Empirical estimation of the option premium for residential redevelopment*

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Abstract:

This paper presents a novel empirical approach for identifying towns with high value of option to redevelop and measuring the value of this option using a standard hedonic dataset. Our analysis generalizes the standard hedonic model to account for the option value of reconfiguring hedonic characteristics. We test this model with over 162,000 real estate transactions in 53 towns in Connecticut between 1994 and 2007 by adding a non-linear intensity variable, which increases with the aggregate value of structure and decreases with land value. About 20% of towns have positive option to redevelop, with a mean value of 29-34% for properties most like vacant land. Multiple tests across towns support predictions of real options theory. Positive option value towns have higher house price volatility and estimated option value varies positively with price volatility, a finding inconsistent with NPV theory. We also find positive association between option value and drift in house prices and a U-shape relation with house price adjusted for structural characteristics. Higher property taxes reduce the value of option to redevelop.

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1. Introduction

Real options theory has made important contributions to the valuation literature. One of its key insights is that investment in irreversible assets should take place only when a trigger value is above investment costs because of the presence of the non-negative option to wait (McDonald and Siegel, 1986; Dixit, 1989, Majd and Pindyck, 1987). Using simulations, Dixit and Pindyck (1994) show that the optimal hurdle price that triggers irreversible investment can be 3 times as large as when the investment is reversible. Related literature has shown that the timing of corporate investment decisions depends on the value of the option to wait (Able, 1983, Dixit and Pyndick, 1994). Applications of real options framework include among others capital budgeting decisions (Childs, Ott and Triantis, 2002), consumer automobile lease contracts (Giaccotto, Goldberg, and Hegde, 2007), natural resource extraction (Paddock, Siegel and Smith, 1988), plant openings and closings (Kovenock and Phillips, 1997; Moel and Tufano, 2002) and firm investment in capacity (Grenadier, 2002; and Aguerrevere, 2003).

Real estate is the most widely studied application of real options (Wang and Zhou, 2006); the value of the underlying asset is the property value with a new, optimal building and the strike price is the cost of construction. Titman (1985) and Williams (1991, 1993) developed the first applications of real options theory for pricing of land, focusing on the optimal timing and scale of vacant land development and redevelopment. Capozza and Li (1994) and Capozza and Sick (1994) combine options theory with monocentric urban economic theory and analyze the effect of changes in model parameters on development of vacant land at the urban fringe. Rosenthal and Helsley (1994) focus on the decision to demolish and redevelop housing. Brueckner and

Rosenthal (2006) and Rosenthal (2008) point out that depreciated structures on high valued land are likely to be redeveloped. Dye and McMillen (2007) use hedonic regressions and demolition permits to estimate value at the point of redevelopment.

Several papers studying the correlation between different measures of uncertainty and aggregate real estate development generally find support for real options theory. For example, Sivitanidou and Sivitanides (2000) find that greater demand volatility is associated with lower office-commercial construction rates. Downing and Wallace (2001) study the decision to improve residential real estate by homeowners and find that the volatility of the spread between the return on housing and the cost of capital depresses investment. Moel and Tufano (2002) find that the volatility of gold prices is negatively related to the probability that a closed mine will be opened. On the other hand, allowing flexibility in the use of operating capacity may result in a positive relationship between uncertainty and capacity (Aguerrevere, 2003).

Cunningham (2006) finds negative association between real estate development and price uncertainty, and positive association between land prices and uncertainty. He shows that a one-standard-deviation increase in uncertainty decreases the probability of development by 11 percent and increases vacant land prices by 1.6 percent. Consistent with option theory, Cunningham (2007) further finds that after the imposition of an urban growth boundary in Seattle area, price uncertainty no longer delays investment.

The problem with this stream of literature is that there are competing explanations for the observed relationships suggested by real options theory. For example, a negative relationship between uncertainty and investment can also be attributed to non-diversifiable risk or incomplete markets in the presence of risk aversion. Therefore, net present value (NPV) theory predicts the same negative relationship between risk and investment as option theory. Grenadier (2002) points out that competition can eliminate most or all of the value of delay, so the NPV rule may be empirically relevant.[1] To address this issue, Bulan, Mayer and Somerville (2009) decompose total uncertainty into systematic and idiosyncratic risk. They find negative association of both measures with the probability of investment, providing support for real options theory rather than alternative interpretations. Similarly, Holland, Ott, and Riddough (2000) find negative short-term relationship between systematic and total risk and aggregate rate of construction for commercial real estate.

In net present value theory, an increase in expected volatility decreases investment value, whereas option value theory predicts an opposite sign because the portion of the asset value that can be attributed to option value is increasing in volatility. Our approach is to devise a new empirical method for measuring option value, then check for the predicted relationship between option value and volatility as well as other predictors of option value.[2]

Real option value has long been modeled as a non-negative addition to the value of an existing real asset without the option.[3] This implies the possibility of empirically estimating the value added by the option to develop or redevelop – NPV theory predicts that this part of value will be near zero. To the best of our knowledge, only one empirical

[1] Grenadier (1999) argues that information cascades can cause firms to ignore private information, possibly developing property earlier than without strategic exercise.

[2] Bulan, Mayer and Somerville (2009) and Grenadier (2002) point out that competition may drive markets to develop early, pushing the optimal time towards the net present value rule and eliminating the value of the option to wait. Our model predicts a positive association between volatility and options value, whereas NPV theory predicts that value declines with volatility.

[3] Dixit (1989) and Capozza and Li (1994) model option value as additive to the present value of operating income from an existing asset.

paper, Quigg (1993), estimates the value of a real option as an addition to intrinsic value.[4] Quigg defines an option premium as the percentage difference between the price when the option is in the money and intrinsic price, which is defined as the price when the option has near zero value. She finds that residential urban land prices contain a 1% to 11% option premium, with a mean of 5-6% in Seattle during the 1976-79 period.

Quigg's (1993) theoretical model assumes that the price of the underlying asset (i.e., an optimal building) is observable. Her empirical analysis finds optimal building value for vacant land using hedonic model estimates for a sample of developed properties. However, she ignores the presence of option value in these developed properties. To remedy this and generalize from vacant land, we focus on the option to redevelop an existing structure. We use a general hedonic model that includes a non-negative additive option value term.

The present paper contributes to the literature by developing methods to identify municipalities, counties or metropolitan areas likely to have significant redevelopment option value. We show that standard data readily available to practitioners using large databases, such as house sales and a few basic municipal characteristics can successfully identify towns with high and low option value.[5] Moreover, our method allows identification of individual properties likely to have high option value.

We start with the assumption that most towns have little redevelopment option value for a typical house within the town: i.e., any option value is isolated to a few

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[4] Quigg (1993) uses an infinite horizon continuous time options theoretic framework. She defines intrinsic asset value as the value when the variance of the underlying stochastic price process approaches zero. She assumes that before redevelopment the property yields net rents equal to a percentage of the value of the underlying (redeveloped) asset. Williams (1997) allows the pre-redevelopment value to depend on current realizations from the stochastic process and he allows repeated redevelopment.

[5] A town is said to have high option value if the cross-sectional variation of property prices within the town is at least partly attributable to real options value.

neighborhoods. The reasons for this include: owner occupiers have high psychic costs associated with option exercise;[6] exercise increases supply and reduces option value for remaining properties; available vacant land (low household density) reduces redevelopment option value;[7] low price or low volatility of price reduce option value; price is greater than a trigger value in only a few sub periods; and, high effective property tax rates discourage redevelopment.

Starting with the knowledge that option value is limited in most towns, we motivate our study with the following question: can we identify towns with high option value and measure the value of option to redevelop individual houses using a standard hedonic dataset?

Our measure of option value begins with hedonic theory (Rosen, 1974). The product of the existing hedonic vector and the vector of implicit market prices of each attribute represents the present value of the service flow from existing structure - the use value.[8] The assumption underlying this standard hedonic model is that option value is near zero. Options pricing theory allows us to relax this assumption by adding option value to use value, i.e., property value is then the sum of use value and option value. The option value term is necessarily non negative and it is a function of the expected present value of the service flow from the redeveloped property less redevelopment cost and the foregone rent from the existing vector of hedonic characteristics.

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[6] For example, an elderly couple in a small, old house in a neighborhood with large new houses (i.e., when the option is clearly deep in the money) may not want to exercise.

[7] The use value of the existing structure must be sacrificed when it is exchanged for a new structure; this is not the case for vacant land.

[8] Of course, standard hedonic explanatory variables may “pick up” option value. But our goal is to measure the amount of option value, if any.

We capture the presence of option value with an intensity variable (i.e., the existing value of structure divided by land value), which is added to a standard vector of hedonic characteristics.[9] Low intensity corresponds to high value of the option to redevelop – intensity increases with the value of the interior area, decreases in land value, and is lower in highly valued locations where the land value is high relative to the value of the structure. For each town, we estimate the marginal effect of intensity as the percentage price difference between low-intensity and high-intensity properties. A town is said to have high option value for a typical house if the marginal effect of intensity is positive and significant. This method assumes good control for location within a town and for existing structural characteristics: i.e., the method is motivated by the difference in value between a large new house (a "McMansion") and a neighboring small old house.

We test our model with over 162,000 real estate transactions in 53 towns in Connecticut (CT) between 1994 and 2007. This complements the analysis performed in Clapp and Salavei (2010) which focuses on a single town where they have detailed information on spatial characteristics such as distance from Long Island Sound. In this study we have a typical hedonic data set which lacks detailed location information; e.g., the Federal Housing Finance Authority (FHFA) house price indices use data aggregated at the region, metropolitan area and state level.[10]

This study conducts town level analysis; this level controls for property taxes, schools and other local public goods, as well as many location amenities. We focus on cross-town analysis where price indices estimated from the standard hedonic model can

[9] Our method does not require teardowns whereas Rosenthal and Helsley (1994) and Dye and McMillen (2007) do. All we need is the possibility of substantial renovation – e.g., major rehabilitation of a historic building, where the exterior is protected from major change.

[10] The FHFA produces house price indices with broadest coverage within the US. Their researchers cannot control for location below the zip code level.

be used to estimate the volatility of price. While the majority of towns in CT do not have much option value, nearly 20% of towns are identified to have positive option value with a mean value of about 32%.[11] We show that volatility is an important variable separating those towns with high option value from others. Most important, both our cross-town and cross-period findings reject NPV theory in favor of option value theory: 1) towns with high volatility have high value of option to redevelop and 2) option value increases with volatility in the 2001-2007 period but not the 1994-2000 period. Consistent with real options theory we also find that drift in house prices is positively associated with the value of option to redevelop; there is a U-shape relation between option value and house price adjusted for structural characteristics; effective property tax rates reduce the value of option to redevelop.

The paper makes several contributions to the literature. First, it develops a novel approach to identifying high option value towns and measuring the value of option to redevelop for specific properties within those towns. There are several advantages to our proxy for the option to redevelop. First, it can be easily calculated for large datasets. Second, while motivated by theory, the measure is data driven and is not sensitive to the assumptions about model parameters as in Quigg (1993). Third, our method uses data on the sales of existing houses, which is much more widely available than sales of vacant land, zoning and demolition permits used in most previous studies of the option to redevelop.

Second, to the best of our knowledge, this is the first paper to evaluate the relation between estimated values of redevelopment options and volatility. It complements previous results that found a negative relation between volatility and propensity to

[11] This number applies only to the 25% of properties most like vacant land.

develop (Bulan, Mayer and Somerville, 2009).[12] Third, it is the first paper to test the relation between the value of the option to redevelop and socio-economic characteristics.

The remainder of this paper is organized as follows: Section 2 discusses the implications of option to redevelop for the hedonic pricing model; Section 3 outlines empirical methods and hypotheses; Section 4 describes the data; Section 5 presents results; Section 6 compares our results to findings in related studies and Section 7 concludes.

2. Option to redevelop and hedonic pricing model

Hedonic theory deals with the pricing of commodities that can embody varying amounts of a vector of attributes *q*. Rosen (1974) develops a theoretical framework in which hedonic price function *P(q)* is the equilibrium price arising from bids of buyers and sellers. A standard hedonic equation takes on the following form.

$$P_i = \gamma + \alpha_1 q_{1i} + \alpha_2 q_{2i} + \ldots + \alpha_n q_{ni} + \varepsilon_i \tag{1}$$

where *i* indexes individual sales, each with *n* hedonic characteristics, γ is the intercept, and α_i measure implicit market prices. The iid disturbance term ε arises from negotiation between buyers and sellers.

Clapp *et al*. (2008) derive a more general form of hedonic pricing model that incorporates the option to redevelop, and they show that cross-sectional hedonic equilibrium exists in the presence of additive option value. Rosen specifically excluded the value of durable assets from his theory to "avoid the complications of capital theory (1974, p. 37)." The hedonic model with real options is a solution to a standard hitting

[12] Quigg (1993) estimates volatility implied by her model, which assumes positive relationship between the value of the option to redevelop and volatility.

time problem, where the investor maximizes the expected net present value of an aggregate measure of the vector of hedonic characteristics, q_a. I.e., they consider the option to replace the vector of characteristics with a new aggregate level (the teardown option).

Empirical implications of theory can be motivated by the following standard solution for the price of a dividend paying asset in the presence of a call option:[13]

$$P(q_a) = \frac{q_a p}{r-\mu} + B_0 q_a^{B_1} \text{, where } B_1 < 0 \text{ and } B_0 \geq 0 \tag{2}$$

where q_a is a scalar index of aggregate structure, *r* is the discount rate and μ is the drift in price (*p)* per unit of housing.[14] The B_i parameters are functions of: 1) the current level of price; 2) the parameters of the stochastic process for *p*; 3) the parameters of the cost function; and 4) the solution to the fundamental quadratic equation.

The first term in equation (2) is the standard hedonic model specification and represents present value of the service flow from the current attributes of the asset. The second term is the value of the option to redevelop to an optimal aggregate level, q_a^n. It equals the expected present value of the level of service flow after redevelopment less the cost of redevelopment and less the loss of rents from the existing level of the asset. The existing level of the aggregate vector q_a enters the option value term because the strike price increases in q_a. In cross-sectional hedonic equilibrium, it is q_a that differs across sales. An important implication of this model is that the option term is additive to the

[13] Sick (1990, equations IV.7 – IV.11) derives a similar valuation equation for a dividend paying asset. In his model, as in equation (2), he first term is the present value of an infinite stream of dividends and the second (options value) term declines with the present value of dividends, which are added to the cost of exercise.
[14] A similar solution with depreciation, δ, is developed in Williams (1997), equation (14).

standard hedonic specification summarized by the first term on the right hand side of equation (2).

Equation (2) has q_a in both terms. How does an empiricist separately identify use value (the first term) and option value (the second term)? The key is that land and structure affect property value in two different ways. Option pricing theory suggests that redevelopment is more likely when land value is high but structure value is low – i.e., a smaller, older structure on a valuable land parcel. On the other hand, hedonic pricing theory suggests that net present use value increases with both the value of land (e.g. better location and larger lot) and structure (e.g. larger interior area and newer building).

As discussed in Clapp and Salavei (2010), the standard hedonic model with an option to redevelop can be identified by the inclusion of a non-linear function of intensity measured as the ratio of the assessed structure value to assessed land value.[15] When the value of structure is high relative to land value (e.g. large properties on small lots; new properties in suburban developments), the proposed measure of intensity is high; the property is close to optimal intensity. In such cases, we expect option value to be small. On the other hand, low structure to land value ratio corresponds to low intensity and high value of the redevelopment option. An example of this is the teardown of small, old houses on large highly valued lots and their replacement with larger structures.

3. Empirical methods and hypotheses

We test the ability of the model in equation (2) to identify towns where properties are likely to have high option value and to measure the value of option to redevelop. We

[15] Assessed land and structure value for property tax purposes is publicly available information in most parts of the US and in many European countries.

estimate the hedonic model with a sample of 162,454 residential real estate transactions in 53 towns in the State of Connecticut between 1994 and 2007. We estimate the standard hedonic model and three specifications of the hedonic model augmented with intensity to capture the option to redevelop. The latter specifications allow us to identify towns with high option value. To verify whether the towns so identified really contain option value, we test if these towns are associated with the characteristics implied by real options theory; the key characteristic of interest is the volatility of house prices. First, we perform univariate analysis by comparing towns with positive option value to towns with zero option value. We then analyze the determinants of the likelihood of a town having positive option value using a logit model. Finally, we examine determinants of the value of the option to redevelop with tobit regressions.

We estimate the models separately for each town with sufficient data. This allows for Tiebout sorting effects: public services and taxes will be different for each town and these differences will be capitalized into property values. Town values can diverge over time, making options more or less valuable. In addition, each town has different zoning restrictions and different regulations governing demolition or major rehabilitation.[16]

3.1. Standard and option-based hedonic models

First, we estimate the following specification of the standard hedonic model.

Model 1: The standard cross-sectional hedonic model: [17]

$$\ln \text{Price} = \alpha q + \varepsilon \tag{3}$$

[16] Permits for renovation, major rehabilitation and teardown of residential properties are not typically denied in Connecticut. However, regulations can make the process more or less onerous.
[17] We omit property subscript i in all equations for brevity.

where *Price* is the sale price, q is a vector of hedonic characteristics (including a vector of ones), and α is a vector of implicit market prices for each attribute. Our data provides for the following standard hedonic variables: age and age squared (Age and Age^2), indicator variable that equals one if the property has two or three bedrooms (*Bed2or3*), indicator variable that equals one if the property has more than three bedrooms (*Bed3p*), interior square footage and footage squared (Ftg and Ftg^2), size of the lot in square feet and size squared ($Lotsf$ and $Lotsf^2$), and year dummies.[18] Property location is controlled for through a set of land value indicator variables (LV_q) interacted with footage and footage squared. LV_q equals one when the residuals from regressing the log of assessed land value on the log of lot size is in its q^{th} quartile. Equation (4) for our data takes the following form:

$$\begin{aligned} \ln \text{Price} = \alpha_0 + \sum_{q=2}^{4} \text{LV}_\text{q}\left(\alpha_{1\text{q}} + \alpha_{2\text{q}}\text{Ftg} + \alpha_{3\text{q}}\text{Ftg}^2\right) + \alpha_4\text{Ftg} + \alpha_5\text{Ftg}^2 + \alpha_6\text{Lotsf} + \\ \alpha_7\text{Lotsf}^2 + \alpha_8\text{Age} + \alpha_9\text{Age}^2 + \alpha_{10}\text{Bath3p} + \alpha_{11}\text{Bath2or3} + \alpha_t\text{Year}_t + \varepsilon \end{aligned} \quad (4)$$

where $Year_t$=1 if the sale occurs in year t, otherwise zero.

As discussed earlier, a non-linear function of intensity can capture the value of option to redevelop if added to the standard hedonic model. Intensity is defined as the ratio of assessed structure value to assessed land value. An advantage of this measure is that the value of land and structure are assessed infrequently, and the assessed values are determined by sales prices that occurred during earlier years.[19] Therefore, our intensity variable is predetermined, reducing endogeneity concerns. For example, in Greenwich,

[18] See Table 1 for more detailed variable description.

[19] Major construction on any property triggers revaluation, but on the same basis as other valuations. For example, if a bedroom is added, it is valued as if it existed at the time of the last general revaluation.

CT the assessor's office revalues properties every four years as required by state law.[20] To deal with the problem of the revaluations that occur within our sample period, we de-trend the log of intensity (*LINT*) using the following auxiliary regression for each town:

$$\text{LINT} = \delta_0 + \delta_t \text{Year}_t + \omega \tag{5}$$

The residual of regression (5) (*LINT'*= $\hat{\omega}$) is then ranked and converted into two indicator variables: 1) *LINT25'* represents low intensity, which equals ten when the value of *LINT'* is in bottom 25% and zero otherwise, and 2) *LINTG75'* represents high intensity, which equals ten when the value of *LINT'* is in top 25% and zero otherwise. These two indicator variables constitute the empirical counterpart to the intensity term, the last term in equation (2).

We estimate three different specifications of option-based hedonic model. The first model simply adds *LINT25'* and *LINTG75'* to equation (4). We also include a dummy variable *LINT_Z* to capture the disproportional effect of missing or very low intensity values. *LINT_Z* equals ten when the value of *LINT'* is in bottom two percent or is missing, and zero otherwise.

Model 2: Option-based hedonic model:

$$\ln \text{Price} = \alpha q + \beta_0 \text{LINT\_Z} + \beta_1 \text{LINT25}' + \beta_2 \text{LINTG75}' + \varepsilon \tag{6}$$

Here, α is a vector with dimension corresponding to q. The product αq summarizes all the terms in equation (4).

In Model 3 we isolate, more explicitly, the option value effect on age and depreciation by interacting *Age* and Age^2 with *LINT25'* and *LINTG75'*. Real options theory predicts that intensity should have a bigger effect for older properties. The strike

[20] Some towns obtain exceptions allowing longer time between revaluations.

price of the property that produces low revenue stream in its current form will be smaller. Therefore, a highly depreciated property will have a higher value of option to redevelop and a higher sensitivity to intensity changes than a newer property.

Model 3: Option-based hedonic model with LINT25' and LINTG75'-Age interaction

$$\begin{aligned}\ln \text{Price} = {} & \alpha q + \beta_0 \text{LINT\_Z} + \\ & \text{LINT25}'\left(\beta_1 + \beta_2 \text{Age} + \beta_3 \text{Age}^2\right) + \text{LINTG75}'\left(\beta_4 + \beta_5 \text{Age} + \beta_6 \text{Age}^2\right) + \varepsilon\end{aligned} \tag{7}$$

Our final model, Model 4, accounts for changing market conditions by including an indicator variable *B00* that equals one if the property is sold in or before 2000 and zero otherwise; and another indicator variable *A00* that equals one if the property is sold after 2000 and zero otherwise.

Model 4: Option-based hedonic model with LINT25' and LINTG75'-Age interaction and B00 and A00 indicators

$$\begin{aligned}\ln \text{Price} = {} & \chi q + \beta_0 \text{LINT\_Z} + \\ & \text{B00}\left[\text{LINT25}'\left(\beta_1 + \beta_2 \text{Age} + \beta_3 \text{Age}^2\right) + \text{LINTG75}'\left(\beta_4 + \beta_5 \text{Age} + \beta_6 \text{Age}^2\right)\right] + \\ & \text{A00}\left[\text{LINT25}'\left(\beta_7 + \beta_8 \text{Age} + \beta_9 \text{Age}^2\right) + \text{LINTG75}'\left(\beta_{10} + \beta_{11} \text{Age} + \beta_{12} \text{Age}^2\right)\right] + \varepsilon\end{aligned} \tag{8}$$

We estimate Models 1-4 separately for each of 53 towns. Next we address interpretation of the *LINT* related coefficients: in particular, how are these coefficients used to identify the presence of option value for a typical property separately from the role of land value in the standard hedonic model?

Interpreting the LINT and land value coefficients

Land value enters the standard urban economic model through rent per unit of housing services: i.e., better locations command higher rent per square foot of interior space. Land value is calculated as a residual, property value (capitalized value of net operating income) minus the cost of the structure.[21] We model the effect of land value on capitalized rents with the *LV* terms in equation (4).

Correct specification of land value is important because the *LINT* variable is inversely related to land value and therefore could capture any omitted location characteristics other than option value within each town. We use a flexible functional form to separately identify the effect of land value and option value. In equation (4), land value enters as quartile dummies interacted with interior square footage. If these dummies are working to properly shift land value, then the effect of a given footage on value should increase as a function of the quartile dummy. From equation (4), the marginal effect of the land value dummy is:

$$ME\_LV_q = \alpha_{1q} + \alpha_{2q} FtgM + \alpha_{3q} FtgM^2 \tag{9}$$

where FtgM is the mean value of footage within the town.

A necessary condition for our option-based models to separate land value from option value is that ME_LV_{q} must increase as the land value quartile increases:

Hypothesis 1: *If land value increases capitalized rent for a given square footage in equation (4), then* ME_LV_{q} *increases as follows:*

$$\begin{aligned} &ME\_LV_2 > 0 \\ &ME\_LV_3 > ME\_LV_2 \\ &ME\_LV_4 > ME\_LV_3 \end{aligned} \tag{10}$$

Hypothesis 1 may not hold when a non-negative option value term is omitted from equation (4), or when the effect of land value is not fully captured by the functional form. When LINT variables are included in equations (5) – (7), option value is said to be present for the lower quartile of properties only if Hypothesis 1 holds and the marginal

[21] See Clapp and Salavei (2010) for more on how land value is specified in the hedonic equation.

effect of *LINT_Z* plus *LINT25'* is positive. This is a strong requirement for the presence of option value because if Hypothesis 1 does not hold, any misspecification in land value will be reflected negatively in *LINT_Z* and *LINT25'*. In other words, the *LINT* variables simply pick up, negatively, misspecification in land value, biasing estimates of option value downward. If a town does not have positive option value for the lower quartile of houses ranked by intensity, then a negative sign on the sum of these two *LINT* variables would be expected; in this case, the land value quartiles (equation (4)) may not capture all the intra-town variation in land value.

To summarize, we determine the presence of option value by calculating the marginal effect of properties in the lowest quartile of intensity for each town *k* for each model, denoted as $ME1_k$. $ME1_k$ measures the ln(*Price*) difference between a house low (lower quartile) intensity and one with middle (25^{th} to 75^{th} quartile, the omitted category) intensity:

$$\text{Model 2: } ME1_k = 10 \times \left(b_{1,k} + b_{0,k} \right) \tag{11a}$$

$$\text{Model 3: } ME1_k \left(Age \right) = 10 \times \left[b_{1,k} + b_{2,k} Age_k + b_{3,k} Age_k^2 + b_{0,k} \right] \tag{12a}$$

$$\text{Model 4: } \begin{aligned} ME1_k \left(Age, \text{subperiod} \right) = B00 \times 10 \times [b_{1,k} + b_{2,k} Age_k + b_{3,k} Age_k^2] + \\ A00 \times 10 \times [b_{7,k} + b_{8,k} Age_k + b_{9,k} Age_k^2] + b_{0,k} \end{aligned} \tag{13a}$$

where b_{ik} is the i^{th} estimate of β_{ik} in Models 2 to 4 for the k^{th} town and the marginal effect can be evaluated at any property Age. Note that equation (13a) implies different marginal effects for each time period identified by *B00* (≤ 2000) and *A00* (> 2000).

Positive marginal effects ($ME1_k>0$) suggest positive option value, with the amount of option value equal to $ME1_k$. Non-positive marginal effects ($ME1_k \leq 0$) indicate a town with zero option value. The marginal effects are for the lowest intensity (lowest quartile of *LINT*) properties: i.e., those with the highest possible redevelopment potential.

Next we consider a specification of option value that further controls for omitted location (land value) characteristics. This method uses the highest intensity properties, those in the *LINTG75'* category. It is motivated by two observations:

1. We would expect the best locations to be developed and redeveloped first, so the houses near optimal configuration (*LINTG75'*=10) are expected to be in better locations within a town. If location characteristics have been adequately controlled for, *LINTG75'* houses should have little option value and its coefficient should be smaller than $ME1_k$.
2. Large new houses ("McMansions") are found within the same town as small older houses, often in the same block or neighborhood. In this case, we expect the coefficient on *LINTG75'* to be smaller than $ME1_k$. That is, the property with the smaller, older property is worth more than the larger, newer property because of option value. This can only be the case if we have correctly controlled for structural characteristics and land value with the explanatory variables in equation (4).[22]

Therefore, we further compare $ME1_k$ with the coefficient on *LINTG75'* by calculating $ME2_k$, which is the ln(Price) difference between a house with low (lower quartile) and one with high (upper quartile) intensity. If the following strong conditions also hold in towns with $ME1_k>0$, then land value has been controlled for and we have identified a town with high option value:

$$\text{Model 2: } \mathrm{ME2}_k = \mathrm{ME1}_k - 10 \times b_{2,k} = 10 \times \left(b_{1,k} + b_{0,k} - b_{2,k}\right) > 0 \qquad (11b)$$

[22] If H1 is not confirmed (i.e., land value is not completely controlled in equation (4)), then $ME1_k>0$ and $ME2_k>0$ will provide conservative (downwardly biased) estimates of option value.

$$\text{Model 3: } \mathrm{ME2_k}(\mathrm{Age}) = \mathrm{ME1_k}(\mathrm{Age}) - 10 \times \left[\mathrm{b_{4,k}} + \mathrm{b_{5,k}Age_k} + \mathrm{b_{6,k}Age_k^2} \right] > 0 \quad (12b)$$

$$\begin{aligned} \text{Model 4: } \quad & \mathrm{ME2_k}(\mathrm{Age,subperiod}) = \mathrm{ME1_k}(\mathrm{Age,subperiod}) \\ & - B00 \times 10 \times \left(b_{4,k} + b_{5,k} Agek + b_{6,k} Age_k^2 \right) \\ & - A00 \times 10 \times \left(b_{10,k} + b_{11,k} Agek + b_{12,k} Age_k^2 \right) > 0 \end{aligned} \quad (13b)$$

Hypothesis 2: *Option value has been identified separately from land value if towns with* $\mathrm{ME2_k}>0$ *are also towns with* $\mathrm{ME1_k}>0$*. The two have not been correctly identified if towns have* $\mathrm{ME2_k}>0$ *but* $\mathrm{ME1_k}\leq0$ *or if* $\mathrm{ME1_k}>0$ *and* $\mathrm{ME2_k}\leq0$.

The logic of hypothesis 2 is explained in Figure 1, where the dashed lines represent possible estimates of the log of the option value term in equation (2). Option value is only present in quadrant 1, where the intercept is positive and the slope is negative. In this case, the coefficients on the *LINT25'* and *LINT_Z* dummy variables will be positive and greater than the coefficient on *LINTG75'*. The intuition is that the larger newer quartile of properties (*LINTG75'*=10) will be less valuable than the smaller, older houses (*LINT25'*=10) only if we have correctly controlled for land value and structural characteristics. If $\mathrm{ME1_k}>0$ and $\mathrm{ME2_k}>0$, then we have identified ***positive option value towns***. The rest of the towns (quadrant 2) are zero option value towns. Significant positive signs for these two quantities necessarily provide a conservative estimate because any misspecification of land value or structural characteristics will tend to produce rejection of H2 as indicated by the upward sloping dashed line in quadrant 2.

Statistical tests for the presence of option value

In this section, we develop statistical tests for our contention that $\mathrm{ME1_k}>0$ and $\mathrm{ME2_k}>0$ indicate the presence of option value. Options theory predicts positive relationship between option value and price volatility. We measure volatility, $\sigma_j(\Delta\alpha_{t,k})$, as the standard deviation of annual capital returns for each model *j* and each town *k*, where $\Delta\alpha_{t,k}$ is the first difference of the estimated time coefficients between time *t* and *t*-1.

Hypothesis 3: *Option value is positively associated with town volatility.*

If we find positive correlation, then we have increased confidence that option value can be distinguished from value due to the potential for positive NPV projects. In other words, we have addressed the issue raised by Bulan, Mayer and Somerville (2009).

We propose univariate and multivariate tests for the presence of option value. All tests are based on the following town-level variables that are associated with the presence of option value:

Positive:

- *Drift in house prices* within the town is positively associated with returns from developing to the optimal level. This is analogous to the dividend payout on a stock which can motivate the exercise of an option.
- *Volatility of house prices* within the town should be positively associated with option value.
- *Household density* (number of households per square foot of land area) indicates more need for redevelopment because less undeveloped land is available.
- *Percent of land developed* also indicates less undeveloped land is available.
- Price adjusted for structural characteristics *(Adjusted price)* – predicted price from a hedonic model with a constant set of characteristics for all towns. Cost to build (positively related to strike price) should be similar across towns, so higher price is associated with high option value. However, deep in the money options trade like stocks: the value of the option disappears. Therefore, we expect an inverted U-shape.
- *House age* increases option value by reducing a portion of the strike price: the foregone value of the existing structure.[23]
- *Population growth* increases demand for housing.

Negative:

- Per capita income *(PCI)* after controlling for predicted price. Higher PCI indicates fewer liquidity constraints on exercise, faster exercise eliminates option value in two ways: 1) the property is near optimum configuration after redevelopment; 2) exercise increases supply, reducing the value of remaining options.

[23] The redevelopment option is an exchange option: the value of the existing vector of hedonic characteristics is exchanged for a new configuration.

- *New house sales as a percent of total sales.* This is associated with a lot of vacant land, which reduces the value of the redevelopment option.[24]
- *Percent change in land developed*.
- *Effective property tax rates* reduce option value by increasing the cost of maintaining the new, more valuable property.
- *Growth in the property tax levy* in the town. Owners of more valuable property can expect further growth in property tax rates.

Neutral:

- Percent of housing stock that is owner occupied *(Percent owner occupied)*. Theory applies equally to owner occupied and rental housing. We assume here that PCI is controlled, so any effect of owner occupancy on liquidity has been controlled.

We test for the predicted signs of this list of town variables. We hypothesize that towns with $ME1_k>0$ and $ME2_k>0$ should have significantly different values for these variables than other towns:

Hypothesis 4: *Option value is associated with town characteristics in the direction predicted above.*

4. Data

Our sample contains 162,454 single-family residential properties sold between 1994 and 2007 in 53 towns in Connecticut. The state of Connecticut represents a particularly good opportunity to study redevelopment because most of the land, especially in the most desirable locations, has been developed many years ago. The scarcity of vacant land with approvals for development suggests that option value for existing residential properties is important in Connecticut.

Our data is from the Warren Group, publishers of Bankers & Tradesman, a business and real estate newspaper covering New England states (B&T thereafter). B&T collects the data via visits and electronic connections with Connecticut town halls. B&T

[24] However, large increase in new construction can also imply that the land became relatively expensive. Spiegel (2001) develops a general equilibrium model which predicts that developers purchase land when it has a high expected return relative to homes in good condition, and develop and sell their land when it becomes relatively expensive.

data contains all residential property transactions in the state of Connecticut. The dataset contain property characteristics at the time of sale: see Table 1 for description of relevant variables. We apply filters used in Clapp and Salavei (2010) to ensure data quality.[25] When each model (Model 1 to 4) is estimated, the DFFITS procedure is applied to detect and remove influential observations in each town. An observation is classified as influential if its DFFITS value is larger than two times the square root of the number of parameters divided by the number of observations.[26]

Among 53 towns, the most active housing markets have more than 7,000 sales over the study period. The least active still records more than a thousand sales. As a whole, 53 towns have an average sale price of $462,677, property age of 40 years, interior square footage of 1,853sf, and lot size of 34,860sf. The mean value of *LINT* is 0.293, indicating that structure value averages 34% (=exp(.293)-1) higher than land value.[27] Lower intensity is not associated much with higher building age; for example, several towns have very low *LINT* while their building age is not particularly high. On the other hand, high intensity is found in towns with high building age, probably because of their relatively low land value. Overall, there seems to be little association between *LINT* and other hedonic variables, suggesting that intensity could provide additional information that helps single out the options component in the hedonic framework. The distributions of the hedonic and intensity variables by towns are summarized in Tables 2 and 3, respectively. The amount of option value embedded in each town may differ

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[25] As in Clapp and Salavei (2010), our sample is restricted to single-family residential properties with 1) warranty deeds, 2) sale price over $50,000, 3) interior footage over 300sf and lot size between 1,500sf and 10 acre, 4) more than three rooms and at least one bathroom, 5) structures built between 1901 and 2006, and 6) records of assessed building and land value. We also excluded those towns with not more than three sales in a year which might give an unreliable estimate of time effects and hence return volatility.

[26] See Belsley et al. (1980) for details. The DFFITS procedure removes about 5% of the observations from our sample.

[27] *LINT'* has a zero mean by construction; see Equation (5).

considerably, given the variations in *LINT* and other hedonic variables (e.g. Age) across towns.

5. Results

5.1. Standard hedonic model (Model 1)

Table 4 shows the results of estimating standard hedonic model as specified in equation (4) (Model 1) separately for each town. The average adjusted R^2 for Model 1 is 85.2%. The coefficients on hedonic characteristics are as expected for most towns. Previous literature finds that the house price should be decreasing in *Age* but increasing in Age^2: i.e., the rate of depreciation declines with age.[28] We observe this relationship in most towns in Connecticut. Coefficient α_8 on *Age* is negative and significant for 49 towns (92%) and is insignificantly different from zero for 3 towns (6%). Coefficient α_9 on Age^2 is positive and significant for 45 towns (85%), insignificantly different from zero for 5 towns (9%), and negative and significant for 3 towns (6%).[29]

The equation also includes variable *Bath2or3* that equals one for houses with 2 or 3 bathrooms and variable *Bath3p* that equals one when the house has more than three bathrooms, an indicator of large, luxurious houses ("mansions"). We expect and find that the coefficients on both of these variables are positive for most towns. Coefficient α_{11} on *Bath2or3* is positive and significant for 52 towns (98%) and is insignificantly different from zero for 1 town (2%). Coefficient α_{10} on *Bath3p* is positive and significant for 40 towns (80%) and is insignificantly different from zero for 10 towns (20%).[30] The average

[28] Dye and McMillen (2007) and many others have documented this pattern.

[29] Hartford is the only town for which significant coefficients on Age and Age^2 are of exact opposite direction than expected. In Hartford, the coefficients indicate that property value increases up to only four years, then decreases. Thus, the generally negative effect of age holds even in Hartford.

[30] Coefficient α_{10} could not be calculated for three towns due to the lack of observations.

coefficient for *Bath3p* adds 11.4% (=exp(.108)-1) to value, compared to 6.0% for *Bath2or3,* indicating some success in capturing the mansion effect.

House price should be increasing in lot size (*Lotsf*), but at a decreasing rate. Therefore, we expect α_6 to be positive (coefficients on *Lotsf*), and α_8 to be negative (coefficients on $Lotsf^2$). We find evidence consistent with this prediction for most towns. Coefficient α_6 on *Lotsf* is positive and significant for 50 towns (94%), negative and significant for 2 towns (4%) and insignificantly different from zero for 1 town (2%). Coefficient α_7 on $Lotsf^2$ is negative and significant for 45 towns (85%), is insignificantly different from zero for 6 towns (11%) and is positive and significant for 2 towns (4%), the same 2 towns that have negative and significant coefficients for *Lotsf*. Thus, the significant effect of *Lotsf* is always positive beyond some small value. Overall, the marginal effect of *Lotsf*, evaluated at mean *Lotsf*, is positive for 51 towns (96%).

Similarly, house price should be increasing in interior square footage (*Ftg*), but at a decreasing rate. For houses at the lower land value quartile (LV_1), coefficient α_4 on *Ftg* is positive and significant for 51 towns (96%), and 33 towns (62%) have negative and significant coefficient α_5 on $Footage^2$.

Table 4, Panel B confirms Hypothesis 1: at a given value of footage (the mean), the capitalized value of rents increases with higher land value quartiles. The increase in ME_LV_q (equation (10)) is significant at the 1% level according to t-test and Wilcoxon signed rank test across the towns. However, the effect of land value on footage is insignificant in many towns as indicated by Panel A: the interaction terms between *Ftg* and other land value quartiles (LV_2, LV_3, and LV_4) are mostly insignificant – for example, coefficients on $Ftg \times LV_3$ and $Ftg^2 \times LV_3$ are insignificant for 37 towns (70%) and 38 towns

(72%), respectively.[31] This suggests a potential downward bias in ME1 and ME2 since they may capture land value not correctly captured in equation (4). If they are greater than zero, then we have a conservative estimate of option value.

5.2. Option-based hedonic models (Model 2-4)

Table 5 compares the marginal effects of properties in the lowest quartile of intensity for Models 2 to 4. Table 5, Panel A shows estimates of coefficient β_0 on variable *LINT_Z*, β_1 on variable *LINT25'* and β_2 on variable *LINTG75'* of Model 2 (equation 6) and calculates the marginal effects, ME1 and ME2, based on equations 11a and 11b.[32] Among the 53 towns, 12 have significantly positive ME1 and 24 have significantly negative ME1.[33] For ME2, 11 show significantly positive values and 29 show significantly negative values. These results suggest that a majority of towns does not have much option value. As suggested by Hypothesis 1, the significant negative values are likely due to variation in land value that is captured negatively in the *LINT* variables. ME1 and ME2 for positive option value towns are highlighted in bold.[34] For these towns the mean (median) ME1 is 32% (29%) and the mean (median) ME2 is 29% (24%).[35]

Hypothesis 2 predicts that towns with positive ME2 – the lowest quartile of intensity adds more to house value than the highest quartile, even though the latter are likely to be better located – should also be the towns with positive ME1. This hypothesis

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[31] Land value appears to be captured by the LV_2, LV_3, and LV_4 dummies. Table 4, panel A indicates that house value increases by about 8%, 15% and 25% at the 2nd, 3rd and 4th quartile dummies, with most towns having significant effects.

[32] For brevity, we do not report coefficients on standard hedonic characteristics in Table 5.

[33] We used a standard F-test of the significance of a linear combination of coefficients.

[34] Recall that positive option value towns are those for which ME1>0 and significant and 5% level and ME2>0 and significant at 5% level.

[35] We translate ME1 and ME2 into percentage effects using exp(coeff)-1.

is confirmed, with the same 11 towns showing significantly positive ME1 as well as ME2 in Model 2. There is only exception, for which ME1>0 and significant but ME2<0 and insignificant.

Table 5, Panel B shows ME1 and ME2 for Model 3, which allows the intensity variables to interact with Age and Age^2; see equation (7) for the formula used. The results for marginal effects for Model 3 (equations 12a and 12b) are very similar to those for Model 2 – most of the towns do not have high option value. We find that ME1 is negative and significant for 26 towns but positive and significant for 10 towns, while ME2 is negative and significant for 28 towns but positive and significant for 10 towns. Among positive option value towns, the mean (median) ME1 is 31% (25%) and that for ME2 is 29% (21%). The ten towns identified to have positive and significant ME2 are exactly those with positive and significant ME1, so Hypothesis 2 is again confirmed.

Table 5, Panel C shows results of estimating Model 4, which further relaxes Model 3 by allowing the effects of the intensity variables to vary before and after year 2000 (see equation (8) for the formula used). We find that the marginal effects as described in equations (13a) and (13b) have changed over time. First, more towns are identified to have high option value in the latter period: before 2000, 7 (10) towns have significantly positive ME2 (ME1); after 2000, 13 (11) towns have significantly positive ME2 (ME1). Second, among positive option value towns, the median ME1 increases from 27.6% to 37.1%. The same holds true for median ME2, which increases from 14% to 33%. The mean for ME1 decreases slightly from 34.4% to 33.9%; the mean for ME2 increases from 31.6% to 34.2%. This suggests that option value may change with interest rates, volatilities, underlying asset prices, strike prices, etc.[36]

Hypothesis 2 is generally supported in Model 4. Before 2000, seven towns share significantly positive ME1 and ME2, except for three towns. These three towns indeed have positive signs for both ME1 and ME2; it is just that their ME2 is not significant. After 2000, significantly positive ME1 and ME2 are found in 11 towns. There are only two exceptions, for which ME1>0 and ME2>0 but with ME1 being not significant.

To summarize, we find that almost 20% of towns in CT have positive OV. Option value for properties in lowest quartile of intensity in positive option value towns has a mean value of 32%.[37] Towns with positive and significant ME1 generally have positive and significant ME2.

5.3. Price volatility and other determinants of option value

5.3.1. Univariate analysis: comparison of positive and zero option value towns

In this section we test whether characteristics of towns with positive value of option to redevelop identified using Models 3 and 4 are consistent with real options theory as predicted by hypotheses 3 and 4.

The main objective of this section is to distinguish option value from redevelopment that occurs whenever the net present value (NPV) of the redeveloped property is greater than zero: see Bulan, Mayer and Somerville (2009) for discussion of

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[36] Our data does not permit us to cross intensity with more sub-periods, but year 2000 seems to provide a natural time point to capture any significant shift in options value. The average interest rate of 1-year treasury bills was 5.5% p.a. during 1994-2000, compared to 3.1% p.a. during 2001-07. The higher interest rates before 2000 should make call options more valuable. On the other hand, housing prices grew much faster during 2001-07, suggesting that higher rates of drift increased call option value after 2000. Also, we find that housing returns in Connecticut during 1994-2000 were less volatile than those during 2001-07 (5.5% p.a. vs. 6.2% p.a.). Section 5.4 provides further analysis on the relationship between option values and volatilities during the whole time period and the two subperiods.

[37] This value is obtained by averaging ME1 and ME2 for positive OV towns across models.

this point. Increases in the volatility of the underlying stochastic process for the price of the house should increase option value but decrease NPV. Therefore, if we find that our estimate of option value is positively related to price volatility this would be a direct test of the contention that we can measure option value with the intensity variable (i.e. hypothesis 3). For each model we estimate town level volatility using the standard deviation of the annual capital return as measured by changes in the time coefficients for each town. We estimate the mean value of volatility to average 7.62% across all models (see Table 6, Panel A). Consistent with predictions of hypothesis 3, we find that the correlation between volatility and option value is positive and significant for all models, except for Model 4 before 2000.[38] This result is robust to using both ME1 and ME2.

Table 7, Panel A shows characteristics of positive option value towns compared to zero option value towns.[39] Positive option value towns are those for which ME1>0 and ME2>0. We find that consistent with real options theory, volatility for positive option value towns (median=11.34%) is higher than for zero option value towns (median=6.71%) and the difference is statistically significant.[40]

In addition to analyzing difference in volatility between positive and zero option value towns, in Table 7, Panel A we compare other town characteristics as discussed in relation to hypothesis 4.[41] We find that positive option value towns have higher mean and median drift in house prices than zero option value towns. Median (mean) drift equals 7.36% (7.20%) for positive option value towns compared with 6.20% (6.43%) for zero option value towns. Median price adjusted for structural characteristics, *Adjusted price,* is

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[38] Option value equals ME1 or ME2 for positive option value towns and zero otherwise.

[39] In Tables 7, 8 and 9 we omit results for Model 2 for brevity. Results for Model 2 are very similar to results for Model 3.

[40] Volatility is estimated from Model 3 time dummy coefficients.

[41] Please see Table 1 for precise definitions of all variables.

higher for positive option value towns ($290,869) than for zero option value towns ($219,538). Both the effective property tax and the growth in the tax levy are lower for positive option value towns. The median effective property tax rate is 1.25% for positive option value towns and 1.57% for zero option value towns. The tax rate increased by 4.97% for positive option value towns compared with 6.05% increase for zero option value towns.

Positive and zero option value towns do not differ with respect to household density, percent of land developed, house age, population growth, PCI, new house sales, percent change in land developed and percent owner occupied. The result for the latter variable is as expected. A potential reason why household density does not differentiate positive and zero option value towns is because household density is high both in high crime and low income urban towns in CT (such as New Haven and Hartford) where option value is near zero and in desirable locations with high option value. The insignificant result for percent land developed, percent change in land developed, new house sales is likely explained by the fact that we do not control for within town location. It is possible that most desirable locations are already developed and option value increases only for already developed land. Age is a noisy variable that often does not reflect major renovations and can capture better quality of construction of older properties.

In Table 7, Panels B and Panel C we separately analyze periods before 2000 and after 2000, respectively. Most results are similar to those in Panel A, except for drift and volatility. Before 2000 positive option value towns do not differ from zero option value towns with respect to volatility and drift of house prices. A possible explanation for this finding is that there were fewer sales in this time period and for some towns our estimate of volatility and drift might be noisy. Results after 2000 reported in Table 7, Panel C are consistent with Model 3 results reported in Table 7, Panel A. After 2000, positive option value towns have higher volatility (median= 13.15%) compared with zero option value towns in this period (median=5.62%). Median volatility for positive option value towns increased from 4.50% in before 2000 period to 13.15% in post 2000 period.

Overall, univariate analysis for Model 3 and Model 4 after 2000 supports real option theory and hypothesis 3 and finds that positive option value towns have higher volatility than towns without redevelopment option. This result is inconsistent with NPV framework. Univariate analysis for Model 3 and Model 4 after 2000 supports hypothesis 4 for drift in house price, adjusted price, effective property tax rate, and growth in the property tax levy. For Model 4 before 2000 univariate analysis supports hypothesis 4 for adjusted price, effective property tax rate, and growth in the property tax levy.

5.3.2. Multivariate analysis of option value determinants

In this section we test hypotheses 3 and 4 in a multivariate setting. First, we use logit model to examine if the likelihood of a town having positive option value is associated with town characteristics as predicted. We standardize all variables on the right hand side to a mean of zero and a standard deviation of 1.

Table 8 shows separate analysis for positive and zero option value towns for Model 3, Model 4 before 2000 and Model 4 after 2000. In the first specification, we include all of the variables that were identified to be important determinants of option value in previous section using univariate tests. We find that volatility is positively associated with the likelihood of positive option value for Model 3 and Model 4 after

2000 in multivariate setting. However, the coefficient on volatility is insignificant in Model 4 before 2000. Drift in house prices has positive coefficient for Model 3 and Model 4 after 2000, but is not significant. Adjusted price has negative and significant coefficient, which is contrary to our expectation of a positive relation between adjusted price and option value. However, the relation between option value and adjusted price is hypothesized to be u-shaped. Therefore, we include a square term of adjusted price in specification 2. As expected, we find positive coefficient on adjusted price and negative coefficient on its square term.[42] In all models, effective property tax rate is negatively associated with the likelihood of positive option value. Growth in the property tax levy has negative coefficient, as expected, but it is significant only for Model 4 before 2000. In results not shown, we include all other characteristics of towns (one at a time) to specifications 1 and 2. Consistent with our univariate analysis, none of the other variables are significant. Overall, logit analysis of the likelihood of positive option value supports hypotheses 3 and 4 for volatility, drift, adjusted price, and property tax for the entire sample period of 1994-2007 and the period after 2000.

Next we estimate a tobit model with option value as a dependent variable, which equals ME1 for positive OV towns and zero otherwise (Table 9).[43] For example, for Model 3 ten towns will have positive option value and 42 will have option value equal to zero. Therefore, we use a tobit model with left censoring; this allows the magnitude of ME1>0 to be associated with the explanatory variables. All results in Table 9 are very similar to those in Table 8. This is especially comforting given that our dependent variable has substantial estimation error in edition to censoring. The only difference is

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[42] These coefficients are significant for Model 3 and Model 4 after 2000, but not for Model 4 before 2000.
[43] Our results are also robust to using a more restrictive definition of positive option value towns, by replacing ME1 with ME2 in all definitions.

that the coefficient on volatility becomes more significant for Model 3 and Model 4 after 2000, and the coefficient on drift of house price becomes significant in specification 1a. As in the case of logit model, we tried alternative specifications adding one at a time all other variables reported in Table 7 to specifications 1 and 2 but do not find any of them to be statistically significant.

6. Relationship to prior literature

Our paper differs from most of prior literature in how we estimate the value of the option to redevelop in the context of a hedonic pricing model. Our results are closely related to findings of Quigg (1993), which, to the best of our knowledge, is the only other paper that values a real option as an addition to intrinsic value. Quigg estimates the value of the option to develop for different types of vacant land in Seattle for the period of 1976-1979. Quigg finds that the value of option to develop low-density residential real estate, the sample most directly comparable to ours, ranges from 1% to 11% with a mean of 5.75%.

Our comparable estimates for positive option value towns, measured by ME2>0 and statistically significant, ranges from 28.7% to 31.6% (Table 5). Since less than 20% of the towns have positive option value, this suggests that the average town has option value of about 6%, well within the range estimated by Quigg. Note that this estimate is relevant only for the lowest quartile of intensity, the part of our sample most similar to Quigg's vacant land. After adjustment for the conservative (downward) bias in our estimates, the average option value is at most 8-9%.[44]

[44] Our tests of H1 suggest that the LINT coefficients are negatively biased by misspecification of land value. The average of negative estimates is about 10%, giving us a rough estimate of 2.0% to 2.5% downward bias for the average town.

Several differences between our method and Quigg's might explain the wider range of estimates we obtain. First, Quigg's model applies to vacant land, a special case of our model when intensity equals zero. Second, Quigg assumes that all developed properties are at their optimal intensity for hedonic estimation of the value of the underlying asset. This omits any consideration of additive option value, our intensity variable. Third, Quigg's option value estimates rely on multiple assumptions and is highly sensitive to them.[45] By way of contrast, our method is data driven.

Our paper is also related to the stream of literature that estimates the impact of volatility on property value.[46] Consistent with real options theory prior literature finds that there is a positive relation between volatility and real estate prices; presumably this is due to a positive association between prices and option value. Our paper is the first to estimate the amount of option value embedded in developed properties. This allows us to test directly the association between option value and volatility and other town characteristics.

7. Conclusions

This paper develops a parsimonious approach to empirically estimating the value of the option to redevelop residential real estate. Our analysis is guided by a generalization of the standard hedonic model to account for the option value of reconfiguring hedonic characteristics. We test this model by adding a non-linear intensity variable to capture the value of the option to redevelop; intensity is measured as a ratio of assessed structure value to assessed land value. Low intensity corresponds to

[45] For example, Quigg makes assumptions about risk-adjusted drift parameters of price and building costs, interest rates, development cost scale parameter, annual standard deviation of development costs, etc.

[46] See Sivitanidou and Sivitanides (2000), Holland, Ott, and Riddough (2000), Downing and Wallace (2001), Cunningham (2006), Cunningham (2007), and Bulan, Mayer and Somerville (2009) among others.

high value for the option to redevelop. Intensity is distinct from the vector of hedonic characteristics because it is decreasing in land value and therefore lot size. Moreover, it correctly captures low option value of large houses and of any house on a low-valued lot. For each town we estimate several specifications of option-based hedonic models that include various functions of intensity and its interaction with other variables.

We pose and test four sets of hypotheses. First, we develop conditions under which land value is properly captured by hedonic vector, implying that the marginal affect of our intensity variable can be used to estimate the value of option to redevelop. Second, we identify option value separately from land value and structure value when a dummy for the lowest quartile of intensity (smaller, older houses) adds significantly more to house value than the upper quartile (larger, newer houses). Third, options theory predicts a positive relation between option value and volatility. Fourth, we develop predictions for the relation between town social and economic characteristics and option value.

Using a sample of over 162,000 sales of residential real estate in the state of Connecticut over the period 1994 through 2007 we find positive option value (our second hypothesis) for nearly 20% of the towns with the mean positive value equal to about 32%. We find support for all four sets of hypotheses. The relationship between option value and volatilities is found to be positive, with virtually all of the effect concentrated in the boom period from 2001 - 2007. This is consistent with the well known nonlinearity of option value: at-the money options are sensitive to changes in parameters whereas other options are much less sensitive. We also find that towns with higher price drift and lower taxes have higher option value.

References:

Abel, A.B. 1983. Optimal Investment Under Uncertainty. *American Economic Review* 73: 228-33.

Aguerrevere, F .L. 2003. Equilibrium Investment Strategies and Output Price Behavior: A Real-Options Approach. *Review of Financial Studies* 16, 1239-1272.

Belsley, D.A., E. Kuh and R.E. Welsch. 1980. *Regression diagnostics: identifying influential data and sources of collinearity*. New York: Wiley.

Brueckner, J., and S. Rosenthal. 2006. Gentrification and neighborhood housing cycles: Will America's future downtowns be rich? Working paper.

Bulan, L., C. Mayer, and C. T. Somerville. 2009. Irreversible investment, real options, and competition: Evidence from real estate development. *Journal of Urban Economics* 65(3): 237-251.

Capozza, D., and Y. Li. 1994. The Intensity and Timing of Investment: The Case of Land. *American Economic Review* 84 (4): 889–904.

Capozza, D. and G. Sick. 1994. The Risk Structure of Land Markets. *Journal of Urban Economics* 35: 297–319.

Childs, P., S.H. Ott and T.J. Riddiough. 2002. Optimal Valuation of Claims on Noisy Real Assets: Theory and an Application. *Real Estate Economics* 30: 415-444.

Clapp, J.M, J. Jou and T. Lee. 2007. Buy to Scrape? Hedonic Pricing with redevelopment Options. Draft paper at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1048801.

Clapp, J.M, and K. Salavei. 2010. Hedonic Pricing with Redevelopment Options: A New Approach to Estimating Depreciation Effects. Journal of Urban Economics 67 (3): 362-377.

Cunningham, C. R. 2006. House Price Uncertainty, Timing of Development, and Vacant Land Prices: Evidence for Real Options in Seattle. *Journal of Urban Economics* 59: 1, 1–31.

Cunningham, C. R., 2007. Growth Controls, Real Options and Land Development. *Review of Economics and Statistics*, LXXXIX(2), 343-358.

Dixit, A. and Pindyck, 1994. Investment under uncertainty. Princeton, NJ, Princeton University Press.

Dixit, A. K. 1989. Entry and Exit Decisions under Uncertainty. Journal of Political Economy, 97(3), 620-638.

Downing, C. and N. Wallace. 2001. A Real Options Approach to Housing Investment. University of California Berkeley working paper.

Dye, R.F. and D.P. McMillen. 2007. Teardowns and Land Values in the Chicago Metropolitan Area. *Journal of Urban Economics* 61: 45-63.

Giaccotto, C., Goldberg, G. M and S. Hegde. 2007. The Value of Embedded Real Options: Evidence from Consumer Automobile Lease Contracts. *Journal of Finance* 62 (1): 1- 482.

Grenadier, S.R. 1999. Information Revelation through Option Exercise. *Review of Financial Studies* 12, 95-130.

Grenadier, S.R. 2002. Option Exercise Games: An Application to the Equilibrium Investment Strategies of Firms. *Review of Financial Studies* 15, 691-721.

Harding, J., Sirmans, C.F. and Rosenthal, S.S., 2007. Depreciation of Housing Capital, Maintenance and house price inflation: Estimates from a repeat sales model. *Journal of Urban Economics* 61 (2): 193-217.

Kovenock, D. and G.M. Phillips. 1997. Capital Structure and Product Market Behavior: An Examination of Plant Exit and Investment Decisions. *Review of Financial Studies* 10: 767-804.

Holland, A., S. Ott and T. Riddiough. 2000. The Role of Uncertainty in Investments: An Examination of Competing Investment Models using Commercial Real Estate Data. *Real Estate Economics* 28: 33–64.

Majd, S. and R. S. Pindyck. 1987. Time to Build, Option Value, and Investment Decisions. *Journal of Financial Economics* 18: 7-27.

McDonald, R. and D. Siegel. 1986. The Value of Waiting to Invest. *Quarterly Journal of Economics* 101(4): 707-728.

Moel, A. and P. Tufano. 2002. When Are Real Options Exercised? An Empirical Study of Mine Closings. *Review of Financial Studies* 15(1): 35-64.

Munneke, H. J. 1996. Redevelopment Decisions for Commercial and Industrial Property. *Journal of Urban Economics* 39(2): 229-253.

Paddock, J. L., D. R. Siegel and J. L. Smith. 1988. Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases. *The Quarterly Journal of Economics* 103 (3): 479-508.

Quigg, L. 1993. Empirical Testing of Real Option-Pricing Models. *Journal of Finance* 48(2): 621-640.

Rosen, S. 1974. Hedonic Price and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* 82: 34-55.

Rosenthal S. S. 2008. Old Homes, Externalities and Poor Neighborhoods: A Model of Urban Decline and Renewal. *Journal of Urban Economics* 63(3): 816-840.

Rosenthal, S. and R. Helsley. 1994. Redevelopment and the Urban Land Price Gradient. *Journal of Urban Economics* 35: 182-200.

Sick, G. 1990**.** Capital Budgeting with Real Options. *Monograph Series in finance and Economics*, Monograph 1989-3 New York, NY.

Sivitanidou, R. and P. Sivitanides. 2000. Does the Theory of Irreversible Investments Help Explain Movements in Office-Commercial Real Estate? *Real Estate Economics* 28(4): 623-662.

Spiegel, M. 2001. Housing Return and Construction Cycles. *Real Estate Economics*, 2001, 29(4), 521-551.

Titman, S. 1985. Urban Land Prices under Uncertaint. *American Economic Review* 75(3): 505-514.

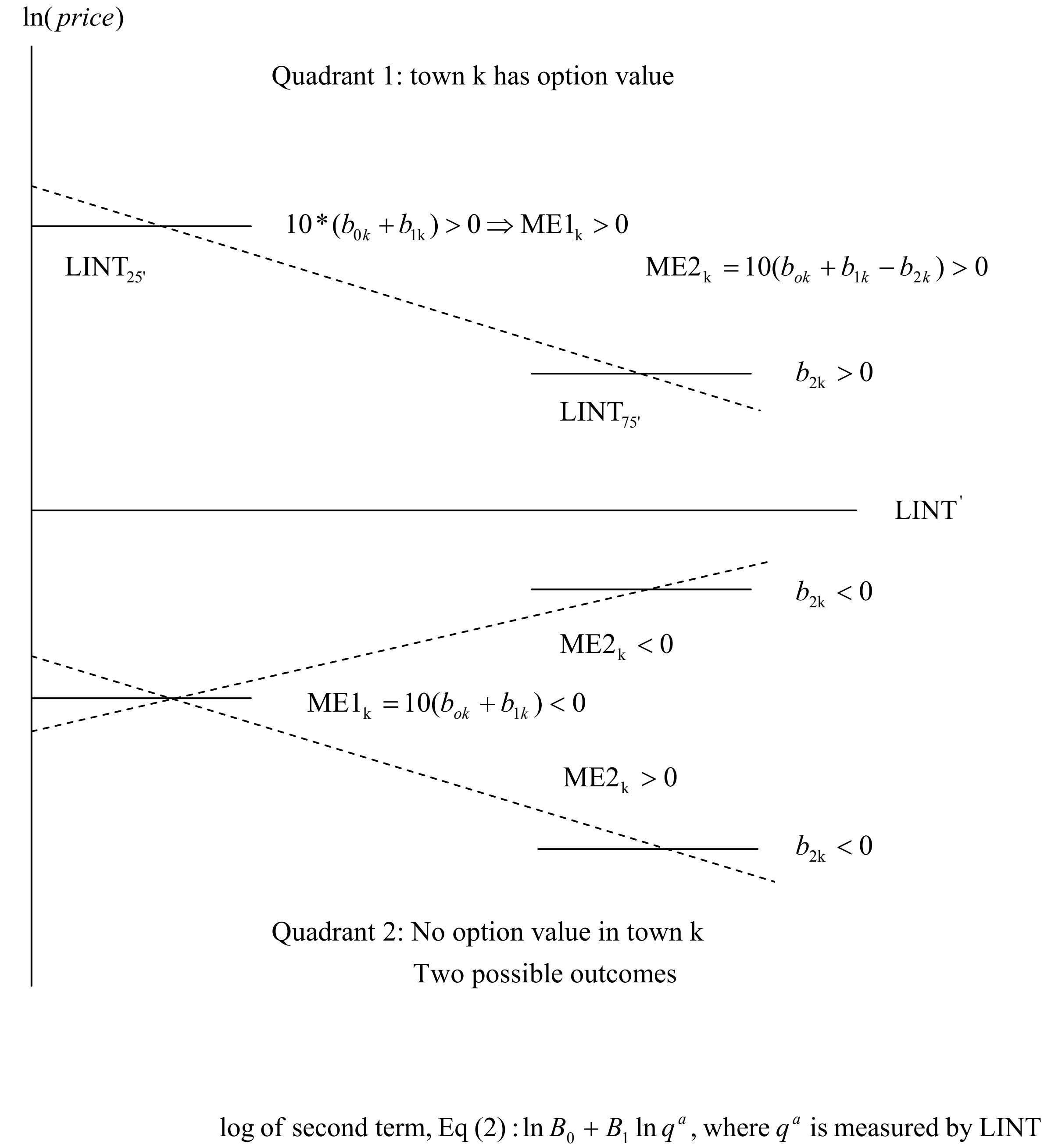
Wang, K. and Y. Zhou. 2006. Equilibrium Real Options Exercise Strategies with Multiple Players: The Case of Real Estate Markets. *Real Estate Economics* 34 (1): 1-49.

Williams, J. T. 1991. Real Estate Development as an Option. *Journal of Real Estate Finance and Economics* 4(2): 191-208.

Williams, J. T. 1993. Equilibrium and options on real assets." *Review of Financial Studies*. 6 (4): 825-850.

Williams, J. T. 1997. Redevelopment of Real Assets. *Real Estate Economics* 25(3): 387-407.

Figure 1: The relationship between theory, equation (2), and estimation of model 2, equation (6)



In quadrant 1 (quadrant 2) the coefficient on $\mathrm{LINT_{75'}}$ may be negative (positive) without loss of generality.

Table 1: Variable description and source of data

Variable Name	Variable Description	Data Source
Standard hedonic		
PRICE	Price at which the property was sold.	B&T
AGE	Age of the property in years.	B&T
BATH2OR3	Equals one if the property has two or three bathrooms; zero otherwise.	B&T
BATH3P	Equals one if the property has more than three bathrooms; zero otherwise.	B&T
FTG	Interior square footage of the property at the time of sale.	B&T
LOTSF	Size of the property's lot in square feet.	B&T
$YEAR_t$	Equals one if the year in which the property was sold is year t; zero otherwise.	Calculated
B00	Equals one if the property was sold in or before year 2000; zero otherwise.	Calculated
A00	Equals one if the property was sold after year 2000; zero otherwise.	Calculated
LV	Assessed value of the lot.	B&T
LV_q	Equals one when the residuals from regressing ln(LV) on ln(LOTSF) is in its q^{th} quartile; zero otherwise	Calculated
Options related		
INTENSITY	Assessed value of the building divided by the assessed value of the lot.	B&T
LINT	Natural logarithm of INTENSITY, with its 2nd percentile by town assigned to any properties below the 2nd percentile.	Calculated
LINT'	The de-trended component of LINT.	Calculated
LINTZ'	Equals ten when LINT' is at its bottom 2% values; zero otherwise	Calculated
LINT25'	Equals ten when LINT' is at its bottom 25% values; zero otherwise	Calculated
LINTG75'	Equals ten when LINT' is at its top 25% values; zero otherwise	Calculated
Town characteristics		
Percent of land developed	Percent of developed land in 2006 for each town is obtained from *The Connecticut Economy (2010)*, based on data from the Center for Land Use Education and Research (CLEAR), University of Connecticut that uses satellite images. Water, 3 types of wetland, and utility corridors are classified as land not available for development. Developed land includes developed land plus maintained-turf-and-grass; undeveloped land includes other grasses, agricultural fields, deciduous forest, coniferous forest, and barren.	CLEAR
Percent change in land developed	Percent change in *percent of land developed* from 1985 to 2006.	CLEAR
Drift in house price	Annualized rate of change of adjusted price for model *j* for each town *k* between time t and t+1.	Calculated
Adjusted price	Price predicted by model *j* for each town *k* for a median property across all towns.	Calculated
Volatility of house prices	Volatility, $\sigma_j(\Delta\alpha_{t,k})$, is the standard deviation of annual capital returns for each model *j* and each town *k*, where $\Delta\alpha_{t,k}$ is the first difference of the estimated time coefficients between time t and t-1.	
Household density	Number of family households in town divided by town's land area (in square miles) in 2000.	US Census
House age	Median age of properties in town *k*.	Calculated
Population growth	Population growth for respective period for town *k*.	CT Census
PCI	Per capita income in 2000.	US Census
New house sales	Number of sales of houses 15 years old or less divided to the total number of sales in town *k*.	Calculated
Effective property tax rate	Effective property tax rate of town *k*.	Econ Dept., U of CT
Growth in the property tax levy	Growth in the property tax levy of town *k*.	Econ Dept., U of CT
Percent owner occupied	Ratio of owner occupied housing to total number of housing units.	US Census

Table 2: Summary statistics for the hedonic variables by towns

The table shows the distribution of town means (Town Mean) and town standard deviations (Town SD) of hedonic variables. The definition of all variables is given in Table 1. The sample includes 162,454 single-family residential properties sold between 1994 and 2007 in 53 towns in Connecticut.

		1^{st} quartile	Median	Mean	3^{rd} quartile
ln(PRICE)	Town Mean	12.06	12.39	12.46	12.66
	Town SD	0.41	0.46	0.48	0.54
LV_2	Town Mean	0.249	0.250	0.249	0.250
	Town SD	0.433	0.433	0.432	0.433
LV_3	Town Mean	0.250	0.250	0.251	0.251
	Town SD	0.433	0.433	0.434	0.434
LV_4	Town Mean	0.250	0.250	0.250	0.250
	Town SD	0.433	0.433	0.433	0.433
AGE	Town Mean	31.82	38.72	39.96	47.97
	Town SD	18.16	20.10	19.95	21.62
FOOTAGE	Town Mean	1,525	1,734	1,853	2,096
	Town SD	567	740	864	903
LOTSF	Town Mean	17,234	29,033	34,860	47,171
	Town SD	19,422	29,539	30,056	38,499
BATH2OR3	Town Mean	0.362	0.525	0.501	0.621
	Town SD	0.469	0.481	0.477	0.495
BATH3P	Town Mean	0.012	0.034	0.067	0.070
	Town SD	0.106	0.180	0.201	0.255
YEAR	Town Mean	2,001	2,002	2,001	2,002
	Town SD	3.70	3.91	3.82	4.17
	Total no. of observations:	162,454			
	No. of towns:	53			

Table 3: Summary statistics for the intensity variables by towns

The table shows the distribution of town means (Town Mean) and town standard deviations (Town SD) of intensity variables. The definition of all variables is given in Table 1. The sample includes 162,454 single-family residential properties sold between 1994 and 2007 in 53 towns in Connecticut.

		1st quartile	Median	Mean	3rd quartile
LINT	Town Mean	0.065	0.376	0.293	0.588
	Town SD	0.448	0.552	0.608	0.741
LINT_Z	Town Mean	0.199	0.200	0.202	0.201
	Town SD	1.397	1.399	1.406	1.403
LINT25’	Town Mean	2.499	2.500	2.500	2.501
	Town SD	4.331	4.331	4.331	4.332
LINTG75’	Town Mean	2.499	2.500	2.500	2.501
	Town SD	4.330	4.331	4.331	4.332
Total no. of observations:		162,454			
No. of towns:		53			

Table 4: Regression results of Model 1

We run separate hedonic regressions (equation 4) for each town. This table shows distribution of coefficients across town regressions. Town level results are available upon request. The definition of all variables is provided in Table 1. N(+,sig) is the number of positive coefficients significant at the 5% level. N(-,sig) is the number of negative coefficients significant at the 5% level. Year dummy coefficients are suppressed; available upon request.

Panel A: Distribution of Hedonic Coefficients

	1st quartile	Median	Mean	3rd quartile	N(+,sig)	N(-,sig)
Constant	11.14	11.46	11.42	11.71	53	0
LV_2	-0.033	0.043	0.069	0.151	15	3
LV_3	0.035	0.159	0.150	0.258	30	3
LV_4	0.071	0.248	0.253	0.376	34	3
FTG	2.94E-04	3.68E-04	3.76E-04	4.41E-04	51	0
LV_2 x FTG	-5.49E-05	2.25E-05	1.56E-05	1.01E-04	9	9
LV_3 x FTG	-5.45E-05	1.13E-05	8.91E-06	1.09E-04	8	8
LV_4 x FTG	-1.10E-04	-1.89E-05	-2.26E-06	6.66E-05	11	13
FTG^2	-4.21E-08	-2.32E-08	-3.03E-08	-9.98E-09	1	33
LV_2 x FTG^2	-2.17E-08	-3.87E-09	-3.93E-09	1.32E-08	8	10
LV_3 x FTG^2	-1.91E-08	-4.28E-09	-2.16E-09	1.54E-08	7	8
LV_4 x FTG^2	-1.13E-08	4.84E-09	3.72E-09	1.93E-08	10	9
LOTSF	2.54E-06	3.82E-06	5.38E-06	6.84E-06	50	2
$LOTSF^2$	-3.49E-11	-1.45E-11	-2.90E-11	-6.28E-12	2	45
AGE	-8.18E-03	-6.49E-03	-6.34E-03	-4.39E-03	1	49
AGE^2	2.49E-05	4.31E-05	4.50E-05	6.47E-05	45	3
BATH3P	0.059	0.108	0.108	0.157	40	0
BATH2OR3	0.038	0.053	0.058	0.077	52	0
R^2	0.831	0.859	0.854	0.884		
Adj R2	0.829	0.857	0.852	0.883		

Panel B: Effect of land value dummies (LV_q) by towns evaluated at mean footage*
*see equation 9

	1st quartile	Median[1]	Mean[1]	3rd quartile	N(+)	N(-)
ME_LV_2	0.043	0.073	0.081	0.111	51	2
		(0%)	(0%)			
ME_LV_3	0.090	0.143	0.153	0.198	53	0
		(0%)	(0%)			
ME_LV_4	0.132	0.202	0.250	0.333	53	0
		(0%)	(0%)			

[1] Parentheses below the Median and Mean values denote the *p*-value of Wilcoxon Signed Rank test statistic for evaluating Median(ME_LV_q - ME_LV_{q-1})>0 and *t*-statistic for evaluating Mean(ME_LV_q - ME_LV_{q-1})>0, respectively. See Hypothesis 1 in equation (10).

Table 5: Marginal effects of properties in the lowest quartile of intensity

The table shows distribution of a) coefficients of intensity variables for Model 2 and b) ME1 and ME2 for Models 2, 3 and 4. Each model is estimated separately for each town. ME1 (ME2) refers to the percentage price difference between a house with low intensity and one with middle (high) intensity, evaluated at median values by town of the concerned variables; see equations (11)-(13). The definition of all variables is provided in Table 1. N(+,sig) is the number of positive coefficients significant at the 5% level. N(-,sig) is the number of negative coefficients significant at the 5% level. Bolded figures denote the ME for towns where both ME1 and ME2 are positive and significant (i.e. positive OV towns). See Appendix for the distribution of coefficients of intensity variables for Model 3 and Model 4.

Panel A: Model 2 results

	1st quartile	Median	Mean	3rd quartile	N(+,sig)	N(-,sig)
LINT_Z	-0.0076	-0.0034	0.0019	0.0056	14	21
LINT25’	-0.0054	-0.0034	-0.0027	-0.0004	6	34
LINTG75’	0.0006	0.0032	0.0031	0.0051	32	2
ME1	-0.119	-0.045	-0.008	0.033	12	24
ME2	-0.140	-0.066	-0.038	0.016	11	29
Positive & significant ME1	0.167	0.271	0.293	0.324	12	0
Positive & significant ME2	**0.188**	**0.242**	**0.288**	**0.285**	**11**	**0**
ME1 for positive OV towns	**0.204**	**0.292**	**0.319**	**0.340**	**11**	**0**

Panel B: Model 3 results

	1st quartile	Median	Mean	3rd quartile	N(+,sig)	N(-,sig)
ME1	-0.126	-0.055	-0.020	0.023	10	26
ME2	-0.155	-0.064	-0.044	0.008	10	28
Positive & significant ME1	**0.213**	**0.253**	**0.306**	**0.328**	**10**	**0**
Positive & significant ME2	**0.184**	**0.213**	**0.287**	**0.305**	**10**	**0**

Panel C: Model 4 results:

	1st quartile	Median	Mean	3rd quartile	N(+,sig)	N(-,sig)
≤ 2000						
ME1	-0.130	-0.049	-0.028	0.016	10	26
ME2	-0.171	-0.082	-0.064	-0.005	7	26
Positive & significant ME1	0.158	0.192	0.285	0.349	10	0
Positive & significant ME2	**0.138**	**0.144**	**0.316**	**0.405**	**7**	**0**
ME1 for positive OV towns	**0.188**	**0.276**	**0.344**	**0.385**	**7**	**0**
> 2000						
ME1	-0.108	-0.045	-0.002	0.019	11	24
ME2	-0.135	-0.059	-0.017	0.010	13	26
Positive & significant ME1	**0.248**	**0.371**	**0.339**	**0.387**	**11**	**0**
Positive & significant ME2	0.178	0.321	0.304	0.382	13	0
ME2 for positive OV towns	**0.223**	**0.330**	**0.342**	**0.433**	**11**	**0**

Table 6: Return volatility

Panel A shows the distribution of volatilities. Panel B shows the correlation between option value and volatility. Volatility is the return volatility of the price index (time dummy coefficients) for each town, as described in the discussion of hypothesis 3. Option value - ME1 (ME2) equals ME1 (ME2) for positive option value towns and zero otherwise. Positive option value towns are those for which ME1>0 and ME2>0 and significant at 5%. In Panel A (Panel B) option value (OV) equals ME1 (ME2). ME1 is defined in equations 11a,12a and 13a for Models 2, 3 and 4, respectively. ME2 is defined in equations 11b, 12b and 13b for Models 2, 3 and 4, respectively. *, **, *** indicates statistical significance at 10%, 5% and 1% level, respectively.

Panel A: Return Volatility

Model	1st quartile	Median	Mean	3rd quartile	N
Model 2	5.54%	7.30%	8.19%	9.50%	53
Model 3	5.60%	7.47%	8.29%	9.85%	53
Model 4 (<=2000)	3.73%	5.40%	5.56%	7.00%	50
Model 4 (>2000)	4.64%	6.13%	8.42%	12.12%	52

Panel B: Correlation between Option Value and Volatility

	Option Value - ME1			Option value - ME2		
Model	Pearson correlation	P-value		Pearson correlation	P-value	
Model 2	27.21%	0.05	**	25.45%	0.07	*
Model 3	26.85%	0.05	**	24.63%	0.08	*
Model 4 (<=2000)	8.36%	0.56		5.25%	0.72	
Model 4 (>2000)	31.99%	0.02	**	32.65%	0.02	**

Table 7: Comparison of positive and zero option value towns

This table shows characteristics of positive and zero option value towns. Positive option value towns in Panel A (Panel B and Panel C) are those for which ME1 in Model 3 (Model 4) is positive and significant at 5%. We assume that option value is zero for the rest of the towns. Variables are defined in Table 1. *, **, *** indicates statistical significance at 10%, 5% and 1% level, respectively.

Panel A: Model 3

Because of missing data number of observations decreases to 42 for zero option value towns for *Drift in house price* and *Volatility of house prices*

Town characteristics	Positive option value towns (N=10)					Zero option value towns (N=43)					T-test			Wilcoxon		
	Mean	Median	Q1	Q3	Std	Mean	Median	Q1	Q3	Std	T	P-value		Z	P-value	
Expected difference: Positive																
Volatility of house prices (94-07)	10.93%	11.34%	8.20%	13.15%	2.58%	7.67%	6.71%	5.16%	8.14%	3.91%	2.50	0.01	***	3.19	0.00	***
Drift in house price (94-07)	7.20%	7.36%	6.85%	7.79%	0.90%	6.43%	6.20%	5.84%	7.16%	1.60%	1.45	0.08	*	1.76	0.04	**
Household density	479	386	191	611	352	423	314	205	598	334	0.47	0.32		0.53	0.30	
Percent of land developed	52.39%	51.35%	31.20%	67.40%	20.15%	52.01%	49.00%	38.40%	67.30%	18.52%	0.06	0.48		0.13	0.45	
Adjusted price (Model 3)	$287,485	$290,869	$210,713	$320,600	$73,321	$284,364	$219,538	$182,972	$306,712	$172,605	0.09	0.46		1.72	0.04	**
House age	42	46	31	49	9	41	40	32	49	11	0.32	0.38		0.46	0.32	
Population growth	0.58%	0.58%	0.36%	0.77%	0.59%	0.58%	0.57%	0.24%	0.84%	0.49%	0.01	0.50		0.01	0.50	
Expected difference: Negative																
PCI	$31,239	$32,041	$23,995	$37,161	$7,955	$35,033	$29,630	$24,953	$37,786	$17,714	-1.03	0.16		0.06	0.48	
New house sales	4.97%	3.04%	2.04%	5.57%	4.36%	5.08%	4.58%	2.02%	6.92%	3.64%	-0.08	0.47		-0.40	0.35	
Percent change in land developed	5.10%	5.30%	3.70%	6.10%	1.79%	5.98%	6.10%	3.40%	7.90%	3.08%	-0.87	0.20		-0.91	0.18	
Effective property tax rate	1.27%	1.25%	1.11%	1.46%	0.21%	1.53%	1.57%	1.32%	1.82%	0.42%	-2.75	0.01	***	-2.28	0.01	***
Growth in the property tax levy	5.15%	4.97%	4.41%	6.72%	1.60%	6.15%	6.05%	5.19%	7.06%	1.22%	-2.20	0.02	***	-1.85	0.03	**
Expected difference: Zero																
Percent owner occupied	71.75%	70.69%	58.30%	85.38%	15.17%	74.11%	80.33%	64.58%	86.54%	16.65%	-0.41	0.34		-0.51	0.30	

Table 7, continued: Comparison of positive and zero option value towns

Panel B: Model 4 before 2000

Because of missing data number of observations decreases to 43 for zero option value towns for *Volatility of house prices.*

Town characteristics	Positive option value towns (N=7) Mean	Median	Q1	Q3	Std	Zero option value towns (N=46) Mean	Median	Q1	Q3	Std	T-test T	P-value		Wilcoxon Z	P-value	
Expected difference: Positive																
Volatility of house prices (94-00)	2.80%	2.88%	2.30%	4.29%	1.94%	2.75%	3.01%	0.77%	4.70%	2.58%	0.06	0.48		-0.01	0.49	
Drift in house price (94-00)	6.45%	5.77%	3.63%	9.57%	3.48%	5.42%	5.28%	3.71%	7.01%	2.64%	0.92	0.18		0.56	0.29	
Household density	482	425	191	611	362	426	317	205	598	334	0.41	0.34		0.46	0.32	
Percent of land developed	51.50%	49.70%	29.00%	67.40%	20.33%	52.17%	49.20%	38.40%	67.30%	18.60%	-0.09	0.47		-0.04	0.48	
Adjusted price (Model 4)	$269,143	$263,791	$205,679	$307,981	$81,000	$286,950	$229,543	$183,560	$312,115	$166,247	-0.45	0.33		0.67	0.25	
House age	42	46	31	50	9	41	40	32	49	11	0.35	0.36		0.54	0.29	
Population growth	0.51%	0.60%	0.13%	0.77%	0.66%	0.59%	0.57%	0.26%	0.84%	0.48%	-0.36	0.36		-0.22	0.41	
Expected difference: Negative																
PCI	$29,682	$24,500	$22,396	$37,161	$8,800	$35,023	$29,893	$25,720	$37,786	$17,145	-0.80	0.21		-0.59	0.28	
New house sales	4.78%	3.41%	2.04%	5.57%	4.14%	5.10%	4.43%	2.02%	6.92%	3.72%	-0.21	0.42		-0.33	0.37	
Percent change in land developed	5.60%	5.60%	3.70%	7.50%	1.60%	5.85%	5.75%	3.40%	7.80%	3.05%	-0.21	0.42		-0.21	0.42	
Effective property tax rate	1.25%	1.18%	1.05%	1.52%	0.24%	1.51%	1.50%	1.32%	1.81%	0.41%	-1.62	0.06	*	-1.96	0.03	**
Growth in the property tax levy	5.02%	4.74%	3.18%	7.14%	1.83%	6.11%	6.04%	5.19%	6.93%	1.21%	-2.06	0.02	**	-1.62	0.05	**
Expected difference: Zero																
Percent owner occupied	71.25%	72.81%	55.15%	85.38%	16.80%	74.03%	79.11%	64.58%	86.54%	16.34%	-0.42	0.34		-0.46	0.32	

Table 7, continued: Comparison of positive and zero option value towns

Panel C: Model 4 after 2000

Because of missing data number of observations decreases to 41 for zero option value towns for *Drift in house price* and *Volatility of house prices*

Town characteristics	Positive option value towns (N=11)					Zero option value towns (N=42)					T-test			Wilcoxon		
	Mean	Median	Q1	Q3	Std	Mean	Median	Q1	Q3	Std	T	P-value		Z	P-value	
Expected difference: Positive																
Volatility of house prices (00-07)	11.70%	13.15%	7.04%	15.50%	4.62%	7.54%	5.62%	4.26%	8.34%	5.96%	2.14	0.01	***	2.80	0.00	***
Drift in house price (00-07)	10.23%	10.82%	8.57%	11.48%	1.92%	9.47%	9.04%	8.15%	10.68%	1.94%	1.20	0.13		1.30	0.10	*
Household density	456	348	191	611	342	427	317	205	598	337	0.25	0.20		0.20	0.42	
Percent of land developed	51.46%	49.70%	31.20%	67.40%	19.36%	52.24%	49.20%	38.40%	67.30%	18.68%	-0.12	0.23		0.02	0.49	
Adjusted price (Model 4)	$281,626	$285,982	$209,747	$330,651	$72,237	$285,377	$218,488	$183,551	$305,564	$173,395	0.11	0.23		1.55	0.06	*
House age	41	46	30	49	10	41	40	33	49	11	-0.04	0.24		0.09	0.46	
Population growth	0.63%	0.60%	0.36%	1.13%	0.59%	0.56%	0.57%	0.24%	0.79%	0.49%	0.38	0.18		0.66	0.26	
Expected difference: Negative																
PCI	$31,954	$32,301	$23,995	$39,102	$7,910	$34,936	$29,280	$24,953	$34,987	$17,917	-0.82	0.10	*	1.12	0.13	
New house sales	5.14%	3.41%	2.04%	6.92%	4.18%	5.03%	4.43%	2.02%	6.89%	3.67%	0.09	0.23		0.27	0.39	
Percent change in land developed	5.35%	5.60%	3.70%	7.50%	1.90%	5.93%	5.85%	3.40%	7.80%	3.10%	-0.78	0.11		-0.96	0.17	
Effective property tax rate	1.28%	1.32%	1.11%	1.46%	0.20%	1.53%	1.59%	1.32%	1.82%	0.42%	-2.85	0.00	***	-3.18	0.00	***
Growth in the property tax levy	5.23%	5.20%	4.41%	6.72%	1.55%	6.15%	6.04%	5.19%	7.06%	1.23%	-2.09	0.01	***	-1.51	0.07	*
Expected difference: Zero																
Percent owner occupied	72.08%	72.81%	58.30%	85.38%	14.43%	74.08%	80.34%	64.58%	86.54%	16.85%	-0.36	0.18		-0.30	0.38	

Table 8: Likelihood of positive option value (Logit model)

This table shows estimation of the probability of a town having positive option value using logit model. In specifications Xa dependent variable equals one if ME1 in Model 3 is positive and significant at 5%, and zero otherwise. In specifications Xb dependent variable equals one if ME1 in Model 4 before 2000 is positive and significant at 5%, and zero otherwise. In specifications Xc dependent variable equals one if ME1 in Model 4 after 2000 is positive and significant at 5%, and zero otherwise. Variables are defined in Table 1. *Volatility of house prices, Drift in house price* and *Adjusted price* are calculated for the same model and time period as dependent variable. *, **, *** indicates statistical significance at 10%, 5% and 1% level, respectively.

	Model 3				**Model 4 before 2000**				**Model 4 after 2000**			
	Specification 1a		**Specification 2a**		**Specification 1b**		**Specification 2b**		**Specification 1c**		**Specification 2c**	
Variables	**Coeff**	**Wald χ2**	**Coeff**	**Wald χ2**	**Coeff**	**Wald χ2**	**Coeff**	**Wald χ2**	**Coeff**	**Wald χ2**	**Coeff**	**Wald χ2**
Intercept	-3.145	11.45 ***	-6.136	8.79 ***	-2.780	13.53 ***	-3.003	11.54 ***	-2.462	12.05 ***	-5.908	8.11 ***
Volatility of house prices	1.622	5.16 **	3.083	4.40 **	0.157	0.06	0.246	0.13	1.506	4.58 **	3.058	3.92 **
Drift in house price	1.190	2.08	2.403	3.56 *	-0.190	0.09	-0.324	0.24	0.527	0.86	2.061	4.77 **
Adjusted price	-4.233	6.07 ***	11.675	3.03 *	-1.758	3.55 *	1.362	0.16	-3.534	5.53 **	14.337	3.69 **
Effective property tax rate	-3.591	6.25 ***	-5.027	5.42 **	-2.521	5.77 **	-2.556	5.24 **	-3.352	6.50 ***	-6.165	5.83 **
Growth in the property tax levy	-0.815	1.59			-1.037	2.98 *	-1.155	3.01 *	-0.548	0.82		
Adjusted price squared			-23.802	6.30 ***			-3.305	0.69			-27.020	6.03 ***
N	52		52		50		50		52		52	
Likelihood ratio χ2	25.05 ***		35.83 ***		13.61 **		14.67 **		15.19 ***		35.89 ***	

Table 9: Determinants of option value (Tobit model)

This table shows tobit model. In specifications Xa dependent variable equals ME1 if ME1 in Model 3 is positive and significant at 5%, and zero otherwise. In specifications Xb dependent variable equals ME1 if ME1 in Model 4 before 2000 is positive and significant at 5%, and zero otherwise. In specifications Xc dependent variable equals ME1 if ME1 in Model 4 after 2000 is positive and significant at 5%, and zero otherwise. Variables are defined in Table 1. *Volatility of house prices, Drift in house price* and *Adjusted price* are calculated for the same model and time period as dependent variable. *, **, *** indicates statistical significance at 10%, 5% and 1% level, respectively.

	Model 3						**Model 4 before 2000**						**Model 4 after 2000**					
	Specification 1a			**Specification 2a**			**Specification 1b**			**Specification 2b**			**Specification 1c**			**Specification 2c**		
	Coeff	**T**		**Coeff**	**T**		**Coeff**	**T**		**Coeff**	**T**		**Coeff**	**T**		**Coeff**	T	
Intercept	-0.338	-3.02	***	-0.408	-3.11	***	-0.527	-2.57	***	-0.555	-2.47	**	-0.290	-2.73	***	-0.364	-3.08	***
Volatility of house prices	0.175	2.88	***	0.194	3.15	***	-0.019	-0.19		-0.023	-0.23		0.203	2.82	***	0.182	3.01	***
Drift in house price	0.149	2.17	**	0.154	2.30	**	0.000	0.00		-0.003	-0.03		0.051	0.86		0.108	2.07	**
Adjusted price	-0.507	-4.09	***	0.528	1.23		-0.438	-2.37	**	-0.181	-0.33		-0.438	-3.34	***	0.901	1.98	**
Effective property tax rate	-0.438	-4.03	***	-0.383	-4.05	***	-0.567	-2.75	***	-0.566	-2.67	***	-0.402	-3.52	***	-0.351	-4.11	***
Growth in the property tax levy	-0.082	-1.60					-0.143	-1.57		-0.149	-1.58		-0.071	-1.27				
Adjusted price squared				-1.359	-2.27	**				-0.288	-0.46					-1.689	-2.71	***
Sigma	0.194	4.03	***	0.173	4.08	***	0.324	3.26	***	0.328	3.23	***	0.228	4.14	***	0.171	4.23	***
N	52			52			50			50			52			52		
# left censored	42			42			43			43			41			41		
Log likelihood	-5.57 **			-2.75 *			-10.17***			-10.03***			-8.81 ***			-3.51 *		

Appendix I

The distribution of coefficients of intensity variables in Models 3 by towns

	1st quartile	Median	Mean	3rd quartile	N(+,sig)	N(-,sig)
LINT_Z	-0.0092	-0.0037	0.0011	0.0042	13	22
LINT25’	0.0012	0.0052	0.0061	0.0117	21	3
LINT25’*AGE	-0.0006	-0.0004	-0.0004	-0.0001	0	30
LINT25’*AGE^2	6.69E-07	2.71E-06	2.94E-06	4.59E-06	18	1
LINTG75’	0.0045	0.0069	0.0071	0.0110	37	3
LINTG75’*AGE	-0.0004	-0.0002	-0.0002	1.95E-05	4	19
LINTG75’*AGE^2	-1.75E-06	8.40E-07	7.67E-07	3.80E-06	15	7

The distribution of coefficients of intensity variables in Models 4 by towns

	1st quartile	Median	Mean	3rd quartile	N(+,sig)	N(-,sig)
LINT_Z	-0.0079	-0.0036	0.0015	0.0040	13	20
LINT25’*(≤ 2000)	-0.0064	0.0026	0.0042	0.0124	14	6
LINT25’*AGE*(≤ 2000)	-0.0006	-0.0003	-0.0003	0.0002	4	16
LINT25’*AGE^2*(≤ 2000)	-4.20E-06	1.85E-06	1.62E-06	6.58E-06	14	6
LINTG75’*(≤ 2000)	0.0050	0.0104	0.0104	0.0157	33	0
LINTG75’*AGE*(≤ 2000)	-0.0005	-0.0003	-0.0003	8.55E-07	2	19
LINTG75’*AGE^2*(≤ 2000)	-9.52E-07	2.17E-06	1.86E-06	5.59E-06	10	2
LINT25’*(> 2000)	0.0013	0.0059	0.0082	0.0133	20	2
LINT25’*AGE*(> 2000)	-0.0006	-0.0003	-0.0004	-0.0001	1	21
LINT25’*AGE^2*(> 2000)	4.18E-07	2.67E-06	3.16E-06	5.29E-06	16	2
LINTG75’*(> 2000)	0.0013	0.0046	0.0048	0.0088	24	2
LINTG75’*AGE*(> 2000)	-0.0003	-0.0001	-0.0001	0.0002	5	13
LINTG75’*AGE^2*(> 2000)	-3.19E-06	-3.71E-08	1.39E-09	3.04E-06	12	8