Intrinsic Real Option Value: Empirical Evidence from Commercial Real Estate Investors[☆,☆☆]

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Abstract

We investigate how local information externalities affect investments in tangible durable assets via real options. Using geocoded transaction-level data on US commercial properties from 2000 to 2018, we find that investors have a higher propensity to invest in a property for immediate redevelopment when its capital intensity and type of commercial activity differ from those of recently built nearby properties. Information externalities affect 'buy-to-redevelop' investment strategies as much as the asset capital depreciation – the main determinant of real option exercise highlighted in the literature – and can increase up to 30 percent the investors' willingness to pay to invest in the property.

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1. Introduction

Real options allow investors, managers, and firm owners to modify the level and/or intensity of existing capital investments in tangible durable assets at any point in time.[1] Starting with the seminal work of Arrow (1968) and Myers (1977), the area of application of real options has progressively expanded over time and it nowadays includes disparate fields, such as corporate finance, strategic management, real estate, and research and development, only to cite a few.[2] To date, however, despite the importance of real options – and the large body of literature investigating structural real option valuation models – there is little empirical research investigating how much investors value real options in the real world and the information signals upon which they rely to build their valuation. The present paper aims to answer these questions by investigating 'buy-to-redevelop' investment strategies of commercial real estate investors.

We start by developing a simple theoretical framework in which investors price the intrinsic value of real options according to the optimal capital intensity and type of economic activity at which they think they can reconfigure the real asset at the moment of the transaction. The theoretical framework serves two main purposes. First, it allows us to formalize the key determinants affecting the propensity of investors to exercise a real option right after having invested into a tangible durable asset. Second, the framework allows us to devise a novel identification strategy to deal with potential endogeneity issues biasing the empirical valuation of intrinsic real option values.

Next, we bring our theoretical framework to the data. To this end, we exploit a rich database on geocoded commercial real estate transactions between institutional investors in the US from 2000 to 2018 provided by Real Capital Analytics (RCA). A distinctive feature of the data is that – in addition to buildings, buyers, and sellers characteristics – it contains information on whether investors purchase a commercial property for immediate

[1] Because real options can be exercised at any time, are not issued by a third party, are not traded on an exchange, and they usually alter the supply of the underlying tangible asset, they are conceptually equivalent to American warrants.

[2] See Lambrecht (2017) for a recent comprehensive literature review documenting the fields of application of real options in finance.

redevelopment. We find that the capital intensity gap between a given commercial property and nearby recently built ones affects the propensity of investors to purchase the property for immediate redevelopment to a larger extent than the building capital depreciation: A one standard deviation increase in capital intensity gap and capital depreciation increases such propensity, on average, by 29% and 11% in relative terms, respectively. A mismatch between the type – residential, retail, industrial, or offices – of a given commercial property and the one of nearby recently built properties also increases the propensity to purchase the property for immediate redevelopment. Finally, our most conservative estimate suggests that the capital intensity gap and economic activity mismatch capitalize, ceteris paribus, up to a 30% higher transaction prices, highlighting the importance of information externalities in the investors' valuation process.

A major challenge when estimating the value that investors attribute to real options is given by the potential reverse causality between the propensity to exercise the option and the value of the real asset itself. Even when focusing only on immediate option exercise, pricing the intrinsic value of a real option entails some risks for investors given the uncertainty associated with optimal redevelopment decisions. Indeed, the post-exercise new capital intensity and type of economic activity might be sub-optimal given the length of the construction process and the evolution of market fundamentals.[3] As such, investors might be more reluctant to implement 'buy-to-redevelop' investment strategies for pricey building, as this increases their capital exposure to such risks. Similarly, lending institutions might be more reluctant to lend large amounts money when the aim of the investors is to acquire a commercial property to exercise a real option.[4] If this were true, higher prices would discourage and/or prevent investors to invest in the asset to exercise the real option, thereby biasing estimates of the real option value downward.

We address this endogeneity issue by relying on our theoretical framework, which shows that investors incorporate in their willingness to pay external information on capital inten-

[3] We assume that once the investors starts the redevelopment project it cannot abandon it due to significant costs.

[4] In the US buyers have to disclose to the financial institution lending the money the purpose of the investment.

sity and type of economic activity of recently built nearby buildings only via real option values. Therefore, we instrument the intention of an investor to redevelop a real asset at the moment of the transaction with the property's capital intensity gap and type of economic activity mismatch while conditioning on the current property's price determinants. Empirically, this exclusion restriction seems reasonable given that we condition on all model-based characteristics that generate the property revenue at the moment of the transaction, such as building capacity and net operating income per unit of surface. Simply put, we assume that, conditional on the revenue generated by the property, investors turn to a relative valuation of the property in its highest and best use (HBU) using information externalities provided by nearby recently built building *only* to quantify a property's real option value.

Additionally, we argue that these information externalities are exogenous to unobservables contained in the error term of the transaction price equation. Despite we cannot directly test this hypothesis, the numerous controls we use make difficult to challenge the exogeneity claim. In particular, throughout our analysis we condition on county fixed effects.

Our paper contributes to two main strands of the literature. The first strand investigates the relationship between information externalities and real options. Such relationship is investigated by Grenadier (1996, 1999, 2002), Grenadier and Malenko (2011) and, to date, is mostly limited to theoretical studies. A notable exception is the paper by Décaire et al. (2020), who empirically investigate the impact of peers decisions on the timing of natural gas shale drilling decisions of other firms in Oklahoma. We contribute to this strand of the literature by quantifying the importance of information externalities for the immediate exercise of real options – and 'buy-to-redevelop' investment strategies in particular – and by showing how these information externalities capitalize into the price paid by investors to acquire a real asset. Note that, given the nature of the research question, our study is the first to focus on the cash-flow determinants behind real option exercise rather than on the stochastic discount rate investigated by existing real option valuation models.

The second strand of the literature pertains to the pricing of real options attached to real estate assets.[5] The early literature pricing of real options attached to real estate assets is pioneered by Capozza and Li (1994) and Grenadier (1995). A common denominator of this early work is that the option value to modify the capital investment in real estate assets is usually derived by calibrating the parameters characterizing the stochastic price-dynamics of the underlying asset into a present value framework. In contrast, a subsequent strand of literature focuses on empirically testing predictions arising from real options models investigated in previous research. Quigg (1993) is the first to test whether former pricing models for real options hold implications that can be empirically tested. She finds that the option to wait to develop land is associated with higher transaction prices. Using data on commercial and industrial properties, Munneke (1996) provides empirical evidence for the theoretical prediction that the redevelopment option is exercised when the price of vacant land is high enough relative to its value with the current building structure. Dye and McMillen (2007) provide empirical evidence that the sale price of teardown homes approximates the land value on which the property is located. Clapp and Salavei (2010) and Clapp et al. (2012) empirically show the importance of accounting for variables proxying for the asset real option value in hedonic pricing models. In the absence of such variables, hedonic estimates of implicit market prices of those asset characteristics that positively correlate with real option value – such as building age – will tend to be biased upward. McMillen and O'Sullivan (2013) find that, under uncertainty over the future price of structural capital, the redevelopment option value may increase with the quantity of structural capital. Munneke and Womack (2018) asses how the potential for redevelopment of a residential property capitalizes into its price. They show that this capitalization varies considerably across space.

We empirically implement the concept of obsolescence related to capital intensity and type of capital investment. We base such measures on our theoretical framework. Our capital intensity obsolescence measure is given by the ratio between the Highest and Best Use (HBU) capital intensity and the observed capital intensity of the tangible asset. Note that the former measures the Floor to Area Ratio (FAR) given current market fundamentals.

[5] The reader might want to refer to Munneke and Womack (2018) for a more comprehensive literature review of real options in real estate.

In contrast, the latter was chosen according to 'historic' values of the market fundamentals.[6]

Our obsolescence measures rely on a geolocalized comparative equity valuation of each building. More precisely, we compute the ratio between the capital intensity of *recently built* properties *near* a given building and the capital intensity of that building. If this ratio is high, it means that nearby recently built properties have a much higher capital intensity than the considered tangible asset. This implies a high capital intensity obsolescence for the existing building. We derive a similar measure for the obsolescence of the type of capital investment. Specifically, we compare the type of commercial property – i.e. residential, commercial, office, and retail – to the one of new buildings. If the share of nearby newly built buildings matching the existing building type is low, then the current building type is subject to obsolescence.

Assuming that developers and investors build or redevelop new properties to the HBU, the above ratios provide proxies for the obsolescence of the tangible assets relating to capital intensity and usage. Because our estimates suggest that our measures of obsolescence significantly affect the decision of investors to redevelop a property, we provide new empirical evidence about the relevance of peers decisions for the exercise of real options, as formalized by Grenadier (1996, 1999, 2002), Grenadier and Malenko (2011), and empirically investigated by Décaire et al. (2020).

Second, we provide novel evidence on the investors' willingness to pay to exercise real options. In particular, we devise a new identification strategy that allows us to isolate the intrinsic option value of redevelopment for commercial real estate properties in a causal way. Such causal identification is a difficult task due to both endogeneity and functional form issues. Relying on the theoretical framework, we show that our measures of obsolescence relating to capital intensity and asset usage can be used to instrument the stated intention of investors to acquire a building for redevelopment. Using these instruments allows us to isolate the intrinsic option value. Providing a causal estimate of the real option value to redevelop is essential for several reasons.

[6]The average age of properties purchased for redevelopment is slightly more than half a century.

On the one hand, the theoretical real option pricing literature must rely on strong assumptions for real estate assets. This is especially the case when performing a calibration of structural parameters, which drive the tangible asset's stochastic behavior. Because data on real estate assets is usually observed only at the moment of the transaction – which, in contrast to financial assets, occurs infrequently – the parameters describing the mean and dispersion of asset prices are assumed the same for all properties. This assumption potentially neglects significant spatial heterogeneity in the local market fundamentals. On the other hand, existing empirical literature mostly focuses on the predictive power of terms proxying for real options when included in hedonic pricing model and/or how such terms affect estimates of other hedonic characteristics. Thus, they are unable to make strong causality claims about the value buyers attach to real options.

Third, we focus our analysis on an important but understudied asset class, namely commercial real estate properties. In general, the scarce existing empirical literature on real options tends to focus on firms' decisions to undergo or opt-out from investment projects, such as opening and closing mines (Moel and Tufano, 2002) or performing natural gas shale drilling (Décaire et al., 2020). Importantly, such literature primarily focuses on *when* real options are exercised, neglecting pricing considerations. In the specific case of real estate assets, as described in the literature review above, real options have been usually investigated for residential land and residential housing assets, thus lacking a pure investment perspective. As pointed out by Piazzesi et al. (2007), the consumption component of housing goods affects their pricing. Arguably, this makes the empirical testing of real option pricing models – which are designed from a pure investment perspective – questionable.

The lack of research on real options in commercial real estate may strike as surprising given the sheer size of the commercial real estate market. In 2018, the commercial real estate market was worth about 17 trillion USD, making it one of the most essential asset class for investors.[7] Expanding our knowledge about commercial real estate investors' decision-making process is important due to their vital role in the economy.

[7]Source: CoStar All Properties Database 2018 and Costar's Real Estate Market Size Estimates 2018. For comparison, the total market capitalization of the US stock market was 32 trillion USD in 2018 and the bond market was valued at 29 trillion in 2018 according to SIFMA.

The remainder of the paper is structured as follows. Section 2 introduces the theoretical framework. Section 3 presents the empirical methodology and discuses the identifying assumptions. Section 4 describes the data and the construction of several measures. Section 5 illustrates the results and Section 6 concludes.

2. Theoretical framework

In this section, we lay out the fundamental mechanisms behind the exercise and valuation of redevelopment options. To this end, we build on the work of Capozza and Li (1994) and Clapp and Salavei (2010). We develop a simple theoretical framework allowing us to i) rationalize the empirical specifications illustrated in Section 3, and ii) formalize a solution to the endogeneity issues related to the estimation of the redevelopment option value. Importantly, to be consistent with the empirical analysis, our focus is on the *intrinsic* value of the option to redevelop and not on its time value.[8] We provide details on the mathematical derivations in the Appendix A.

Let P_{it} denote the value of commercial property i at time t. The property generates a periodic net operating income $y_{is}c_{is}$ in $s \geq t$, where y_{is} and c_{is} denote the net operating income per unit of building capacity and the total building capacity, respectively.[9] Building capacity is the output of a Cobb-Douglas production function displaying constant returns to scale. The production factors are land L_i and capital C_{is}, i.e., $c_{is} = AL_i^{\alpha}C_{is}^{1-\alpha}$, where $0 < \alpha < 1$ denotes the land output elasticity, and A the total factor productivity.[10] The land component of the building capacity is time-invariant, whereas the capital-investment component depreciates at a constant rate ρ. Thus, the total building capacity decreases over time.[11] Finally, we assume a constant discount rate r, and that investors expect the net revenue y_{is} to grow continuously at constant rate g.[12]

[8]For this reason, we choose a certainty framework and refrain ourselves from modeling stochastic time dynamics.

[9]We interpret capacity as the floor area of the real estate asset. We abstract from quality considerations, which we assume are captured in the term y_{is}. However, in our empirical specifications we do control for terms proxying the hedonic quality of the real estate asset.

[10]This formulation is common in the literature. See, for example, Brueckner (1987).

[11]In Section 5.3 we check the validity of our results when considering a non-linear depreciation rate.

[12]In our empirical analysis, we relax these assumptions by including time and county-level fixed effects.

Let P_{it}^N and P_{it}^R denote the price of a given real estate property that is *never* redeveloped and that is redeveloped once, respectively. Because investors will choose the alternative that maximizes the building value, it follows that $P_{it} = \max(P_{it}^N, P_{it}^R)$. It can be shown that $P_{it}^R = P_{it}^N + V_{it}^R$, where V_{it}^R is the additional value created by redeveloping the building (which can be negative). This leads to $P_{it} = P_{it}^N + \max(0, V_{it}^R)$, where $\max(0, V_{it}^R)$ is the redevelopment option value. Using a standard present value approach, the value of a property built at time $t_0 < t$ that is never redeveloped is given by

$$P_{it}^N = \frac{y_{it} A L_i S_{it_0}^{1-\alpha}}{r + (1-\alpha)\rho - g} e^{-(1-\alpha)\rho(t-t_0)}, \tag{1}$$

where $S_{it_0} = C_{it_0}/L_i$ is the capital to land ratio – which represents a measure of the intensity of capital investment at the time the building was built. As expected, the value of a building that is never redeveloped unequivocally decreases with building age $t - t_0$ due to physical depreciation.

Investors optimize the additional redevelopment value V_{it}^R along two main dimensions, namely the optimal time of redevelopment T and the intensity of capital investment S_{it}^{*R}.[13] Because we allow investors to change the 'best use' of the property – for example switching from offices to housing units – we denote by y_{it}^{*R} the after-redevelopment unitary net operating income. This income is not necessarily generated by the same market segment as before the exercise of the real option. Given our empirical focus on the intrinsic value of redevelopment, let us set $T = t$. This implies that the current period is the optimal time to redevelop. It follows that

$$V_{it}^R = \frac{L_i}{r + \rho(1-\alpha) - g}\left(y_{it}^{*R} A S_{it}^{*R,1-\alpha} - y_{is} A S_{it_0}^{1-\alpha} e^{-(1-\alpha)\rho(t-t_0)}\right) - L_i K(S_{it_0}, S_{it}^{*R}) \tag{2}$$

where $K(S_{it_0}, S_{it}^R) = k_0 S_{it_0} + k_1 S_{it}^{*R}$ is the cost of redevelopment. We assume this cost to be proportional to the initial capital intensity (due to demolition costs), and to the intensity of newly invested capital (due to construction costs). Equation (2) implies that the option

This allows for potential time and space heterogeneity in the investors' expectations.

[13] In the Appendix A, we derive expressions for the optimal stopping time T and level of capital intensity S_{it}^{*R}.

value of the redevelopment $\max(0, V_{it}^R)$ unequivocally increases with building age $t-t_0$. This is because the forgone revenue generated by the never-to-be-redeveloped building decreases over time due to depreciation. Additionally, a higher redevelopment option value is reached, ceteris paribus, for higher post-redevelopment net operating income and/or higher capital intensity.

Combining (1) and (2) yields

$$P_{it} = P_{it}^N \max\left(\frac{y_{it}^{*R} S_{it}^{*R,1-\alpha} e^{(1-\alpha)\rho(t-t_0)}}{y_{is} S_{it_0}^{1-\alpha}} - \frac{K e^{(1-\alpha)\rho(t-t_0)}}{y_{is} A S_{it_0}^{1-\alpha}}, 1\right) = \\ = P_{it}^N r^{Pot}\left(\frac{y_{it}^{*R}}{y_{is}}, \frac{S_{it}^{*R}}{S_{it_0}}, t-t_0\right), \tag{3}$$

where the function r^{Pot} denotes the redevelopment potential associated with the property. In the case of no redevelopment potential, $P_{it} = P_{it}^N$. As apparent from (3), r^{Pot} is an increasing function of $\frac{y_{it}^{*R}}{y_{is}}$, $\frac{S_{it}^{*R}}{S_{it_0}}$ (and $t-t_0$) conditional on y_{is} and S_{it_0}. This implies that the redevelopment is likely to be advantageous for investors under two circumstances besides high capital depreciation levels. First, when the post-redevelopment HBU net operating income largely outweighs the pre-redevelopment one. Second, when the post-redevelopment capital intensity is considerably higher than the pre-redevelopment one.

3. Empirical analysis

In this section, we first bring our theoretical framework to the data. Next, we exploit the structure of the model to formalize a solution to the endogeneity issues that potentially bias the estimation of the intrinsic redevelopment option.

3.1. From model to empirics

Using (1) and (3), we obtain a log-log hedonic specification for property i at time t which incorporates a term for the redevelopment potential of a property

$$\begin{aligned}\ln P_{it} = c + \ln(y_{is}) + (1-\alpha)\ln(S_{it_0}) - (1-\alpha)\rho(t-t_0) + \ln L_i \\ + \ln\left(r^{Pot}\left(\frac{y_{it}^{*R}}{y_{is}}, \frac{S_{it}^{*R}}{S_{it_0}}, t-t_0\right)\right) + \epsilon_{it},\end{aligned} \tag{4}$$

where the term $c = -\ln(r + (1-\alpha)\rho) - g$ gathers constant parameters across properties.[14] The term ϵ_{it} is a stochastic error term.

Estimating (4) is challenging, because r^{Pot} depends on the unobservables y_{it}^{*R} and S_{it}^{*R} in a nonlinear way. In the empirical literature, this issue has been tackled by controlling for non-linear terms proxying building age and/or capital intensity, such as in Quigg (1993) and Clapp and Salavei (2010).[15] Despite based on theoretical consideration and easy to implement, such an approach does not fully address functional form issues related to the redevelopment potential term entering the hedonic pricing equation.

In our case, however, we observe a dummy variable which equals one if investors purchase a real estate asset with the stated intention to redevelop it, i.e., $D_i^{Red} = 1$ if $r_i^{Pot} + v_i \geq 1$, and 0 otherwise. The term v is a stochastic error term capturing the investors' idiosyncratic preferences for redeveloping a property. By estimating the following equation,

$$\ln P_{it} = c + \ln(y_{is}) + (1-\alpha)\ln(S_{it_0}) - (1-\alpha)\rho(t-t_0) + \ln L_i + \beta D_{it}^{Red} + \epsilon_{it}, \tag{5}$$

we avoid functional form issues related to the specification of a redevelopment term into the hedonic pricing equation. The coefficient β, which is the parameter of interest, represent the intrinsic redevelopment option value that investors attach to a real estate asset. How can we

[14]Note, again, that the lower bound of the function r^{Pot} is 1, such that the term $\log r^{Pot} \geq 0$. This non-negativity comes from the right, but not the obligation, for an investor to exercise a real option.

[15]An alternative approach in the literature has been to rely and/or extend a standard Heckman (1978) two-stage procedure to address potential selection bias. This approach controls for (a function of) the predicted probability of redevelopment of a given property. See, for example, Rosenthal and Helsley (1994), and Dye and McMillen (2007), and Munneke and Womack (2018).

interpret the willingness to pay β in (5) within our theoretical framework? Let $t^* > t$ denote the optimal exercise time of future redevelopment. Assuming that investors are rational, and purchase commercial properties for redevelopment only when these latter have reached their optimal exercise time, we have

$$\begin{aligned} \beta &= E\left(\ln P_{it}|D_{it}^{Red}=1\right) - E\left(\ln P_{it}|D_{it}^{Red}=0\right) = \\ &= E\left(\ln P_{it}|T=t\right) - E\left(\ln P_{it}|T=t^*\right) = \\ &= E\left(\ln r_{it}^{Pot}|T=t\right) - E\left(\ln r_{it^*}^{Pot}|T=t^*\right) = E\left(\ln\left(\frac{r_{it}^{Pot}}{r_{it^*}^{Pot}}\right)\right), \end{aligned} \tag{6}$$

where the expectation operator E is taken across properties and time periods. Put into words, the coefficient β estimated in (5) corresponds to the average (log of the) ratio of the current optimal redevelopment potential relative to the redevelopment potential of the buildings that are *not* purchased for redevelopment. This makes sense, as even those buildings that are not purchased for redevelopment do have a redevelopment potential. They simply have not reached their optimal exercise time yet.

3.2. Potential endogeneity issues and identification strategy

To consistently estimate the parameter β in (5) by OLS, the exogeneity assumption of the intention to redevelop dummy $E[D_{it}^{Red}\epsilon_{it}|X_{it}] = 0$ must hold, where the vector X_{it} denotes the set of model-based controls. This hypothesis is likely violated in two main cases.

The first case is the bias arising from omitted variables. Our theoretical framework clearly shows that not controlling for the NOI (y_{it}), capital intensity (S_{it_0}), and age ($t - t_0$) of the current tangible asset in (5) leads to biased estimates of β, as these variables also belong to data generating process of D^{Red}. This type of omitted variable is a serious limitation of empirical studies that do not control – or at least proxy – for such variables. Omitted variable bias might also arise due to unobservables contained in the error term ϵ_{it} that are not modeled in our theoretical framework. As pointed out by Clapp and Salavei (2010), when using transaction-level data, unobservables contained in the error term ϵ_{it} of the hedonic pricing equation might capture buyers and sellers idiosyncratic characteristics. To the extent that these characteristics correlate with the intrinsic willingness v_{it} of a real estate investor to acquire a property for redevelopment, the coefficient β will be biased when estimated by OLS.[16]

In our empirical analysis, we partially address the omitted variable bias by including all the controls suggested by our theoretical framework in (5). These controls include the assets' hedonic characteristics (not included in the model), and several characteristics of the buyers and sellers trading the assets.

In the second case, the coefficient β is biased due to reverse causality. More specifically, when the price P_{it} affects the intention D_{it}^{Red} of an investor to acquire a real estate asset for redevelopment purposes. Such reverse causality might happen for different reasons. The higher the price of a commercial property, the more investors might be reluctant to acquire it for redevelopment. This is due to some uncertainty regarding the NOI after redevelopment.[17] Similarly, financial institutions might be less willing to lend money for highly-priced properties if the aim is to redevelop.[18] This kind of credit constraint creates a negative correlation between the amount of money lent out – which is usually proportional to the property prices – and the intention to redevelop. We argue that the direction of reverse causality bias is negative, as higher prices decrease the probability of acquisition for redevelopment, implying that not taking this mechanism into account might lead to estimates of β that are too low.

To address the second source of endogeneity, we use the following instrumental variable approach for endogenous dummy variables outlined in Wooldridge (2010). First, we predict the probability $\hat{D}_{it}^{Red}$ of purchasing a real estate asset for redevelopment using the following probit model for the determinants of redevelopment

$$Pr(D_{it}^{Red} = 1 | X_{it}, Z_{it}) = \Phi(\theta_0 + \theta_1 X_{it} + \theta_2 Z_{it}), \tag{7}$$

[16]This endogeneity issue is seen when assuming a linear probability model for the redevelopment dummy, i.e., $D_{it}^{Red} = \gamma X_{it} + v_{it}$. Assuming that the controls are exogenous, we have $Cov(D_{it}^{Red} \epsilon_{it} | X_{it}) = Cov(v_{it} \epsilon_{it} | X_{it}) \neq 0$.

[17]This uncertainty might also be due to delays in the tear-down and construction process. Both types of uncertainty might leave the investor exposed to financial losses arising from mortgage payments and the opportunity cost of capital.

[18]By law, in the US, borrowers are forced to communicate to the financial institution for which purpose they intend to acquire the asset for which they are borrowing money.

where Φ is the cumulative standard normal distribution function, and the vector Z_{it} contains the instrumental variables. Next, we estimate (5) by instrumenting D_{it}^{Red} with the predicted probabilities $\hat{D}_{it}^{Red}$. Specifically, we estimate (5) with a 2SLS approach, where the first stage equation is given by

$$D_{it}^{Red} = \gamma_0 + \gamma_1 \hat{D}_{it}^{Red} + \gamma_2 X_{it} + \epsilon'_{it}. \tag{8}$$

The variable ϵ'_{it} is the stochastic error term of the first-stage regression equation. For this procedure to provide unbiased estimates of β the set of instruments Z_{it} must be exogenous and satisfy the exclusion restriction.[19] As pointed out by Wooldridge (2010), this procedure has the main advantage of producing more efficient causal estimates of β compared to a standard 2SLS procedure in which D_{it}^{Red} is directly instrumented with Z_{it}.[20]

Our theoretical framework suggests two potential instruments that satisfy the exclusion restriction. The (the log of) net operating income and capital intensity ratios, $\frac{y_{it}^{*R}}{y_{is}}$ and $\frac{S_{it}^{*R}}{S_{it'}}$, respectively.[21] According to our theoretical framework, these two variables enter (5) only via the redevelopment potential function r^{Pot} affecting the decision to purchase for redevelopment D_{it}^{Red}. Investors do a comparative equity valuation of the real estate asset only if they plan to purchase the building for further redevelopment. As explained in the detail in Section 4, we operationalize $\frac{y_{it}^{*R}}{y_{is}}$ and $\frac{S_{it}^{*R}}{S_{it'}}$ by assuming that the HBU NOI y_{it}^{*R} and capital intensity S_{it}^{*R} of a given building can be proxied by those of nearby recently built properties.

However, we argue that the exclusion restriction is likely not fulfilled in the case of $\frac{y_{it}^{*R}}{y_{is}}$. This is because demand shocks to the market segment of new properties – which affect y_{it}^{*R} – ripple to the market of existing properties via equilibrium adjustments, thereby affecting y_{it}. In other words, the level of y_{it}^{*R} might affect the price P_{it} via y_{it}, thereby violating the exclusion restriction.[22] This problem does not arise in the case of S_{it}^{*R} and S_{it}, as the

[19]Note that this approach is different from directly plugging in the fitted probabilities $\hat{D}_{it}^{Red}$ (instead of D_{it}^{Red}) into (5) and estimating it by OLS. As pointed out by Angrist and Krueger (2001), this would lead to inconsistent estimates.

[20]In the robustness Section 5.3, we provide empirical evidence in that regard, thereby justifying the choice of the approach.

[21]In Section 4.1, we illustrate how we empirically compute these instrumental variables.

[22]This violation can be formalized by extending our theoretical framework to include a spatial equilibrium

'historic' capital intensity level S_{it} is fixed in time and does not adjust to new market shocks without redevelopment. Following this argument, we also derive an additional instrumental variable capturing the match of the existing building usage – which we assume static if no redevelopment occurs – and the building usage of new buildings.[23]

The exogeneity of these two instruments hinges on the assumption that, conditional on all the controls, 'historic' outcomes levels – such as capital intensity and building usage – are uncorrelated with unobserved contemporaneous dynamics.[24] This seems reasonable, as the average age of properties purchases with the intention to redevelop is about half a century. Thus a correlation between the instrumental variables and ϵ_{it} is unlikely. [25]

4. Data and descriptive statistics

We use georeferenced transaction data on US commercial real estate properties from 2001 to 2018, provided by Real Capital Analytics (RCA). In our empirical analysis, we use the following groups of variables.

Model-based variables and hedonic characteristics The data set features all the main variables entering our theoretical framework. These variables are the property transaction price (P_{it}), the age of the building ($t - t_0$), its operating income (y_{it})[26], the capital intensity (S_{it}), and the size of the plot of land (L_{it}) on which the building is located. We complement these variables with hedonic characteristics that might influence the transaction price. These characteristics include the type of commercial building (residential, industrial, office, or

condition for the supply and demand of real estate surface. If the market of new HBU properties is not perfectly separated from the one of 'old' properties, any demand shock to one segment of the market will propagate to the other segment, thereby creating a correlation between y_{it}^{*R} and y_{it}.

[23]See 4 for more details.

[24]Relying on historical data to instrument contemporaneous variables is not new in the economic literature. See, for example, Ciccone and Hall (1996).

[25]This seems especially true given the extensive set of controls we use. We further support this claim in several ways. In Section 5, we perform an overidentification test by regressing the two instrumental variables directly on D_{it}^{Red} and do not find evidence of endogeneity issues. Additionally, in Section 5 we verify that our results remain stable when excluding 'younger' properties from those purchased for redevelopment, likely reinforcing our exogeneity claims.

[26]The buildings' NOI is available in approximately 30 percent of the transactions. In Appendix B, we describe how we impute such missing values for the remaining observations. Note that in Section 5 we perform several robustness checks to verify the sensitivity of our results to such imputation and find that our results remain stable.

retail), a quality index based on the building's physical characteristics, and the number of real estate units in the building.

Market potential We also take into account variables capturing the attractiveness of the local market in which the property is located (hereafter labeled 'market potential'). These variables might affect the willingness to pay of investors. Specifically, we control for i) a building walk-score index measuring the degree of access to the building without relying on the car or public transportation, ii) a street retail dummy indicating whether street retail in the building is possible, iii) a dummy indicating whether the building is subsidized, and iv) a dummy indicating whether the building is located in an opportunity zone.

Buyer and seller characteristics The buyer characteristics include our variable of interest, namely the stated intention of a buyer to acquire a real estate asset for redevelopment (D_{it}^{Red}). To capture the idiosyncratic tastes of buyers and sellers, we control for the following variables. i) The buyer/seller type of capitalization[27], ii) the geographic scope of the buyer/seller (local, national, continental, and global), iii) whether the buyer is foreign (dummy), iv) the type of deal between buyer and seller (appraised, approximate, confirmed, private, street talk), v) and whether the owner of building resolved a situation of distress (dummy).

4.1. Measuring capital intensity and usage obsolescence

As described in Section 3, we rely on two instrumental variables to estimate the value that investors attach to buy a property for redevelopment. The first instrument is given by the (log of the) ratio of capital intensities $\frac{S_{it}^{*R}}{S_{it'}}$. We proxy the capital intensity of the plot of land to its HBU S_{it}^{*R} with the weighted average of the capital intensity of nearby recently built buildings, i.e.,

$$S_{it}^{*R,Proxy} \approx \frac{1}{\#\{jl \in I(it)\}} \sum_{jl \in I(it)} w_{jl} S_{jl}, \tag{9}$$

[27]Buyers and sellers are classified in about 20 types of capitalization. The most common categories are developers, equity funds, investment managers, REIT, and corporate.

where the property and time specific set $I(it)$ contains the 10 closest properties to i that were built *and* transacted within 5 years from t. The weight w_{jl} are defined as the inverse of the (normalized) distance between property $jl \in I(it)$ and property it. This implies that investors attribute less importance to more distant properties when performing a comparative equity valuation of the building capital intensity.[28] The definition of the set $I(it)$ allows us to reach a sufficient sample size of properties proxying for the HBU capital intensity while remaining relevant for the variable we want to instrument.[29] We then define our first instrument as $z_{it}^{S} = \ln(S_{it}^{*R,Proxy}/S_{it'})$, where high values of z_{it}^{S} indicate high levels of capital intensity obsolescence.

We define the second instrument as an index capturing the extent to which the *type* of revenue-generating activity of a given commercial building (residential, industrial, office, or retail) does not match the one of HBU properties. Specifically, we attribute to each building 1 minus the share of HBU properties of the same type, i.e.,

$$z_{it}^{Type} = 1 - \frac{\#\{jl \in I(it) \cap Type_{jl} = Type_{it}\}}{\#\{jl \in I(it)\}}. \tag{10}$$

A value of zero (one) indicates that all (none) of the HBU properties are of the same property type. A higher index value thus implies a high building usage obsolescence. For example, if a given commercial building is used for residential purposes and HBU properties are 80 percent residential and 20 percent retail, $z_{it}^{Type} = 1 - 0.8 = 0.2$. If the considered property was used for retail purposes, $z_{it}^{Type} = 1 - 0.2 = 0.8$.

[28] Formally, $w_{jl} = \frac{\frac{1}{d_{jl}}}{\sum_{jl \in I(it)} \frac{1}{d_{jl}}}$, such that the sum of all weights w_{jl} equals 1.

[29] Additionally, the choice of a five years interval can be justified as follows. First, investors likely perform a comparative equity valuation by considering not only buildings constructed in the same year in which they want to buy a building, but also those built in the recent past. Second, the construction of commercial buildings may take several years Thus investors in time t may be already aware of the capital intensity of buildings under construction for which the transaction will only be registered several years later.

Table 1: **Transactions of US commercial properties from 2001 to 2018**

	Mean	SD	10%	90%
Panel A: Redevelopment properties (3,133 obs.)				
Price (1000 USD)	21,196	49,548	2,826	44,170
Age (Years)	53	29	18	96
NOI (USD/m2)	217	401	53	392
FAR	1.953	3.243	0.224	5.094
Land (m2)	21,519	54,095	523	55,078
FAR instrument	2.551	2.229	0.547	5.829
Prop. type instrument	0.705	0.251	0.300	1.000
Property types	Residential	Industrial	Office	Retail
	15.13%	19.69%	35.17%	30.00%
Panel B: Non-redevelopment properties (80,477 obs.)				
Price (1000 USD)	15,679	47,269	2,550	32,695
Age (Years)	37	28	6	85
NOI (USD/m2)	152	159	47	282
FAR	1.210	2.122	0.212	3.231
Land (m2)	19,832	35,525	707	52,609
FAR instrument	1.715	1.546	0.515	3.461
Prop. type instrument	0.641	0.274	0.200	1.000
Property types	Residential	Industrial	Office	Retail
	38.95%	17.33%	21.15%	22.57%

Notes: SD is the standard deviation, lower is the 10^{th} quantile and higher is the 90^{th} quantile. NOI is the Net Operating Income per unit of surface of the property. The FAR is the Floor Area Ratio, which corresponds to the total building surface divided by the land surface.

4.2. Descriptives

Table 1 summarizes the main model-based determinants of transaction prices for redevelopment properties (Panel A) and non-redevelopment properties (Panel B).[30] We also include summary statistics for our two instrumental variables. As expected, we observe some differences between redevelopment properties and non-redevelopment properties.

On average, the redevelopment properties' transaction price tends to be higher than the one of the non-redevelopment properties. This is despite redevelopment properties being older. The higher transaction price is because redevelopment properties are usually traded

[30] Due to space constraints, we restrict ourselves to present only the main model-based variables. Descriptive statistics for the other controls are available in Appendix B

in more central areas than non-redevelopment properties. Because central areas historically develop first, buildings tend to be older. However, they are developed at a higher intensity to accommodate stronger demand pressures. This claim is supported by the higher NOI generated by redevelopment properties and the fact that they display higher capital intensity. Note, however, that the standard deviation of the considered variables is extremely elevated, such that none of the differences between the above averages are statistically significant.[31] Interestingly, land surface on which the properties are located is similar between redevelopment and non-redevelopment properties. Finally, we observe that commercial residential properties tend to be underrepresented among redevelopment properties, whereas office and retail ones are more frequent than non-redevelopment properties.

Concerning our instrumental variables, Table 1 shows that HBU properties display, on average, a higher capital intensity. This is because the FAR-based instrument is bigger than one for both redevelopment and non-redevelopment properties. As expected, however, the FAR-based instrument takes, on average, higher values for redevelopment properties than for non-redevelopment properties. Similarly, the property type instrument signals, on average, a stronger mismatch of redevelopment properties with the usage of HBU properties.

5. Results

In this section, we present our empirical results. We start by analyzing the determinants leading investors to redevelop a commercial property. Next, we estimate the intrinsic option value of redevelopment and verify our estimates' sensitivity to several robustness checks.

5.1. Obsolescence and the investors' intent to redevelop

Table 2 illustrates the results for the determinants of the probability of purchasing a property for redevelopment formulated in the probit model 7.

The main aim of this section is to gain insights on the determinants behind the compu-

[31]The high standard deviation is due, in part, to the fact that commercial properties are scattered throughout the US territory, implying great differences in market fundamentals. To cope with this issue, in our empirical specifications, we include county fixed effects, thereby exploiting variation coming only from within these administrative units.

Table 2: **Determinants of the investors' intent to redevelop**

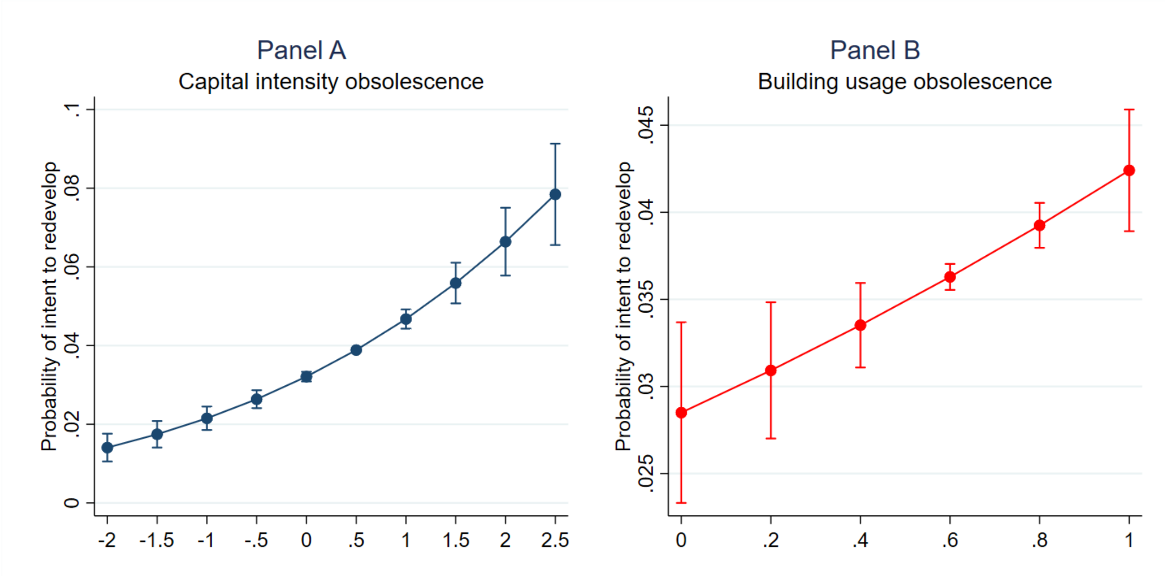
Panel A - Dependent variable: Redevelopment dummy (D^{Red})			
	(1)	(2)	(3)
Capital intensity obsol.	0.273***	0.210***	0.205***
	(0.025)	(0.024)	(0.025)
Property usage obsol.	0.284***	0.247***	0.214***
	(0.066)	(0.072)	(0.072)
Age	0.113***	0.098***	0.095***
	(0.010)	(0.009)	(0.009)
ln NOI	0.041*	0.036	0.029
	(0.022)	(0.024)	(0.023)
ln FAR	0.338***	0.268***	0.255**
	(0.099)	(0.100)	(0.101)
ln Land	0.254***	0.350***	0.320***
	(0.097)	(0.097)	(0.098)
Year FE	Yes	Yes	Yes
County FE	Yes	Yes	Yes
Hedonic char.	Yes	Yes	Yes
Market potential	No	Yes	Yes
Buyer/seller char.	No	No	Yes
Observations	83,610	83,610	83,610
AIC	23,195	22,862	22,094
Panel B - Average Marginal Effect of obsolescence			
Capital intensity obsol.	0.020***	0.015***	0.014***
	(0.002)	(0.002)	(0.002)
Property usage obsol.	0.020***	0.018***	0.015***
	(0.005)	(0.005)	(0.005)

Notes: Clustered standard errors at the county level in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Estimation is carried out using a probit model. A constant term is included in all specifications. Age is measured in decades.

tation of the predicted probabilities $\hat{D}^{Red}$ that are used to instrument D^{Red} when estimating the intrinsic value of redevelopment. As such, i) we include the same set of variables that we use to estimate the intrinsic value of the option to redevelop, and ii) we use the same functional form as the one suggested by the model for the redevelopment option value. Thus, our focus is on the link – without any causality claim – between the instrumental variables and the probability of redevelopment.

Columns 1 to 3 of Panel A in Table 2 show the estimated coefficients' values when progressively controlling for the groups of variables discussed in the previous section. Additionally, we always include transaction year and county fixed effects in our regressions. The

Figure 1: Predicted probabilities of the investors' intent to redevelop



Notes: Standard deviations of predicted probabilities are computed using the delta method. The value range of the obsolescence measures correspond to the one observed in our sample.

former fixed effects capture macroeconomic time dynamics, whereas the latter account for time-invariant spatial differences between real estate markets. Panel B of Table 2 shows the corresponding Average Marginal Effect (AME) for our two measures of obsolescence.[32]

As it can be seen in Panel A of Table 2, the parameter estimates of the two instrumental variables capturing the capital intensity and building usage obsolescence have the expected sign, remain relatively stable across specifications, and are highly significant. Therefore, these two measures are reliable predictors for redevelopment. Interestingly, the magnitude of the coefficient of the two instruments exceeds the one of age, suggesting that these variables are at least as influential for redevelopment decisions as building age.

The AME of the capital intensity instrument – which, as reported in column 3 of Table 2, equals 1.4 percentage points – is very close to the one for the property usage. However, to gain a better understanding of the importance of each obsolescence measure for redevelopment, in Figure 1, we plot the predicted probability of redevelopment ($P(D^{Red}) = 1$) against the range of values taken by the measures z^S and z^{Type}. As it can be seen, higher values of both

[32]Given the large sample size, the partial effects at the mean are virtually identical to the average marginal effects. For space reasons, we only report the AME.

measures unequivocally lead to higher probabilities.

In the case of the instrument z^S capturing capital intensity obsolescence, a given building that is not subject to capital intensity obsolescence ($z^S = 0$) has, ceteris paribus, approximately a three percent probability of redevelopment. If the same building were located in a market where HBU properties have a capital intensity of about 12 times bigger ($z^S = 2.5$), its probability of redevelopment goes up to almost eight percent. In other words, the relative probability of redevelopment increases by 166%.[33]

In contrast, a building that is not subject usage obsolescence ($z^{Type} = 0$) has, ceteris paribus, a probability of redevelopment of about 2.8 percent. If the same building were located in a market where HBU properties are all built for different usage ($z^{Type} = 1$), its probability of redevelopment increases approximately by 4.2 percent, implying a relative probability increase of 50%.

The above computations indicate that, despite their AME are both significant and of similar magnitude, capital intensity obsolescence plays a bigger role than usage obsolescence in leading investors to purchase a property for redevelopment. The predicted probabilities' concave shape indicates that if future local market equilibria evolve such that the capital intensity of HBU properties becomes bigger and bigger, the probability of redevelopment will increase more than proportionally.

5.2. Intrinsic redevelopment option value

We now turn to the estimation of the redevelopment option value. Table 3 shows the estimates of the redevelopment intrinsic option value model. Column 1 of Table 3 shows OLS results. Columns 2 to 4 in Panel A of Table 3 show second-stage estimates – we instrument the redevelopment dummy using our two obsolescence measures according to the procedure outlined in Section 3 – when progressively including groups of controls. Panel B of Table 3 shows the corresponding first-stage results.

[33] Despite being large, a capital intensity of HBU that is 12 times bigger, is not unrealistic. For example, if the existing property has a FAR=1 – which might be the case for several low-rise buildings – and HBU properties have an FAR=12 – which is common in mid and high rise buildings –, we obtain such intensity ratio.

Table 3: **Intrinsic redevelopment option value**

Panel A: 2nd stage – Dependent variable: log-price				
	(1)	(2)	(3)	(4)
	OLS		IV	
Redevelopment	-0.005	0.507***	0.374**	0.308***
	(0.025)	(0.176)	(0.160)	(0.115)
Age	-0.002	-0.008***	-0.008***	-0.007***
	(0.002)	(0.003)	(0.003)	(0.002)
Log-NOI	0.167***	0.164***	0.132***	0.133***
	(0.009)	(0.009)	(0.007)	(0.007)
Log-FAR	0.086**	0.079*	0.080**	0.093**
	(0.044)	(0.044)	(0.038)	(0.037)
Log-land area	0.065	0.056	0.069*	0.087**
	(0.042)	(0.042)	(0.038)	(0.037)
Kleibergen-Paap F	-	316.37	418.05	301.23
Panel B: 1st stage – Dependent variable: Redevelopment dummy				
Redevelopment pot.		1.101***	1.215***	1.171***
		(0.062)	(0.059)	(0.067)
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
Hedonic char.	Yes	Yes	Yes	Yes
Market potential	No	No	Yes	Yes
Buyer/seller char.	No	No	No	Yes
Observations	83,610	83,610	83,610	83,610

Notes: Clustered standard errors at the county level in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. A constant term is included in all specifications. Age is measured in decades.

We find that the OLS estimate of the redevelopment intrinsic option value is extremely close to zero in magnitude and statistically insignificant. As discussed in 3, this estimation approach ignores potential endogeneity problems. As soon as we instrument the redevelopment dummy, we obtain a positive and statistically significant value for the redevelopment option value. The option values reported in columns 2 to 4 in Panel A of Table 3 are relatively stable in magnitude across specifications and always about 1.6 standard deviations from each other. Our most conservative estimate, which we obtain when using the full set of controls, indicates a redevelopment option value of approximately 30%. Put into words, investors are willing, ceteris partibus, to pay a 30% higher price for buildings that they deem worth of redevelopment in the near future.

First-stage results reported in Panel B of Table 3 show a positive and statistically signif-

Table 4: **Summary of robustness checks**

Robustness – Dependent variable: log-price			
(1) County-level time trends	0.365^{***} (0.116)	(2) Non-linear depreciation	0.253^{**} (0.118)
Kleibergen-Paap F	349.42	Kleibergen-Paap F	364.85
(3) Impact of imputation	0.261^{**} (0.115)	(4) Market segmentation	0.357^{***} (0.123)
Kleibergen-Paap F	260.32	Kleibergen-Paap F	307.14
(5) Classic 2SLS	0.317 (0.418)	(6) Instruments polynomial	0.294^{**} (0.116)
Kleibergen-Paap F	17.39	Kleibergen-Paap F	343.82

Notes: Clustered standard errors at the county level in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Dependent variable is log of the transaction price.

icant relationship between the predicted probabilities $\hat{D}^{Red}$ and redevelopment D^{Red}. This strong relationship is reflected in extremely high Kleibergen-Paap statistics reported in Panel A of Table 3, which are well above the conventional rule-of-thumb threshold of 10. The procedure outlined in 3 to improve the efficiency of 2SLS estimates in the case of an endogenous dummy variable thus produces the desired effect.

Finally, we note that parameter estimates of the model-based control variables have the expected sign, and their magnitude hardly changes across specifications. These results add further credibility to our causal interpretation of the option value associated with redevelopment. As predicted by our theoretical framework, building age has a negative impact on the transaction price, whereas it was associated with a positive intention to redevelop. In contrast, NOI, FAR, and land area all have the expected positive impact on the transaction price.

5.3. Robustness checks

In this section, we perform several robustness checks to verify the sensitivity of our estimates for the redevelopment option value. For space reasons, we only report robustness checks for our most conservative estimate reported in column 4 (full set of controls) of Table 3. Table 4 summarizes these results.

County-level time trends To address potential endogeneity issues arising from unobserved time trend differentials across local markets, we check the robustness of our results when partialling out county fixed effects interacted with year fixed effects. In particular, these interaction terms address omitted variable concerns in (5) regarding the investors' expectations and risk perceptions of local real estate markets, as these latter are unlikely to vary significantly within a given county in a given year. To further investigate the role played by risk, we construct two additional risk measures and control for them in (5) (instead of controlling for time-trend differentials at the county level). The first (second) risk measure we implement is the standard deviation at the county level of the NOI (transaction price) of a property in a given year. The first measure aims to capture risk in the revenue generated by the property, whereas the second one proxies for the risk value of the invested capital. Estimates for the redevelopment option value are stable to the inclusion of county time trend differentials and the inclusion of both risk measures.

Non-linear depreciation scheme In our main specifications, we control for building age linearly. However, a common approach in the hedonic literature is to control for age polynomia to capture nonlinearities in the depreciation of invested capital.[34] Thus, we parametrize the depreciation rate ρ as $\rho = \rho_1 + \rho_2(t - t') + \rho_3(t - t')^2$ in (5), which accounts for a third degree polyonomia in the building age. As it can be seen, the estimated option value, although of a slightly lower magnitude, remains essentially the same.

Impact of imputation As mentioned in Section 4, we impute missing NOI values. We check the robustness of our main results concerning this imputation in two ways. In the first approach, we control for the (log of the) average distance of the nearby buildings that were used to impute the NOI in a given period. The reasoning is that we want to control for a measure capturing the reliability of the imputation technique. In the second approach, we do *not* control for the imputed NOI in our main specifications, and check whether this omission is important, given all other controls we use. The estimated option values remain stable for both approaches.

[34] See, for example, Clapp and Salavei (2010) and Clapp et al. (2012).

Market segmentation In Section 3, we argue against using the (log of the) NOI gap $y_{it}^{*R}/y_{it'}$ between previously built properties and HBU ones to instrument D_{it}^{Red}, thereby excluding such variable from our regressions. We argue that, conditional on the other controls, such variable captures the extent to which the market of HBU and existing commercial properties is segmented. If there is no segmentation, the equilibrium NOI per unit of surface should be the same across all properties, implying $y_{it}^{*R}/y_{it'} = 1$. This equality is likely not met if there is a strong segmentation, causing $y_{it}^{*R} \neq y_{it'}$. An open question is whether this measure of market segmentation – which might be contained in the error term of (5) – correlates with the two instruments we use to derive our main results, thus biasing our option value estimates. As it can be seen, this is not the case.

Classic 2SLS estimates We investigate how our estimates obtained following the procedure outlined in Section 3 compares with classic 2SLS estimates, where the two instruments z^S and z^{Type} are directly regressed (individually and simultaneously) on D^{Red} in the first stage. Additionally, we investigate endogeneity issues by performing an overidentification test when the two instruments are used together. The results are reported in Table D.9 in the Appendix D. A few remarks are worth noting. First, the obtained coefficients are much higher in magnitude but considerably less precise. Looking at the Stock-Yogo critical values, there might even be a problem of weak instruments. This justifies our main estimation approach, which as pointed out by Wooldridge (2010), improves the predictive power and efficiency of the instruments. Second, the overidentification test does not highlight significant endogeneity issues, adding further evidence in support of the exogeneity of the instruments.

Instruments polynomial We check whether we can improve the precision of our estimates by including a third degree polynomial of $S_{it}^{*R,Proxy}/S_{it'}$ (instead of $z^S = \ln(S_{it}^{*R,Proxy}/S_{it'})$) and z^{Type} (instead of only a linear term z^{Type}) in the vector Z of the probit equation (7). The estimated option value remains stable.

6. Conclusion (preliminary)

As urban areas evolve and age, attracting new capital investments in the form of redeveloped real estate properties becomes ever more critical. In this paper we investigate the determinants and market value of the option for real estate investors to redevelop a commercial property in the near future.

We find that physical depreciation, as well as economic obsolescence – captured by an inadequate highest best use of the plot of land on which the property is located – jointly and significantly increase the probability that investors acquire a commercial real estate property with the intention to redevelop it.

Our results hold important lessons for the understanding of the development of cities. Policymakers plan market interventions aiming to promote urban growth and renewal of the real estate stock. Urban economic models usually assume that capital – in the form of real estate assets – is perfectly malleable and divisible when exposed to economic shocks. Researchers rely on this malleability to evaluate the consequences of a variety of policies affecting the distribution of residents and labor across space and, more generally, to understand how cities form and evolve in the long-run.

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Appendix A. Mathematical derivations

Appendix A.1. Present value formulas

The value P_{it}^N at time t of a property built at time $t_0 < t$ that is *never* redeveloped is

$$\begin{aligned} P_{it}^N &= \int_t^{+\infty} y_{is} c_{is} e^{-r(s-t)} ds = \\ &= \int_t^{+\infty} y_{it} e^{g(s-t)} c_{it_0} e^{-(1-\alpha)\rho(s-t_0)} e^{-r(s-t)} ds = \\ &= y_{it} c_{it_0} e^{-(1-\alpha)\rho(t-t_0)} \int_t^{+\infty} e^{-(r+(1-\alpha)\rho-g)(s-t)} ds = \\ &= \frac{y_{it} c_{it_0}}{r+(1-\alpha)\rho-g} e^{-(1-\alpha)\rho(t-t_0)}, \end{aligned} \tag{A.1}$$

where we have used the fact that $c_{is} = AL_i^\alpha C_{is}^{1-\alpha} = AL_i^\alpha (C_{it_0} e^{-\rho(s-t_0)})^{1-\alpha} = c_{it_0} e^{-\rho(1-\alpha)(s-t_0)}$.

The value P_{it}^R of a building that is re-developed once is

$$P_{it}^R = \max_{T, C_{iT}} \left(\int_t^T y_{is} c_{it} e^{-r(s-t)} ds + \int_T^{+\infty} y_{is}^R c_{is}^R e^{-r(s-t)} ds - K(C_{it_0}, C_{iT}^R) e^{-r(T-t)} \right) \tag{A.2}$$

$$\begin{aligned} &= \int_t^{+\infty} y_{is} c_{it} e^{-r(s-t)} ds + \\ &+ \max_{T, C_{is}^R} \left(+ \int_T^{+\infty} (y_{is}^R c_{is}^R - y_{is} c_{it}) e^{-r(s-t)} ds - K(C_{it_0}, C_{iT}^R) e^{-r(T-t)} \right) = \\ &= P_{it}^N + \max_{T, C_{iT}^R} \left(+ \int_T^{+\infty} (y_{is}^R c_{is}^R - y_{is} c_{it}) e^{-r(s-t)} ds - K(C_{it_0}, C_{iT}^R) e^{-r(T-t)} \right), \end{aligned} \tag{A.3}$$

Because investors maximize the building value, we have

$$\begin{aligned} P_{it} &= \max(P_{it}^N, P_{it}^R) = \\ &= P_{it}^N + \max\left(0, \max_{T, C_{iT}^R} \left(\int_T^{+\infty} (y_{is}^R c_{is}^R - y_{is} c_{it}) e^{-r(s-t)} ds - K(C_{it_0}, C_{iT}) e^{-r(T-t)} \right)\right) = \\ &= P_{it}^N + \max(0, V_{it}^R). \end{aligned} \tag{A.4}$$

Setting the optimal stopping time $T = t$, we have

$$V_{it}^R = \max_{C_{iT}^R} \int_t^{+\infty} (y_{is}^R c_{is}^R - y_{is} c_{it}) e^{-r(s-t)} ds - K(C_{it_0}, C_{it}^R) = \tag{A.5}$$
$$= \max_{C_{iT}^R} \int_t^{+\infty} \left(y_{is}^R A L_i^{\alpha} C_{it}^{R,1-\alpha} e^{-\rho(1-\alpha)(s-t)} - y_{is} A L_i^{\alpha} C_{it_0}^{1-\alpha} e^{-\rho(1-\alpha)(s-t_0)} \right) e^{-r(s-t)} ds$$
$$- k_0 C_{it_0} - k_1 C_{it}^R =$$
$$= \max_{S_{iT}^R} L_i \int_t^{+\infty} \left(y_{is}^R A S_{it}^{R,1-\alpha} e^{-\rho(1-\alpha)(s-t)} - y_{is} A S_{it_0}^{1-\alpha} e^{-\rho(1-\alpha)(s-t_0)} \right) e^{-r(s-t)} ds$$
$$- L(-k_0 S_{it_0} - k_1 S_{it}^R),$$

Let S_{it}^{*R} denote the optimal redevelopment intensity and y_{it}^{*R} the corresponding unitary net operating income. Using (A.5), we have

$$V_{it}^R = L_i y_{it}^{*R} A S_{it}^{*R,1-\alpha} \int_t^{+\infty} e^{-(r+\rho(1-\alpha)-g)(s-t)} ds + \tag{A.6}$$
$$L_i y_{is} A S_{it_0}^{1-\alpha} e^{-(1-\alpha)\rho(t-t_0)} \int_t^{+\infty} e^{-(r+\rho(1-\alpha)-g)(s-t)} ds - L_i (k_0 S_{it_0} - k_1 S_{it}^{*R}) =$$
$$\frac{L_i}{r+\rho(1-\alpha)-g} (y_{it}^{*R} A S_{it}^{*R,1-\alpha} - y_{is} A S_{it_0}^{1-\alpha} e^{-(1-\alpha)\rho(t-t_0)}) - L_i (k_0 S_{it_0} - k_1 S_{it}^{*R})$$

We now bring the previous theoretical framework to the our data. The value of a property for which there is an intrinsic redevelopment value is $P_{it} = P_{it}^N + V_{it}^R$, where V_{it} is given by (A.6). Using (A.1), we have

$$\frac{P_{it}}{L_i} = \frac{1}{r+\rho(1-\alpha)-g} y_{is} A S_{it_0}^{1-\alpha} e^{-(1-\alpha)\rho(t-t_0)} + \tag{A.7}$$
$$\max \left(\frac{1}{r+\rho(1-\alpha)-g} (y_{it}^{*R} A S_{it}^{*R,1-\alpha} - y_{is} A S_{it_0}^{1-\alpha} e^{-(1-\alpha)\rho(t-t_0)}) - k_0 S_{it_0} - k_1 S_{it}^{*R}, 0 \right) =$$
$$= \frac{1}{r+\rho(1-\alpha)-g} y_{is} A S_{it_0}^{1-\alpha} e^{-(1-\alpha)\rho(t-t_0)}.$$
$$\left(1 + \max \left(\frac{y_{it}^{*R} S_{it}^{*R,1-\alpha} e^{(1-\alpha)\rho(t-t_0)}}{y_{is} S_{it_0}^{1-\alpha}} - 1 - \frac{K e^{(1-\alpha)\rho(t-t_0)}}{y_{is} A S_{it_0}^{1-\alpha}}, 0 \right) \right) =$$
$$= P_{it}^N \max \left(\frac{y_{it}^{*R} S_{it}^{*R,1-\alpha} e^{(1-\alpha)\rho(t-t_0)}}{y_{is} S_{it_0}^{1-\alpha}} - \frac{K e^{(1-\alpha)\rho(t-t_0)}}{y_{is} A S_{it_0}^{1-\alpha}}, 1 \right).$$

Appendix A.2. Optimal stopping time and development

Let us first rewrite V_{it}^R defined in (A.4) as

$$V_{it}^R = \max_{T,C_{iT}^R} \int_T^{+\infty} (y_{is}^R c_{is}^R - y_{is} c_{it}) e^{-r(s-t)} ds - K(C_{it_0}, C_{it}^R) e^{-r(T-t)} = \tag{A.8}$$

$$= L_i \max_{T,S_{iT}^R} \int_T^{+\infty} \left(y_{is}^R A S_{it}^{R,1-\alpha} e^{-\rho(1-\alpha)(s-t)} - y_{is} A S_{it_0}^{1-\alpha} e^{-\rho(1-\alpha)(s-t_0)} \right) e^{-r(s-t)} ds$$

$$- (k_0 S_{it_0} + k_1 S_{it}^R) e^{-r(T-t)},$$

Let us re-write the expression to maximize as

$$\int_T^{+\infty} y_{iT}^R e^{g(s-T)} A S_{iT}^{R,1-\alpha} e^{-\rho(1-\alpha)(s-T)} e^{-r(s-t)} ds \tag{A.9}$$

$$- \int_T^{+\infty} y_{is} A S_{it_0}^{1-\alpha} e^{-\rho(1-\alpha)(s-t_0)} e^{-r(s-t)} ds$$

$$- (k_0 S_{it_0} + k_1 S_{it}^R) e^{-r(T-t)} = \tag{A.10}$$

$$= y_{iT}^R A S_{iT}^{R,1-\alpha} e^{(\rho(1-\alpha)-g)(T-t)} \int_T^{+\infty} e^{-(r+\rho(1-\alpha)-g)(s-t)} ds +$$

$$- y_{it_0} A S_{it_0}^{1-\alpha} e^{(g-\rho(1-\alpha))(t-t_0)} \int_T^{+\infty} e^{-(r+\rho(1-\alpha)-g)(s-t)} ds +$$

$$- (k_0 S_{it_0} + k_1 S_{it}^R) e^{-r(T-t)} \tag{A.11}$$

$$= y_{iT}^R A S_{iT}^{R,1-\alpha} e^{(\rho(1-\alpha)-g)(T-t)} \frac{e^{-(r+\rho(1-\alpha)-g)(T-t)}}{r+\rho(1-\alpha)-g} +$$

$$- y_{it_0} A S_{it_0}^{1-\alpha} e^{(g-\rho(1-\alpha))(t-t_0)} \frac{e^{-(r+\rho(1-\alpha)-g)(T-t)}}{r+\rho(1-\alpha)-g} +$$

$$- (k_0 S_{it_0} + k_1 S_{it}^R) e^{-r(T-t)} \tag{A.12}$$

$$= \frac{y_{iT}^R A S_{iT}^{R,1-\alpha}}{r+\rho(1-\alpha)-g} e^{-r(T-t)} +$$

$$- \frac{y_{it_0} A S_{it_0}^{1-\alpha}}{r+\rho(1-\alpha)-g} e^{-(\rho(1-\alpha)-g)(T-t_0)} e^{-r(T-t)} +$$

$$- (k_0 S_{it_0} + k_1 S_{it}^R) e^{-r(T-t)} \tag{A.13}$$

The optimal exercise time is thus characterized by

$$\frac{\partial V_{it}^R}{\partial T} = -r\frac{y_{iT}^R A S_{iT}^{R,1-\alpha}}{r+\rho(1-\alpha)-g}e^{-r(T-t)} + \\ + y_{it_0} A S_{it_0}^{1-\alpha} e^{-r(T-t)} e^{-(\rho(1-\alpha)-g)(T-t_0)} + \\ + r(k_0 S_{it_0} + k_1 S_{it}^R) e^{-r(T-t)} = 0 \tag{A.14}$$

Which implies

$$y_{iT}^R A S_{iT}^{R,1-\alpha} = \frac{r+\rho(1-\alpha)-g}{r} y_{it_0} A S_{it_0}^{1-\alpha} e^{-(\rho(1-\alpha)-g)(T-t_0)} \\ + (r+\rho(1-\alpha)-g)(k_0 S_{it_0} + k_1 S_{it}^R) \tag{A.15}$$

The optimal structural intensity for a each unit of land is characterized by the following first order condition

$$(1-\alpha)\frac{y_{iT}^R A(1-\alpha) S_{iT}^{R,-\alpha}}{r+\rho(1-\alpha)-g}e^{-r(T-t)} - k_1 e^{-r(T-t)} = 0 \tag{A.16}$$

and an optimal redevelopment capacity $c_{iT}^R = L_i A (S_{iT}^{*R})^{1-\alpha}$. Note that the optimal structural intensity does not depend explicitly on the dynamics of T. The solution of (A.16) characterizes a unique maximum, as

$$-\alpha(1-\alpha)\frac{A y_{it}^R S_{it}^{R,-\alpha-1}}{r+\rho(1-\alpha)-g}e^{-r(T-t)} < 0 \tag{A.17}$$

Appendix B. Data

Appendix B.1. Detailed data description

Table B.5: Hedonic characteristics

Variable	Type/units	Description
Quality score	Index	Index indicating the quality of the property.
Number of units		Number of units in the property.

Table B.6: Market potential

Variable	Type/units	Description
Walking score	Index	Index indicating the property's foot traffic.
NOI trend	Index	Index indicating the MSA's NOI trend.
Street retail	Dummy	Dummy indicating if the property is located on a street with retail.
Subsidized	Dummy	Dummy indicating if the property is subsidized
Opportunity zone	Dummy	Dummy indicating if the property is located on a opportunity zone.

Table B.7: Buyer/seller characteristics

Variable	Type/units	Description
Buyer type	Categorical	Categorical variable indicating the type of buyer. 25 different types, e.g., Developer or Equity fund.
Seller type	Categorical	Categorical variable indicating the type of seller 25 different types, e.g., Developer or Equity fund.
Geoscope buyer	Categorical	Categorical variable indicating the geographic scope of the buyer: Continental, Global, Local, or National.
Geoscope seller	Categorical	Categorical variable indicating the geographic scope of the seller: Continental, Global, Local, or National.
Deal type	Categorical	Categorical variable indicating the type of deal. 9 different types.
Distressed	Dummy	Dummy indicating if the property was distressed when transacted.
Foreign	Dummy	Dummy indicating if the property was bought by a foreign buyer.

Appendix B.2. Imputation details

Because NOI per unit of surface is missing[35] in approximately 70 percent of the cases, we impute such values as follows. First, we find the ten closest properties that are not being redeveloped, are built within ten years, are sold within five years, are within five kilometers, and are the same property type as the target property with missing NOI. Subsequently, we impute the missing NOI per unit of surface using a weighted average of those of previously selected properties. The weight is set equal to the inverse of the distance to the target property. Note that We use market and property type-specific NOI indexes provided to us by RCA to correct the imputed NOIs when the year of sale of the nearby properties is different from the one of the target property. Note that we only allow for a five-year

[35]Missing values take the form of missing or zero NOI.

difference and that we impute the NOI per square foot of **land** (sfl) and not structure. This is because investors want to maximize the income per sfl when they redevelop.

Appendix C. Predicting redevelopment option value

In this section, we provide details about the strategy that we implement to predict the redevelopment option value of individual buildings. As outlined in Section 3, we use the following three-step estimation procedure to efficiently estimate an unbiased coefficient of the parameter β. First, we predict the probability $\hat{D}_{it}^{Red}$ of purchasing a real estate asset for redevelopment using the probit model (7). Second, we use the fitted probabilities $\hat{D}_{it}^{Red}$ to instrument D_{it}^{Red} in (5) with a 2SLS approach. According to this three-step procedure, we have that

$$\ln P_{it} = c + \ln(y_{is}) + (1-\alpha)\ln(S_{it_0}) - (1-\alpha)\rho(t-t_0) + \ln L_i + \beta\hat{\hat{D}}_{it}^{Red} + \epsilon_{it}, \tag{C.1}$$

is the second-stage equation of the 2SLS estimation, where $\hat{\hat{D}}_{it}^{Red}$ are the fitted predictions obtained by *linearly* regressing D_{it}^{Red} on $\hat{D}_{it}^{Red}$ in the first stage.

According to (C.1), an unbiased price prediction $\hat{P}_{it}$ of P_{it} is given by

$$\begin{aligned}\hat{P}_{it} &= \exp\left(E(\ln P_{it}|\text{controls}, \hat{\hat{D}}_{it}^{Red} = 0) + \frac{1}{2}\hat{\sigma}^2\right)\exp(\hat{\beta}\hat{\hat{D}}_{it}^{Red}) = \\ &= \hat{P}_{it}^{ROV=0} exp(\hat{\beta}\hat{\hat{D}}_{it}^{Red})\end{aligned} \tag{C.2}$$

The first term on the right-hand side of (C.2) correspond to the predicted property value when $\hat{\hat{D}}_{it}^{Red} = 0$, i.e. when no redevelopment option value is present. The term $\frac{1}{2}\hat{\sigma}^2$ is the standard adjustment component used to obtain unbiased predictions of $\hat{P}_{it}$ when the error term follows a normal distribution with standard deviation σ.[36]

The second term on the right-hand side of (C.2) correspond to the redevelopment option value shifter, which is equal to 1 if $\hat{\hat{D}}_{it}^{Red} = 0$ and continuously increases with $\hat{\hat{D}}^{Red}$ up to $\exp(\hat{\beta})$. We can re-write (C.2) as $\hat{P}_{it} = \hat{P}_{it}^{ROV=0}(1+s_{it})$, where $s_{it} = \exp(\hat{\beta}\hat{\hat{D}}_{it}^{Red})-1$. The term $\hat{P}_{it}^{ROV=0}s_{it}$ thus represent the part of the property value that arises from the redevelopment

[36]The adjustment is necessary because taking the exponential of the predicted log-prices in (C.1) does not provide predicted price values due to the fact that the exponential is a nonlinear function. The estimator $\hat{\sigma}$ of the standard deviation σ is given by the root mean squared error of the regression.

option. To compute this term we thus proceed as follows:

1. We predict the probability $\hat{D}_{it}^{Red}$ using the probit model (7).

2. We predict the fitted probabilities $\hat{\hat{D}}_{it}^{Red}$ by regressing $\hat{D}_{it}^{Red}$ on D_{it}^{Red} (always using the full set of controls).

3. We estimate (C.1) and

   i) predict log-prices when $\hat{\hat{D}}_{it}^{Red} = 0$, i.e. we compute $E(\ln P_{it}|\text{controls}, \hat{\hat{D}}_{it}^{Red} = 0)$. Next, we compute $\hat{P}_{it}^{ROV=0}$ by adding the adjustment term $\frac{1}{2}\hat{\sigma}^2$ and taking the exponential.

   ii) use the estimated $\hat{\beta}$ to compute $s_{it} = \exp(\hat{\beta}\hat{\hat{D}}_{it}^{Red}) - 1$.

4. We compute the option value $\hat{P}_{it}^{ROV=0} s_{it}$.

Table D.8: **Robustness: Intrinsic redevelopment option value**

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: 2nd stage – Dependent variable: log-price						
Redevelopment	0.365***	0.253**	0.261**	0.357***	0.317	0.294**
	(0.116)	(0.118)	(0.115)	(0.123)	(0.418)	(0.116)
Age	-0.007***	-0.003**	-0.007***		-0.007	-0.006***
	(0.002)	(0.001)	(0.002)		(0.005)	(0.002)
Log-NOI	0.128***	0.127***	0.129***		0.133***	0.133***
	(0.007)	(0.007)	(0.007)		(0.007)	(0.007)
Log-FAR	0.076*	0.093***	0.095**	0.032	0.093**	0.094**
	(0.039)	(0.036)	(0.037)	(0.038)	(0.038)	(0.037)
Log-land area	0.064*	0.090***	0.097***	0.016	0.086**	0.087**
	(0.036)	(0.035)	(0.037)	(0.038)	(0.039)	(0.037)
Kleibergen-Paap F	349.42	364.85	260.32	307.14	17.39	343.82
Panel B: 1st stage – Dependent variable: Redevelopment dummy						
Redevelopment pot.	1.111***	1.174***	1.127***	1.173***		1.130***
	(0.059)	(0.061)	(0.070)	(0.067)		(0.061)
FAR instrument					0.019***	
					(0.003)	
Prop. type instrument					0.025***	
					(0.008)	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Hedonic char.	Yes	Yes	Yes	Yes	Yes	Yes
Market potential	Yes	Yes	Yes	Yes	Yes	Yes
Buyer/seller char.	Yes	Yes	Yes	Yes	Yes	Yes
Observations	72,226	83,610	83,610	83,610	83,610	83,610

Notes: Clustered standard errors at the county level in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. A constant term is included in all specifications. Age is measured in decades.

Appendix D. Tables (To be added)

Table D.9: **IV**

Panel A: 2nd stage – Dependent variable: log-price			
	(1)	(2)	(3)
		IV	
Redevelopment	0.845*	-1.359	0.317
	(0.459)	(1.668)	(0.418)
Kleibergen-Paap F	32.94	7.62	17.39
Overidentification	.	.	0.14
Panel B: 1st stage – Dependent variable: Redevelopment dummy			
FAR instrument	0.018***		0.019***
	(0.003)		(0.003)
Prop. type instrument		0.022***	0.025***
		(0.008)	(0.008)
Year FE	Yes	Yes	Yes
Hedonic char.	Yes	Yes	Yes
Market potential	Yes	Yes	Yes
Buyer/seller char.	Yes	Yes	Yes
Observations	83,610	83,610	83,610

Robust standard errors in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Dependent variable is log of transaction price per unit of land. For the IV models, we instrument for the redevelopment dummy with the fitted redevelopment potential. In the first IV (i) model, we only use the fitted redevelopment potential estimated with the NOI instrument. In the second IV (ii) model, we use the fitted redevelopment potential estimated with the FAR instrument and HBU property type index. In the third IV (iii) model, we use the the three instruments together.