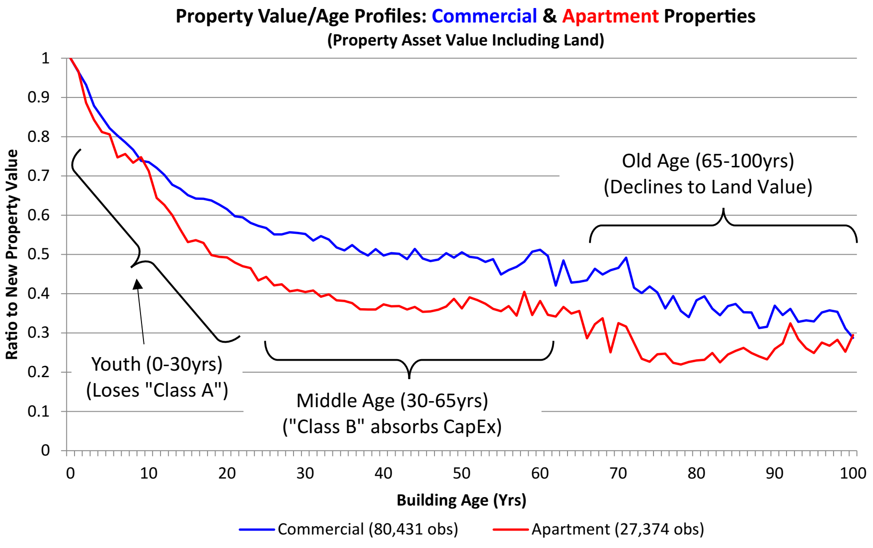

Figure 4. Value/Age Profiles, Three Stages of Life [Colour figure can be viewed at wileyonlinelibrary.com]

From the theoretical perspective, the idea is to apply to our property value/age profile the Residual Theory of Land Value (RTLV). The RTLV is a mainstay of traditional urban economics and real estate land use and valuation theory. It states that the land value of a site, as if vacant, equals the newly developed value of the current highest and best use (HBU) of the site unencumbered by a pre-existing structure, minus the development cost (including normal necessary profit to the developer but of course excluding any land cost). This land value can be directly observed only at the time when a property is being developed or redeveloped (construction of a new building). Unfortunately, the vast majority of the trading of property assets (effectively, the observation of "used asset" prices, the type of empirical data from which our net depreciation value/age profile must be estimated) consists of properties with existing, viable structures, not new development sites. The rigorous economic foundation of the RTLV, based on the principle of opportunity cost and the inelasticity of land supply, does not strictly apply for properties with viable existing structures.[25] But a reasonable and widely

[25]Opportunity cost principles attempt to base valuation on current market values, or where there is no market, then on marginal production cost. But there is no market for the existing structure by itself separate from the land/site; and the marginal production cost of the existing structure is sunk. Therefore, whether from the perspective of market value or production cost there is not a rigorous, unambiguous opportunity cost based definition of the value of an existing (used) structure separate from land. Instead, consistent with the PIM in the national accounts, we seek an accounting convention which "backs out" the structure value from the whole property asset value and a reasonable definition of land value as if the site were vacant, which is the traditional accounting and appraisal definition of land value. (Recall our earlier numerical example of the $30 land value derived from the current HBU value of $150 minus construction cost and developer profit of $120.)

accepted accounting and valuation convention applies the essence of the RTLV to properties with existing buildings anyway, in an approach referred to as the "Indirect Method" of land valuation.[26] The Indirect Method is consistent with the PIM computation of the depreciated structure quantity in the national accounts, provided the accumulated depreciation includes the effect of economic (external) obsolescence (as well as wear and tear and functional obsolescence). The Indirect Method derives the value of the land component of a built property (a site already containing a structure) as the current property market value of the whole asset (land and structure) minus the PIM-based valuation of the depreciated structure (that is, the structure's current replacement cost new minus the accumulated depreciation as a quantity proportion of the new structure). Here, we apply the reverse of this procedure, to back out the depreciated structure value by subtracting the land value from the property value.

With the above theoretical framework in mind, we obtain two empirical indications about the magnitude of the appropriate land value to apply to our property value/age profile. The first indication comes from the property value/age profile itself, as presented in Figure 2. This is possible because, unlike previous studies, our estimated property value/age profile spans the entire property building life cycle, that is, through the average life-expectancy of the typical structure (100 years, based on the survival analysis summarized in Figure 3). Note in particular that the property value/age profiles in Figure 2 seem to more or less bottom out in the range beyond approximately 80 years of age. Ignoring the noisy and unreliable results much beyond age 100, this flattening out of the profile would seem to be pretty consistent with the notion of the structure value becoming minimal, essentially worthless, as the age approaches the building life-expectancy of 100 years indicated by the survival probability analysis. Indeed, we would expect the property value/age profile to essentially flatten out at that point because once the structure becomes worthless there is no further depreciation, and therefore the property value/age profile would stop declining as it then represents only land value (which does not depreciate), and this should occur at the average age at which buildings are demolished because at that point the structure is worthless. This would suggest a land value, as a fraction of newly-built property value, equal to the level of the property value/age profile at this terminal age range where the profile flattens out. As is apparent in Figure 2, this implied land value is just above 30 percent for commercial and 20 percent for apartment properties, as a fraction of the value of a newly-built property.

We also have another source of empirical indication about the appropriate land value, in our RCA data on development site transactions and the subsequent sales of the newly built properties on those sites. In addition to the 107,805 observations of sales of properties with existing structures, our RCA sample includes 12,903 transactions of development sites (used in our survival analysis), of which 830 observations have data on the subsequent resale of the newly developed property with its new building sold within 36 months of the site acquisition. For these 830 sites we can directly compare the acquisition (land) price with the value of the newly completed built property asset (land plus structure). This allows the direct

[26]See Eurostat-OECD (2015a), Chapter 6.

computation of the new development land value fraction (NDLVF) for this sample of 830 transactions. The average NDLVF for the 139 apartment developments is 18 percent and for the 691 commercial projects is 32 percent.[27] These fractions are essentially consistent with the indications noted above from the bottoming-out age region of the non-parametric property value/age profiles, an age region that is also essentially consistent with the survival analysis life-expectancy age.

Thus, we have from two somewhat separate sources an indication of new development land value fraction in the neighborhood of 30 percent for commercial and 20 percent for apartments, in round terms. This would seem to anchor the land value/age profile at levels of 0.30 (commercial) and 0.20 (apartments) on the vertical scale of Figure 2, at both ends of the 100-year life cycle, the points when new development happens on sites where any pre-existing structure is economically worthless.

In fact, the land value/age profile in the present context is a constant, flat horizontal line, because of the cross-sectional nature of the property value/age profile model. The model's price predictions, and therefore its age dummy-variable coefficients (which trace out the value/age profile) all apply to the same epoch of time, the period 2001–14 when all of the RCA database transactions took place. While 2001–14 may seem like a long time in the property markets, in the context of depreciation estimation it is essentially one epoch. It is a short span of time relative to the length of the overall property life cycle (100 years), and as noted, the hedonic price model controls for price movements in the property asset market during 2001–14 by use of annual time-dummy variables in the right-hand-side regressors of the model. (This controls for changes in land values and construction prices during the sample period.) Depreciation is a gradual, secular process, and the relevant prevailing long-term average aggregate land value fractions would not have changed much overall during 2001–14, controlling for asset market price and construction cost price movements and the other aspects as modeled in the hedonic regression. (These longitudinal price movements are controlled for using our year fixed effects dummies.) In other words, the age-dummy coefficients in the model reflect the prices of properties sold during 2001–14 *relative to* the prices of other-age properties also sold *during 2001–14*. Thus, the model's predicted average property prices all reflect essentially the same average land value fraction across the various age-dummies. As a result, our canonical approach in the present study is to apply a constant land value fraction of 0.3 for commercial and 0.2 for apartments, as a fraction of newly built property value, for purposes of deriving the structure value/age profile implied by our empirically estimated property asset value/age profile. (See the electronic Appendix for further explication of our methodology for deriving our net depreciation results.)

We can now turn to our major findings regarding net depreciation. When we subtract the land value fractions described above from the non-parametric property value/age profiles shown in Figure 4, we arrive at the implied structure value/age profiles indicated in Figures 5 and 6 by the area above the dashed land value

[27]See GB Appendix B for further description of this direct NDLVF analysis. Note also that the apartment NDLVF is similar to the 17% reported by Fisher *et al.* (2005) reviewed in Section 3, based on a sample that would have little to no overlap with the RCA sample.

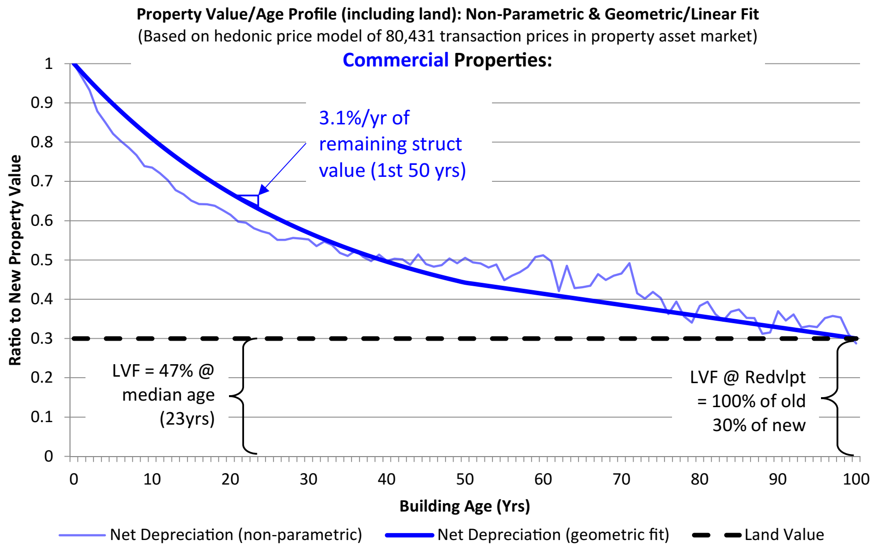

Figure 5. Property & Structure Value/Age Profile, Commercial [Colour figure can be viewed at wileyonlinelibrary.com]

line. These non-parametric structure value/age profiles are the basis for quantifying net depreciation in commercial and apartment property in the U.S. In the case of nonresidential commercial property shown in Figure 5, the non-parametric profile indicates that the structure quantity falls to only about 35 percent of its initial quantity by the age of 30, even though this quantity includes the combination of the original structure plus its subsequent improvements. Of course, this is

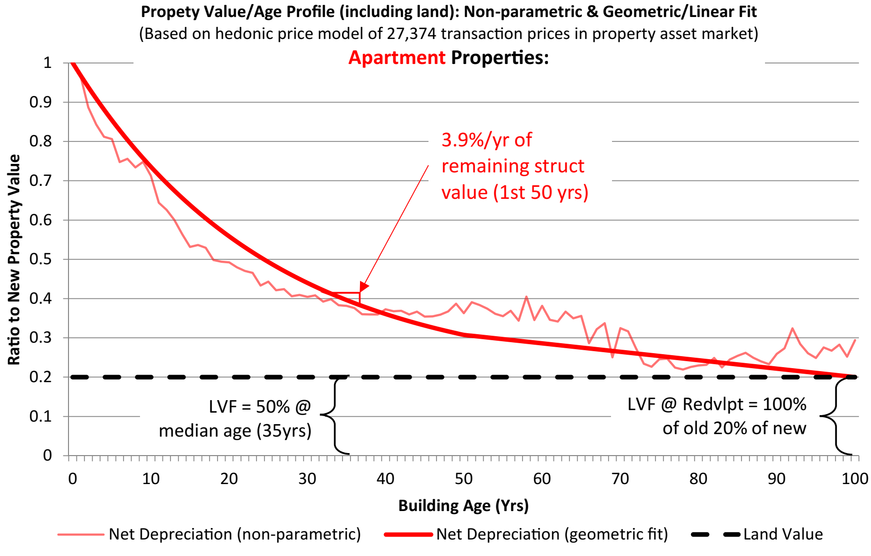

Figure 6. Property & Structure Value/Age Profile, Apartments [Colour figure can be viewed at wileyonlinelibrary.com]

just the structure; the land component of the property asset is fully retaining its quantity, which means, per the Figure, the average property asset is retaining about 55 percent of its initial combined structure-plus-land quantity. Then, during Middle Age, the structure only loses some 10 percent more of its original quantity, to enter Old Age in its mid-60s with still almost a quarter of its original quantity (thanks to some boosting by additional quantity added along the way by capital improvements). After that, the decline is fairly rapid during old age, losing the remainder of the structure quantity on the property over the next (last) 30–40 years of building life.

In the case of apartment structures the story is similar only slightly more accelerated. The structure-plus-improvements falls to only about 25 percent of the original structure quantity by age 30 (including average land value, 40 percent of original combined quantity is retained). But then Middle Age allows better preservation of value, as the structure enters Old Age in its mid-60s with still about 20 percent of its original quantity. The decline is then relatively swift to essentially zero structure quantity (just land) by as early as 75 years.

These non-parametric value/age profiles tell an intuitive and nuanced story. But it can be useful to simplify the essence of this story by fitting more traditional shaped value/age curves. The thicker, smooth, colored (red or blue) curves in Figures 5 & 6 depict more traditional types of asset value/age profiles. They are constructed as two-piece curves with a breakpoint at age 50. For ages 0–50, which characterizes the bulk of our RCA transaction price data, a constant-rate geometric curve is fit to the non-parametric structure value/age profile. Then, from age 51 to 100 a linear (straight-line) function descends to the canonical zero structure value at the 100-year lifetime endpoint. The geometric curve applied over the first 50 years reflects the single depreciation rate that best fits the non-parametric profile and that applies to every age over the entire first 50 years of building age. This best-fit geometric curve is found by regressing the log of the non-parametric structure value/age profile values onto the ages from zero to 50. The best-fit geometric annual net depreciation rates are as indicated in the Figures, 3.1 percent of remaining structure value for nonresidential and 3.9 percent for apartments. The corresponding smooth-curve annual rates for the property asset depreciation (as a fraction of remaining total property asset value) over the first 50 years are 1.7 percent and 2.0 percent for commercial and apartment properties respectively, at the sample median ages for the buildings (23 years for commercial and 35 years for apartments). These median-age property rates reflect a land value fraction of 47 percent for commercial and 50 percent for apartment properties.[28]

[28]The geometric curve is fit to the structure value/age profile, not to the property asset value/age profile. As a result, the structure exhibits a single constant rate of depreciation for the first 50 years of age based on the geometric model, but the property depreciation rate varies with structure age even based on the smoothed geometric profile, as the non-depreciating land value fraction grows as the structure depreciates. For example, for commercial property the rate per year of age declines from 2.2% for a new property (1-year-old structure, 30% LVF), to 1.6% for a property with a 25-year-old structure (48% LVF), to 1.0% for a property with a 50-year-old structure (67% LVF).

6. Capital Improvement Expenditures

We now turn to the second component of total capital consumption, the cost of capital improvement expenditures (capex). We use the disaggregate data on individual properties' historical capital expenditures (described in Section 4) to estimate the magnitude and behavior of capex as a function of the age of the original structure (the horizontal axis in our net depreciation profiles reported in the previous section). In order to not confound our findings with other factors that also affect the amount of capex, for example, the size of the building and the quality of its construction, we employ a hedonic methodology similar to that described previously that controls for differences in characteristics of the property. Here we will summarize the methodology applied to the NCREIF data, which is our primary source of capex information.[29]

There are three major variables of interest in the NCREIF capex data. For both commercial and apartment buildings, we can examine the Annualized Capex per dollar of Market Value of the building.[30] In addition, we can relate capex to the physical dimensions of the building. For commercial buildings, we can look at their Annualized Capex per Square Foot of leasable space. An analogous variable for apartment buildings is the Annualized Capex per apartment unit. We therefore have three hedonic models corresponding to these three variables as the dependent variable on the left-hand-side of the regression model. We can summarize all three of the models together, based on these variables, by the following equation:

$$\text{(2)} \qquad Capex\ \ Measure = \alpha + \beta Age + \gamma AgeSquared + X\delta + \varepsilon$$

where the left-hand side of the model is one of the above-mentioned three variables of interest, labeled here as *Capex Measure*. On the right-hand side, the matrix X represents factors or variables besides building age that affect the capex measure under study. Where applicable, these include the log of square feet, MSA dummies, as well as a standardized cap rate[31] for the property, which is used as an indicator of relative quality level of the building. The Age and Age-Squared variables are the primary variables of interest. Unlike the model for net depreciation, we don't use age dummy indicators for each age since the sample size of the NCREIF data isn't large enough to reliably estimate each age's coefficient. We use a quadratic function of age, and find that the estimates of both Age and Age-Squared are statistically significant in all of the models. This tells us that capex expenditures as a fraction of property value or even per physical unit of property size tends to increase over some range of aging of the property, before possibly

[29]The methodology applied to the GSA data is similar. See GB for more details.

[30]Annualized Capex per dollar of Market Value is based on the average capex and the average market value for each property using all of its data. Since the data is quarterly, this average capex is multiplied by 4 to arrive at the annualized capex. The latter is then divided by the average market value to arrive at the ratio.

[31]The "standardized cap rate" is the *difference* between the property's cap rate (defined as current annual NOI divided by market value) and the average cap rate in the NCREIF database for properties of the same type and location. In general, higher quality, more "expensive" properties sell for lower yields and reflect better quality construction.

TABLE 4
Commercial Capex Regression Results

	(1)	(2)
	Commercial	Commercial
Dependent Variables:	(capex/mv)	(capex/sf)
Variables:		
LnAvgSqft	0.0008237	
	(0.000)	
AvgAge	0.0003172	0.0078664
	(0.000)	(0.005)
AvgAge Squared	−0.0000025	0.0004014
	(0.000)	(0.000)
AvgStdCaprate	−0.0688819	−13.0430248
	(0.005)	(1.023)
Office	0.0075647	2.6985714
	(0.000)	(0.072)
Retail	−0.0022562	1.2281312
	(0.000)	(0.080)
MSA Dummies	yes	yes
Constant	0.0001667	0.0041891
	(0.002)	(0.103)
Observations	11,773	11,773
R-squared	0.107	0.186

declining at a later age (although we must limit our analysis to only the first 50 years). The complete regression results are presented in Tables 4 and 5.

Figure 7 shows the findings for average annual capex as a percent of property asset market value (including land value), as a function of age, for commercial and apartment properties. At the mean building ages, which in the NCREIF sample is 19 years for commercial and 15 for apartments, the commercial capex rate

TABLE 5
Apartment Capex Regression Results

	(1)	(2)
	Apartment	Apartment
Dependent Variables:	(capex/mv)	(capex/unit)
Variables:		
AvgAge	0.0008114	54.1919373
	(0.000)	(4.309)
AvgAge Squared	−0.0000066	−0.3302656
	(0.000)	(0.054)
MSA Dummies	yes	yes
Constant	0.0050905	364.9669387
	(0.001)	(79.707)
Observations	3,927	3,927
R-squared	0.193	0.163

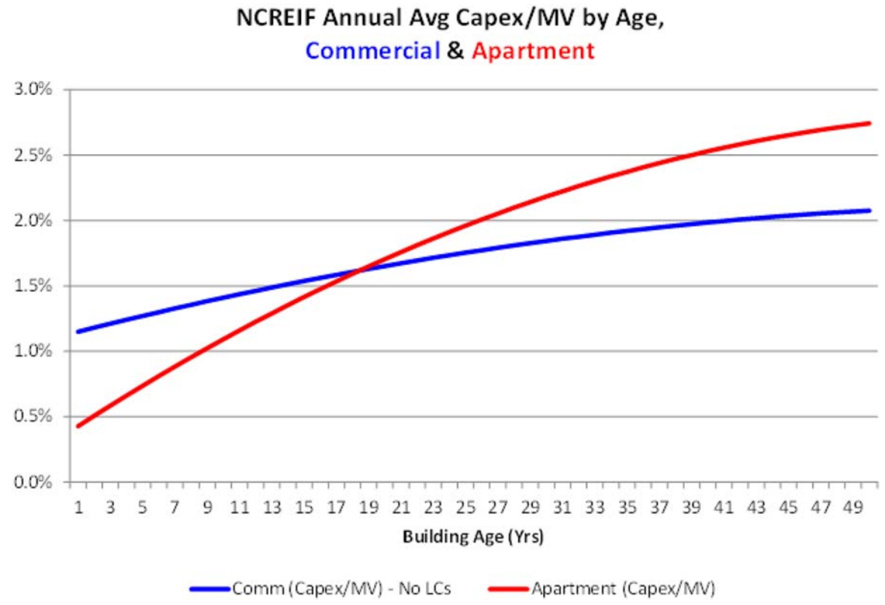

Figure 7. NCREIF Annual Capex Percent of Property Value by Building Age [Colour figure can be viewed at wileyonlinelibrary.com]

slightly exceeds that of apartment, 1.63 percent compared to 1.42 percent per year.

7. Total Capital Consumption

The task in this Section is quite straightforward: we combine Section 5's findings about net depreciation with Section 6's findings about capital improvement expenditures (capex) to produce our estimates of gross depreciation rates, that is, rates of total capital consumption.

In the case of the net depreciation phenomenon covered in Section 5 it was intuitively appealing to present the depreciation results in terms of a value/age profile that depicted the accumulation of the depreciation effects on structure quantity as a function of the age of the structure, relative to the original structure quantity when it was new. However, this type of cumulative graphical presentation of a remaining asset value is less appropriate in the case of gross depreciation, because over the life of the structure the capex process adds to the total original quantity of capital asset that is included in the property structure, even as that combined total quantity is depreciating as indicated by the net depreciation profiles reported in Section 5 as a fraction of just the original structure quantity. Therefore, our capital consumption results presented in this Section are presented not in terms of accumulated depreciation or remaining asset quantity, but rather in terms of annual *rates* of depreciation as a fraction of remaining asset quantity as of each year of age of the structure. Because we can only reliably quantify capex rates over the first 50 years of structure life,

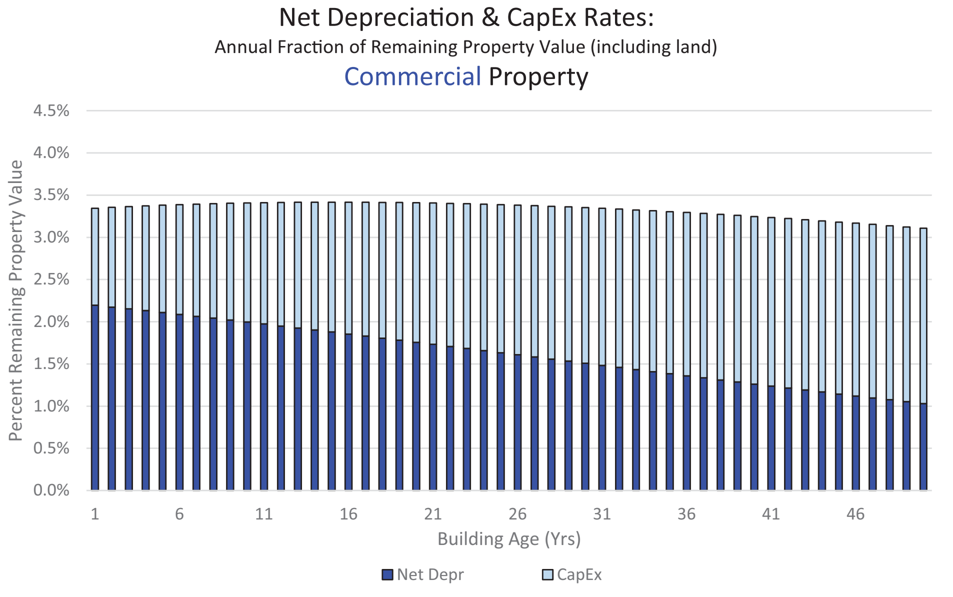

Figure 8. Commercial Property Gross Depreciation Rates By Building Age, Percent of Property Value [Colour figure can be viewed at wileyonlinelibrary.com]

our gross depreciation results in this Section are presented only through structure age 50. The net depreciation component of our overall capital consumption results presented in this Section are based on the geometrically smoothed depreciation profiles described Section 5.

Figures 8 and 9 present the gross depreciation rates as a function of building age, broken out by the two components, net depreciation and capex. Both Figures are the rates as a fraction of remaining property asset quantity, including land, and the two Figures are presented on the same vertical scale to facilitate visual comparison.

First note that the gross depreciation rates tend to be a bit more constant as a function of building age than the net depreciation or capex rates by themselves. This is because, as a fraction of total property asset quantity (including land), the net depreciation rates decline with building age (due to the declining structure component in the property value as the structure ages), while the capex rates increase with building age (no doubt due to the greater need to mitigate the effects of the structure aging). Thus, the changes in the two components as a function of age tend to offset each other.

Secondly, we see that the apartment gross depreciation rates are generally higher than the nonresidential commercial rates. For younger structures this is primarily attributable to faster net depreciation in the apartments, while for older structures (up to our analysis age limit of 50 years), the primary source of higher apartment gross depreciation is the capex rate. Apartment net depreciation rates decline faster, and capex rates increase faster, as a function of age, than is the case for nonresidential commercial properties.

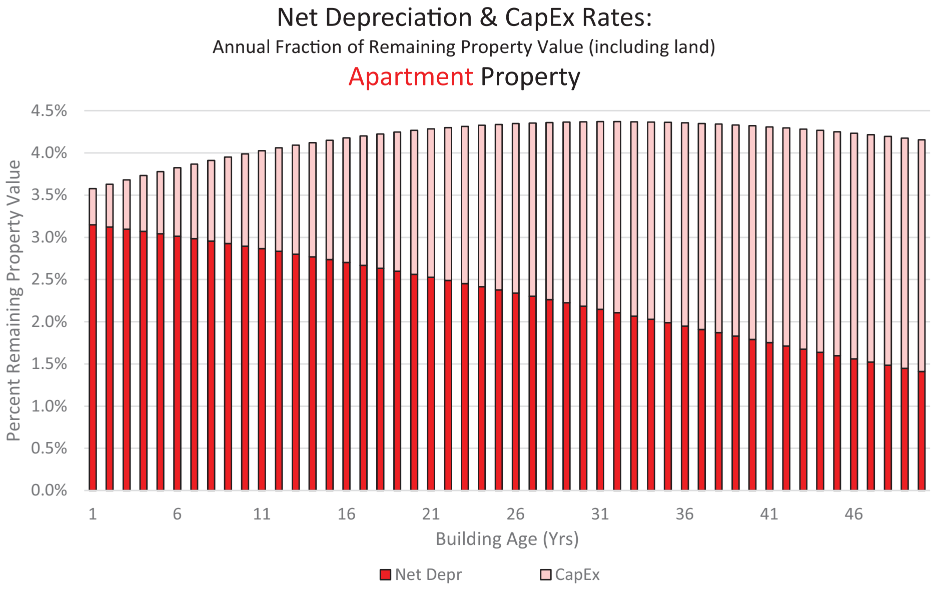

Figure 9. Apartment Property Gross Depreciation Rates By Building Age, Percent of Property Value [Colour figure can be viewed at wileyonlinelibrary.com]

For properties with 25-year-old buildings on them[32], the nonresidential property annual gross depreciation rate is 3.39 percent, consisting of 1.75 percent capex and 1.63 percent net depreciation. The corresponding rate for 25-year-old apartment properties is 4.34 percent, the sum of 1.96 percent capex and 2.38 percent net depreciation.

While these gross depreciation rates as a fraction of the remaining property whole asset are interesting and important from an investment and economic perspective, depreciation is a phenomenon of the building structure, not the land component. Therefore, we want to examine gross depreciation as a fraction of remaining structure quantity alone. To do this, we start with the capex/property market value rates reported in Section 6 as a function of building age. To those capex rates, we add the net depreciation rates as a fraction of property asset value based on the geometric best-fit curve as described in Section 5. This gives us the gross depreciation rates as a fraction of property asset value reported in Figures 8 and 9 described above, based on the geometrically smoothed property value/age profile for the first 50 years of building life. Then we factor up those gross depreciation rates to convert them to fractions of only the structure value, by applying the structure/land value fractions implied by the land value assumptions of Section 5 applied to the property value/age profile that corresponds to the Section 5

[32]25 years old is a good benchmark age for quoting summary statistics. It is the overall median age of all buildings in our transaction sample, and it is the halfway point in our 50-year age span for our capex analysis. It is useful to make comparisons across depreciation metrics holding the building age constant, as the rates vary as a function of age.

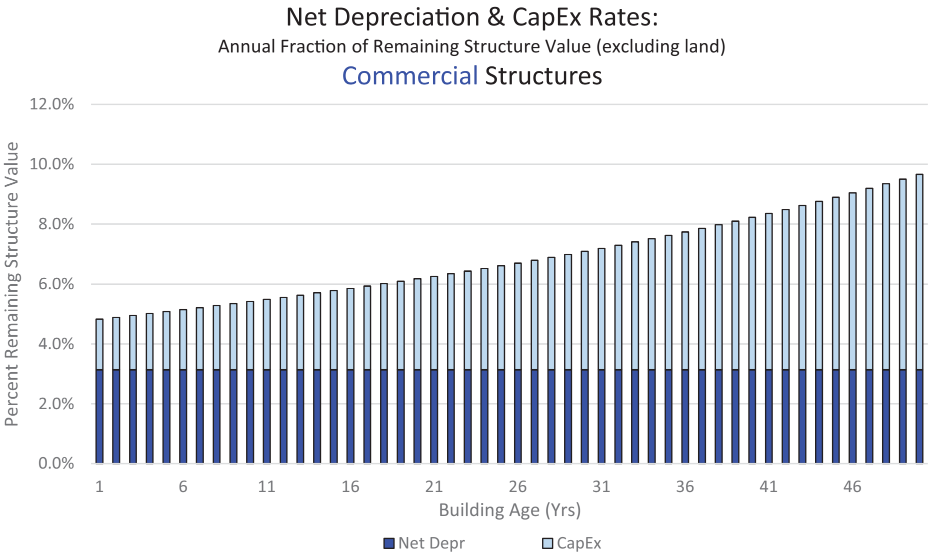

Figure 10. Commercial Gross Depreciation Rates By Building Age: Percent of Structure [Colour figure can be viewed at wileyonlinelibrary.com]

geometric structure value/age profile. The results of this exercise are presented in Figures 10 and 11.

As with the property asset value based depreciation rates discussed previously, Figures 10 and 11 are presented on the same scale, to facilitate comparison.

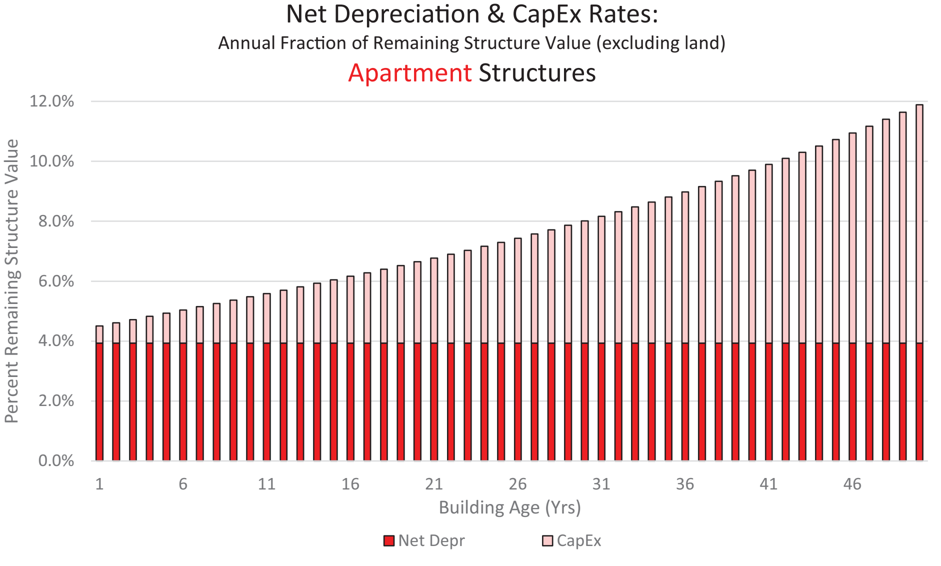

Figure 11. Apartment Gross Depreciation Rates By Building Age: Percent of Structure Value [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 6
Summary of Depreciation Findings

Annual Gross Depreciation Rates for 25-year-old Building:

Percent of Value of:	Commercial: Property	Commercial: Structure	Apartment: Property	Apartment: Structure
Net Depreciation	1.63%	3.14%	2.38%	3.94%
Capex	1.75%	3.47%	1.96%	3.36%
Gross Depreciation	3.39%	6.61%	4.34%	7.30%

Note that in contrast to the property asset value based rates, the gross depreciation rates as a fraction of remaining structure value clearly increase monotonically with the age of the structure. This is because the net depreciation rate is now constant (based on the fitted geometric curve) while the capex rate clearly rises with building age. The two components no longer offset each other (although this would be less true if we were using the non-parametric structure value/age profiles of Section 5, at least over the first 20 to 30 years). The gross depreciation rates as a fraction of structure value are of course much larger than when expressed as a fraction of property whole asset value, and the more so as the structure ages, which explains how the capex fraction increases faster with age in Figures 10 and 11 than in Figures 8 & 9.

For 25-year-old buildings, the nonresidential annual gross depreciation rate is 6.61 percent as a percent of remaining structure value, consisting of 3.47 percent capex and 3.14 percent net depreciation. The corresponding rates for 25-year-old apartment buildings is 7.30 percent, the sum of 3.36 percent capex and 3.94 percent net depreciation.

Table 6 summarizes our depreciation findings for 25-year-old buildings. At our RCA transaction sample median building ages of 23 years for commercial and 35 years for apartments, the gross depreciation rates are 6.43 percent for commercial (3.29 percent capex + 3.14 percent net depreciation), and 8.81 percent for apartments (4.87 percent capex + 3.94 percent net depreciation).

8. Implications and Use for the National Accounts

The findings reported above have important implications for the construction of the official economic statistics of the United States, as compiled by the Bureau of Economic Analysis (BEA). There are two major ways in which our findings about depreciation and capital improvement expenditures can be useful. First, they are directly useful in estimating the magnitude of capital consumption in the Net Domestic Product (NDP) and for updating the net value of the stock of commercial and apartment buildings in the Fixed Assets Accounts of the National Balance Sheets (NBS) based on the Perpetual Inventory Method (PIM). Second, our findings on net depreciation and capex can be useful indirectly in the development of commercial property land price indices which are necessary for

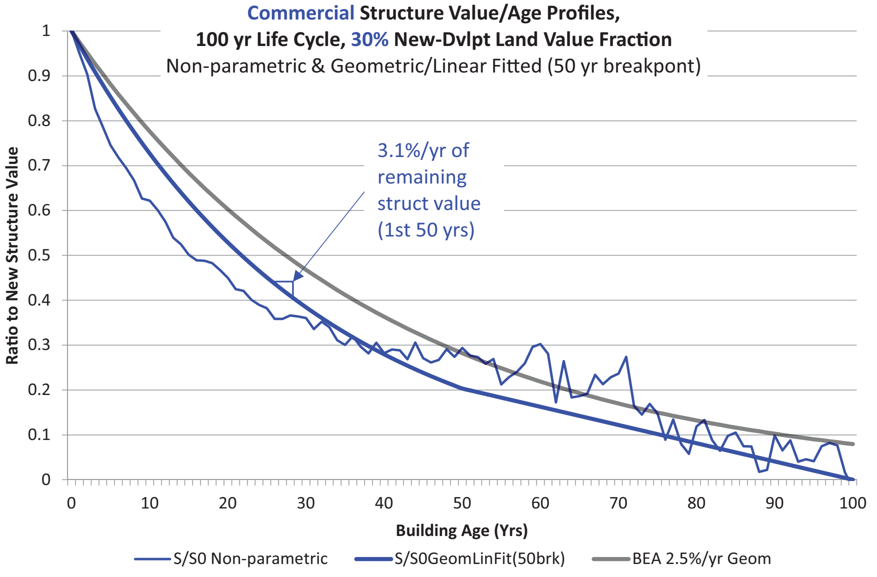

Figure 12. BEA Assumption vs Our Findings, Commercial [Colour figure can be viewed at wileyonlinelibrary.com]

quantifying land value in the NBS. We discuss only the first of these two areas of application below, as the construction of land price indices is beyond the scope of the current paper.

As described in Bureau of Economic Analysis (2013), based largely on the original HW studies, the BEA applies a geometric depreciation rate of approximately 2.5 percent/year to commercial structures and 1.4 percent/year to apartment structures. The PIM uses these rates to update the "quantity" of original structure carried forward each year after construction, as a fraction of the original new-building quantity, for purposes of computing net structure values based on price indices reflecting the current replacement cost pricing for the relevant construction (where: "value" = "quantity" X "price").

The smooth gray lines in Figures 12 and 13 depict the geometric cumulative depreciation reflecting these BEA rates. Comparison of the value/age profiles implied by these curves to those found in the present study (the colored lines in the Figures, duplicating the results described in Section 5) suggests that the BEA may be under-estimating the amount of net depreciation in the stocks of the types of structures studied in the present paper. For example, for a 25-year old commercial building, the BEA curve (approximated by a 2.5 percent/year geometric depreciation rate) implies 53 percent of the original structure quantity remaining, while our geometric-fit curve implies 45 percent and our non-parametric point-estimate is 38 percent.[33] The corresponding figures for apartment structures (5-units and larger) are 70 percent remaining quantity according to the BEA,

[33]Our 90% confidence interval around our non-parametric point estimate is between 38.1% and 38.4%.

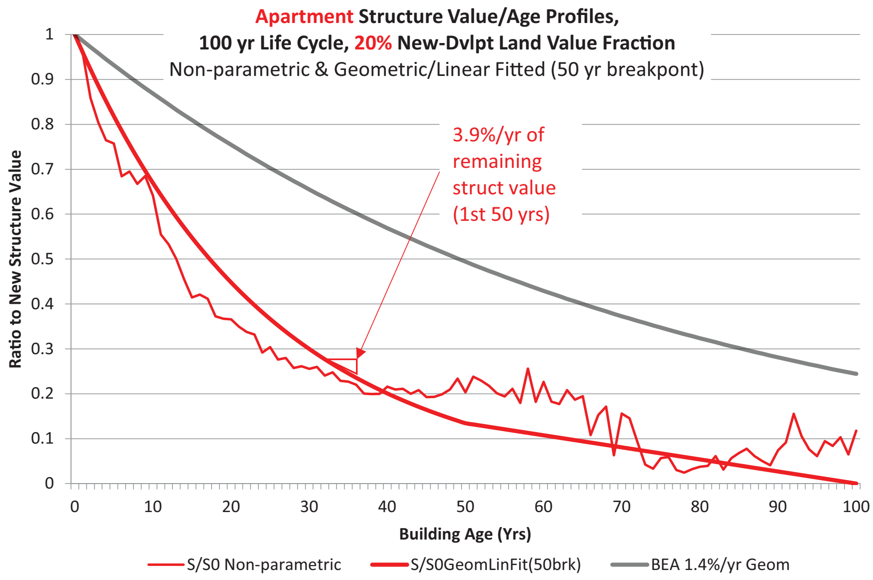

Figure 13. BEA Assumption vs Our Findings, Apartments [Colour figure can be viewed at wileyonlinelibrary.com]

versus 37 percent or 30 percent by our estimates per the geometric-fit or the non-parametric, respectively.[34] These differences could imply a non-trivial over-estimation of the value of the stock of structures in the U.S. For example, if the value-weighted average age of structures in the U.S. nonresidential building stock were 25 years of age, then the \$16 trillion figure quoted at the outset of Section 1 might have to be reduced to something more like: (45/53)16 = \$13.6 trillion, or (38/53)16 = \$11.5 trillion (based on our geometric and non-parametric profiles, respectively).

9. Conclusion

The preceding seven sections have placed this study in the context of the previous literature, presented our data, methodology, and findings regarding net and gross depreciation for commercial and apartment properties, and closed with some of the immediate implications our findings hold for the U.S. national accounts. Overall, we find considerably more depreciation than has been assumed, either in the national accounts or by convention in the real estate investment industry. Our findings even suggest more depreciation than what is implied by Internal Revenue Service depreciation tax allowances.[35] Interestingly, our findings are pretty consistent with the prior literature, as far as that literature went, including with the Hulten-Wykoff studies of 40 years ago that underlie the current BEA procedures. The HW study did in fact find, like we do, considerably accelerated net depreciation during what we term the "youth" phase of structure life,

[34]Our 90% confidence interval is between 30.1% and 30.7%.
[35]See PricewaterhouseCoopers (2016).

though this is not reflected in current BEA and IRS policies. Our greater data resources enable us to substantively nuance and extend the prior literature. This includes the addition of capital expenditures, allowing quantification of total capital consumption (gross depreciation), as well as (perhaps a bit poignantly) the identification of an almost anthropomorphic three-stage life cycle for commercial structures: Youth (0–30 years), Middle Age (30–65), and Old Age (65–100).

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's web-site:

Appendix: Methodology to estimate net depreciation rates