

Clapp, John; Eichholtz, Piet; Lindenthal, Thies

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Real Option Value over a Housing Market Cycle: West Berlin

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Real Option Value over a Housing Market Cycle

By:
John M. Clapp
University of Connecticut, USA
John.Clapp@uconn.edu

Piet Eichholtz and Thies Lindenthal
Maastricht University, The Netherlands
p.eichholtz@maastrichtuniversity.nl and thies@lindenthal.eu

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Abstract

This paper analyzes how the dynamics of house prices are affected by the option to rebuild or enlarge existing dwellings. The curvature of option value and zoning limits provide identification of changes in option value over the cycle. For West Berlin homes with high development potential, our empirical results show that about 40 percent of the price increases during the “Big Bang” boom years (1989 through 1994) was related to increased option value. In the subsequent bust about 50 percent of their price decline was associated with decreased option value. For dwellings with low redevelopment potential 12 percent of the decline in real value can be attributed to changing option value.

Introduction

To understand the effects of real option value on the dynamics of house prices, one needs to focus attention on the option embedded in existing dwellings. Much of the literature on the value of the development option analyzes vacant land¹, but for existing dwellings, option value derives from the possibility to add space, or to demolish and rebuild. Option theory suggests that the value of the option to redevelop existing durable assets is not constant in time, but rather fluctuates over the cycle, thereby possibly affecting the amplitude of that cycle for existing dwellings. We use a cross-sectional hedonic model,

¹ See, for example, Sheridan Titman (1985), Laura Quigg (1993), Dennis Capozza and Yuming Li (1994), and Steven Grenadier (1996).

functional form, and zoning constraints to identify the amount of option value for any given home in each phase of the cycle.²

We propose that option value is a positive function of the unrealized development potential of the lot, measured by the maximum structure size allowed by zoning (or the optimum size if lower) relative to the existing structure. If the existing configuration of the dwelling and the land it stands on is close to the maximum, then the strike price of the option is high. This implies a low value for the redevelopment option, regardless of economic conditions. Conversely, a small old house in a neighborhood with larger newer houses may, depending on economic conditions, have substantial option value.

To implement these ideas, we match houses with little or no development potential with neighboring houses that have development potential in order to identify the amount of option value in the latter. This approach builds on recent research showing that the hedonic envelope function can be modeled as a segmented pairings between heterogeneous groups of agents.³ Several recent empirical studies are related to our approach. Joseph Aldy and Kip Viscusi (2008) model each age cohort as a separate equilibrium, allowing identification of a highly nonlinear response of valuation to age. Orley Ashenfelter and Karl Storchmann (2010) associate soil type and aspect with local compensating variations in vineyard profits. Sandra Black (1999) identifies the effect of school quality on property values using proximity to school attendance zone boundaries. We use a general model in which the value of the redevelopment option is a nonlinear

² Property value and option value are simultaneously determined. Our model allows us to identify the amount of option value for a typical property in any cross-sectional equilibrium, and to compare these amounts over different phases of the cycle.

³ For example, one group of buyers may prefer computers with fast processing speed and another large hard drives even though observable characteristics suggest that one computer dominates the other (Patrick Bajari and C.Lanier Benkard, 2005). Likewise, Kip Viscusi and Joseph Aldy (2007) point out that the age 55 plus group may reach a hedonic equilibrium that is not continuously connected to the equilibrium of those under age 55. See Ivar Eklund, James Heckman and Lars Neshiem (2004) for discussion of a hedonic envelope composed of pairings between supply and demand segments. By way of contrast, Sherwin Rosen (1974) suggested that agents differ in a continuously variable parameter such as tastes or technology.

term additive to a standard vector of hedonic characteristics; small neighborhoods are constructed to control omitted variables.

Our approach differs significantly from previous work on real option value, which focuses on vacant land or on the timing of the decision to build. For example, Stuart Rosenthal and Robert Helsley (1994) model the point of option exercise, when property value is equal to land value. Christopher Cunningham (2006, 2007) investigates how price uncertainty affects the likelihood to invest and the level of land prices under various regulatory conditions. Laarni Bulan, Christopher Mayer and Tsurriel Somerville (2009) show how the presence of real option value delays development of condominiums in Vancouver. By way of contrast we identify fluctuations in the percent of existing house value that can be attributed to option value.

To investigate this, we use unexplored data from the West Berlin housing market. There are two reasons why these data are uniquely fit to study the effect of real option value on the price behavior of existing homes. First, our dataset not only provides transaction prices, location and a set of hedonic characteristics, but it also covers the degree of existing development for each dwelling, and the maximum development permitted by zoning. By employing this database, this paper is the first to use zoning limits for an empirical estimate of the real option value embedded in existing dwellings. Moreover, Berlin offers the finely-grained spatial variation needed to distinguish dwellings for which this legal limit is economically binding from those for which it is not.

Second, during the 30 years covered by the database (1978 – 2007) the city of Berlin experienced significant political and economic volatility, with important consequences for the West Berlin housing market. During this time period, the West Berlin housing market has experienced three very different phases of relative tranquility, boom and bust, which are likely to have affected option values in an economically significant way.

This study documents the substantial role played by option value in the price swings of a housing market. For the boom period between the end of 1989 and the end of 1994, our

results for houses with high development potential show that increases in redevelopment option value added about 40 percent to the growth in real house value. In the subsequent bust, option value accounted for about 50 percent of the decline in the real value of these high development potential houses. But also for other houses, option value accounts for some of the cyclical change, and especially so in the bust phase of the cycle: 12 percent of the decline in real value of the low development potential dwellings can be associated with changing option value. This suggests that the presence of option value amplifies the cyclical price swings of existing dwellings.

Given that options provide a form of leverage, these results are not surprising, but our method provides a new perspective on boom and bust cycles in real estate markets. Our contribution is to use a nonlinear functional form and zoning constraints to identify changes in option value over the cycle, and to measure the association between these values and changes in total house value. We are the first to pair fully developed properties, where option value varies little over the cycle, with neighboring properties that have development potential. Our hedonic model compares cross sectional equilibria established during each phase of the housing market cycle. Finally, we apply these innovations to the historically important period surrounding the fall of the Berlin Wall in 1989.

This paper proceeds with a section introducing the theoretical model. It subsequently sketches events surrounding the boom and bust cycle of Berlin's housing market, and provides details of the data we use. The next section provides a framework for the empirical analysis, and the section after that presents the empirical results, starting with a constant-quality house price index for Berlin, then presenting coefficient estimates for the hedonics and the redevelopment option, and ending with a calculation of the economic significance of the redevelopment option in the different phases of the Berlin housing market. The paper ends with a summary and conclusions.

Real Option Value in Existing Dwellings

The model we propose is a standard hedonic model with an additive redevelopment (call) option value term: i.e., house value consists of use value plus option value. Intuitively, a lump sum option premium may be embedded in the transaction price. The option value term is motivated by the possibility of tearing down and rebuilding, or substantially adding to the house, modifying the vector of hedonic characteristics.

The proposed hedonic model provides a framework for specifying a regression capable of separately identifying the amount paid for the option and the amount paid for use of the existing vector.⁴ As shown here, the main empirical implication of the option value framework is the addition of a nonlinear term for option value.

Embedded Option Value

We begin with a very general hedonic model that includes an additive option value term. Option value is generated by irreversibility, which occurs because it is costly to change the hedonic vector. Consider an aggregate index of hedonic property characteristics represented by the scalar q_i^0 at time t . The hedonic aggregate changes to q_i^n after exercise a one-time call option at cost $C(q_i^n, x_{iT}, \beta_c)$, the construction costs associated with redevelopment at time $T \geq t$. Cost is shifted by a stochastic variable, x_{iT} ; β_c is a vector of parameters. The new hedonic aggregate q_i^n is the smaller of the optimally chosen amount, q_i^* , and the zoning constraint, δ .

⁴ Quigg (1993) uses construction costs and assumed parameters with an option value formula to back out the option component from the value of vacant land. She uses the hedonic model only to estimate the value of an optimal structure. Clapp and Salavei (2010) use a special case (known drift of rents with zero variance) of the model presented here.

This is an exchange option: at time T , chosen optimally, q_i^0 is exchanged for a new structure with aggregate index $q_i^n > q_i^0$. We will show that zoning limits contribute to identification of option value.

Following Svetlana Boyarchenko (2004) and Dennis Capozza and Yuming Li (2002), the expected present value per unit of the hedonic aggregate at time t is given by:

$$p(x_{2t}, \rho, \beta) = E_t \left[\int_t^\infty x_{2s} e^{-\rho(s-t)} ds \right] < \infty. \quad (1)$$

Here, E_t is an expectations operator conditional on information at time t ; x_{2t} is drawn from a stochastic process with parameters β ; it shifts rent per unit from both the new and the existing hedonic vectors. A joint stochastic process may be used for x_{1t} and x_{2t} ; for generality, the stochastic processes are not specified at this time. The constant discount rate is ρ . The value of the existing hedonic bundle is given by $p(x_{2t}, \rho, \beta)q_i^0$ and the expected net present value of the new aggregate if developed at time t is:

$$V(q_i^0, x_{1t}, x_{2t}, \rho, \beta, \beta_c) = p(x_{2t}, \rho, \beta) [q_i^n - q_i^0] - C(q_i^n, x_{1t}, \beta_c). \quad (2)$$

A general form of the optimization problem at time $t \leq T$ is:

$$P_{it} = p(x_{2t}, \rho, \beta)q_i^0 + \max_{\{T, q_i^n\}} [V(q_i^0, x_{1T}, x_{2T}, \rho, \beta, \beta_c), 0] + \varepsilon_{it} \quad \text{s.t. } q_i^n = \min\{q_i^*, \delta\}. \quad (3)$$

Here, P_{it} is the observed market price of the asset and (3) takes the form of a hedonic model with an embedded option.⁵ A disturbance term, ε_{it} arising from negotiations between buyers and sellers, will be modeled empirically with spatial clustering.

⁵ There are two differences between the second term of equation (3) and equation (11) in Svetlana Boyarchenko (2004): 1. the existing asset is sacrificed when the property is redeveloped; 2. we allow the possibility of a separate stochastic process shifting cost.

Several assumptions are implicit in equation (3):

1. The option value term is additive to the value of the existing bundle of hedonic characteristics. Air and water quality are often valued in a similar way. The addition of an option premium to the value of a dividend paying asset is a standard feature of real options models; see Avinash Dixit (1989).⁶
2. The existing asset is exchanged for one of the same type, with value partly determined by the same stochastic process, $x_{2,t}$ and other parameters, β . This is consistent with our use of zoning restrictions to identify option value: e.g., both old and new properties are zoned as residential.
3. We ignore the value of the put (abandonment) option. This assumption is justified by the durability of real estate, where existing structures may have considerable use value even when they are selling well below replacement costs. See Glaeser and Gyourko (2005) for recent empirical work demonstrating the importance of durability.
4. Segmented demand allows dwellings with substantial option value to reach equilibrium in the same neighborhood as fully developed properties. Patrick Bajari and C.L. Benkard (2005) and Kip Viscusi and Joseph Aldy (2007) develop relevant theory.

Next, we point out that our model has surprising implications for a cross-sectional hedonic model, where q_i^0 varies and the x_{jt} , $j = 1, 2$ are fixed. Most important, the general features of equation (3), together with zoning restrictions, allow identification of both use value and option value terms of equation (3).

⁶ Avinash Dixit (1989) has two additive terms in his equation (7), one for the value of the asset if kept in its current state forever.

Empirical implications for the hedonic model with option value

The implications of equation (3) for hedonic regressions are illustrated in figure 1, which is based on a solution derived in the appendix. Additional assumptions are needed to get a closed form solution for the option value term. In this subsection we point out that we need only very general features of the solution in order to identify the two terms in equation (3).

In general, the amount of option value (expected time to redevelopment, T) is a negative (positive) function of the existing hedonic aggregate, q_i^0 . The intuition is that smaller, older houses have high option value and are likely to be developed sooner than their larger, newer neighbors. The appendix demonstrates that there may be a minimum value of q_i^0 , .15 in figure 1. Below this value houses will be rationally redeveloped immediately.

The well-known curvature of option value is the second general feature of any solution to an option value model; e.g., consider settings such as Svetlana Boyarchenko (2004). In the context of a cross-sectional hedonic equilibrium (i.e., the level of rent and parameters of the option model are given) there is a nonlinear relationship between property value and the difference between the maximum allowed by zoning (or optimum quantity, whichever is smaller) and q_i^0 .

We will use this curvature to identify the two terms in equation (3). Consider two cases illustrated by figure 1:

Case 1: The random draws on the x_{ji} and the other parameters of the model are such that most properties are selling well below replacement cost and so they have little option value. Then we are in the part of figure 1 labeled Sector I; the second term of equation (3) is approximately zero for most properties. The

standard hedonic model correctly predicts that value rises approximately linearly with q_i^0 .⁷

Case 2: The random draws for x_{jt} and the other parameters of the model are such that many properties have option value as suggested by Sector II of figure 1. Then the option value component of total value will be convex to the quantity axis (q_i^0) whereas the value of the existing vector will be approximately linear in q_i^0 . This is characteristic of a boom period, where smaller, older houses have substantial option value. The curvature of the option value portion can be approximated by a sufficiently flexible functional form for the second term in equation (3). Option value will decrease nonlinearly in q_i^0 whereas use value will increase linearly in the same variable.

The special case with a closed form solution to equation (3) derived in the Appendix and illustrated in figure 1 suggests a power function for the option value term. But, well established empirical techniques can be used to allow much more flexibility when estimating the model. In this way, more general models such as the one in Boyarchenko (2004) can be accommodated.

Identification by functional form alone is typically considered problematical, so we introduce a zoning constraint for additional identification restrictions.⁸ When zoning is binding, properties that are built up to the zoning maximum will have little option value, regardless of the draws from x_{jt} and other parameters. Properties below the zoning maximum will have more option value during the boom period, less during normal and

⁷ We say “approximately” because a hedonic equilibrium is inherently nonlinear. Ed Coulson (2010) notes that the use of flexible functional forms has abated; semi-log or double log approximations to nonlinearity are now standard in the literature. The log-linearity of use value is the basis of our empirical tests. We perform robustness tests using different functional forms for the use value term.

⁸ Note, however, that the substantial curvature associated with option value makes identification of our model plausible.

bust periods. We match properties with no possibility of redevelopment with those that do have this possibility using spatial location and property characteristics. By comparing the cross-sectional equilibrium values from one time period to another, we separately identify movements in option value and use value.

The Simultaneity of Price and Option Value

Examination of equations (3) and (A.3) clarifies that property value and option value are simultaneously determined. Causality is not relevant here. The relevant issue is identifying the part of property value that is accounted for by the option premium, the second term on the right hand side of these equations. We do this with a cross sectional hedonic regression. By comparing cross-sectional results during boom and bust periods, we propose to evaluate changes in the percent of value associated with option value.⁹

Intuitively, option value changes more than use value over the cycle: for example, option value vanishes when spot rents fall sufficiently, or when the parameters of the model shift sufficiently in a way that reduces value. Our claim is that a hedonic regression based on the functional form given by figure 1 is capable of identifying the amount of option value in each phase of the cycle. By comparing these cross-sectional estimates, we propose to measure the increase in volatility related to option value.

Empirical Implications of Embedded Option Value

The purpose of this section is to derive empirically testable propositions from the equations. In the housing literature, hedonic regressions are typically estimated in logs ($\ln P_{it}$ is the dependent variable). Therefore, we measure the option value variable with the difference $\ln \delta - \ln q_i^0$. A maintained hypothesis is that the zoning limit, δ , is typically binding in Berlin, a densely settled urban area. Below, we present evidence on

⁹ We divide our thirty year period into three distinct housing market regimes, so we can reasonably assert that each cross sectional hedonic represents a long run equilibrium.

this hypothesis, and we point out that conservative estimates are produced by those observations where the difference should be $\ln q_i^* - \ln q_i^o$.

Other quantities in the equations – e.g., the discount rate, ρ and variance, ω – are fixed in the cross-section, so variation comes from δ and q_i^o as in figure 1. Consider an aggregate quantity index of the new structure divided by an index for the old structure: call this ratio “development potential,” D_i . We measure the ratio between the old and new quantities by the maximum size of a house (in square meters) allowed on each lot by zoning divided by the size of the existing house. As suggested by theory, if the ratio is close to one (log close to zero), the property is close to optimal intensity and option value will be low regardless of the point in the housing market cycle.¹⁰ A large development potential ratio suggests that the last term in equation (A.3) has the potential to be large if the parameters and current draws from rent and cost distributions support an option that is at or in-the-money.

The model suggests the following testable hypotheses:

H1: The coefficient for $\ln D_i$ will have a positive sign during periods of significant option value, zero during other periods. This can be tested against the alternative that the coefficients for $\ln D_i$ have negative signs.

H2: The effect of D_i should be nonlinear:¹¹ near zero over some of its range and significantly positive at high levels of D .

¹⁰ Of course, option value is also a function of the parameters of the model, the current level of implicit rent and construction costs. This motivates our approach, which is to shift the regression parameter on the development potential term over time so that it can respond to changes in the economic and political environment.

¹¹ Note that the value of D = development potential increases as one moves from right to left in figure 1.

An additional testable hypothesis follows from the dramatic events in Berlin between the end of 1989 and the end of 1994: option value should be higher because expected drift and variance are expected to increase during this time period.

H3: The coefficients for $\ln D_i$ should be higher during the Big Bang period and lower before and after that time.

Events and Data

Events Associated with the Creation and Destruction of Option Value

After the end of World War II, the artificial border surrounding West Berlin became more and more impermeable, culminating in the erection of a heavily fortified physical barrier in 1961. The ‘Berlin Wall’ locked in the Eastern German population, making free movement of people from East to West impossible. Ironically, the Wall stabilized the political situation, and a period of business as usual took the place of the serial crises that had characterized the city between 1945 and 1961: it all got quiet on the Eastern front.

This period of tranquility ended abruptly and unexpectedly in 1989. Even those who were witnessing political developments from within did not foresee the events that were to follow shortly. In June of 1989, just a few months before the fall of the Wall, Gerhard Schröder, who would later become Germany’s Chancellor, said: “After 40 years of Federal Republic of Germany, one should not lie to a new generation in Germany about a chance of re-unification. This chance does not exist.”¹²

After Hungarian border officials gave up stopping East Germans driving into Austria, the East German regime had no choice but to open the border to the West as well. On the evening of November 9th, a member of the East German Politbureau announced the end of the border controls and in the very same night thousands of East Germans crossed the

¹² Gerhard Schröder on June 12, 1989 in Bild-Zeitung. Source: <http://dipbt.bundestag.de/dip21/btp/13/13247.asc>

border into West Berlin (Serge Schmemmann, 1989). The subsequent political and economic “Big Bang” events evolved at a speed that was unheard of during the preceding 40 years of careful diplomacy. On October 3rd, 1990, East and West Germany were reunited, including a full integration of the monetary system, the administration, and the judicial system.

In a very close vote in June 1991, the unified German parliament decided to make Berlin the political capital of Germany again. Moving the government, parliament, and about half of the federal administration, including approximately 9,000 civil servants, started in 1994 and was finalized by 1999.

These events set in a period of great expectations, not least for the real estate sector. Plans were hatched to redevelop the center of Berlin, many areas of which had been largely untouched since their destruction in 1945, and house prices started rising much more quickly than they had done in the years before. The boom from 1989 to 1994 fueled construction activity in Berlin, suggesting the exercise of development options: about 140,000 housing units were added to the housing stock from 1992 to 2002, which is a net growth of 8 percent of the total stock.

But, soon after the shocks of the early nineties, Berlin’s population started falling and its economy stalled. While it was still a walled city, West Berlin received disproportionate transfers from the West German federal government, ultimately aimed at sustaining the city’s population levels. After 1995, these subsidies were gradually phased out. From 1992 through 2002 the number of Berliners holding any kind of job declined by 6 percent (Destatis, 2009). The number of total hours worked decreased at a faster rate, indicating that full-time jobs vanished even more rapidly. Despite the influx of government

employees, Berlin's population numbers started to decline slightly in 1994, and then declined more rapidly each year until 2001.¹³

The Dataset

Micro-data for housing transactions are difficult to obtain in Germany, as house sales are treated as private information. Every transaction of land or buildings, however, needs to be certified by a notary, who sends the title deed to the local land register. Committees for land price valuation (*Gutachterausschuss für Grundstückswerte*) use land registry data to maintain transaction databases and offer plot-specific appraisals for the government, the mortgage industry and private parties. We got access to these data, which include all transactions of single-family homes for West Berlin from 1978 through 2007.¹⁴ We use the 19,825 transactions that contain information on sales price, date of sale, interior area, lot size, replacement value and maximum floor space allowed by zoning.¹⁵ Replacement value (adjusted to 2007 Euros) provides us with a proxy for building age and condition. The structure's replacement value is estimated by a professional appraiser during an external inspection conducted at the time the sale is entered into the database.

Empirical Approach

Measuring Real Option Value

Based on the ratio of maximum interior area allowed by zoning divided by the current interior floor space, we calculate the unrealized space potential at the dwelling level.

¹³ A recent paper by Edward L. Glaeser and Joseph Gyourko (2005) shows how the combination of population decline and a durable housing supply is likely to cause substantial decline in house prices and new construction. Here, we associate the Big Bang events with the creation and destruction of option value.

¹⁴ Rainer Schulz et al. (2003) and Rainer Schulz and Axel Werwatz (2004) are the only papers we know of that use (subsets of) these data.

¹⁵ Filters were used to eliminate a few transactions with outlying values for interior area and lot size.

More than one quarter of our sample has a development potential ratio of one, which means that these dwellings are fully developed.¹⁶ We observe substantial variation of development potential within and across neighborhoods. In the Dahlem area, for instance, homes have been developed to on average of 81 percent of the upper boundary, while those in Reinickendorf have only 43 percent of the theoretical maximum developed.

There are three requirements for the ratio of maximum allowed floor space to current floor space to be a good yardstick of the magnitude of the redevelopment option. First, the ratio should vary across lot sizes, or else it would not add any information regarding the redevelopment option value above the size of the land parcel. Second, the legal limits should be economically binding. In other words, the economically optimal degree of development of a lot should be higher than the maximum set by the regulator. Third, the zoning limits should be exogenous.

The first issue can be addressed by looking at the correlation between the legal development limit per lot and the lot's land size. If this correlation would be 1, then all dwellings would effectively have the same zoning ratio, and all real option value would be captured by the lot size. However, we find a correlation of 0.84, and the range of the correlations across neighborhoods is between 0.16 and 0.99. This suggests that the legal zoning limit is material in the value of the redevelopment option.

The second issue is whether this legal limit is also limiting in an economic sense. The fact that our data is from a densely built-up urban area suggests that it is: Berlin is a major city and well-located space is scarce. However, we cannot fully rule out the existence of cases in which zoning allows a larger house than the optimal. If that would

¹⁶ This is not surprising in a densely populated urban area with strict density limits.

indeed be the case, our estimate of the option value embedded in house prices would err on the conservative side, as suggested by the errors-in-variables model.¹⁷

The third issue is whether zoning limits can easily be changed in Berlin. But, zoning is governed by formal zoning plans; any change needs to follow a long trail of formal and public procedures involving the city council. A change takes several years. Furthermore, all zoning decisions are made public, limiting the scope for special deals with developers or individual home owners.¹⁸

Moreover, if zoning limits would be endogenous, we would expect to see a relaxation of limits corresponding with the relative attractiveness of neighborhoods and we would expect this relaxation to go up in the boom. But we do not see this heterogeneity in the data. In our sample of owner-occupied homes, the total developable area increases slowly in time – by approximately 0.1 percent per year. There is hardly any variation across neighborhoods, and there is no significant change in the time trend over the cycle.

Controlling for Location

The quality of a location and our measure of space potential are interlinked. Better-located properties are likely to be redeveloped first, implying that option value is correlated with location value, a quantity that is difficult to observe. In areas with low attractiveness the option to add space to the building may be far out of the money while similar redevelopment possibilities in a prospering neighborhood will carry value. Thus, it is not sufficient to simply use our zoning variable to measure the amount of development potential.

¹⁷ An appendix, available on request, demonstrates this. Specifically, if $\ln D = \ln D^* + \xi$; $\xi > 0$, where D^* is the optimal structure size divided by actual and ξ is measurement error, then the coefficient on $\ln D$ will be biased towards zero.

¹⁸ Per lot zoning is very rare in Berlin.

Our empirical strategy to control for location effects is first to match sales of fully developed properties with sales of neighboring properties that may or may not be fully developed. We control for omitted location characteristics with this matching process. We focus on areas where our measure of development potential has economic meaning by identifying sales of homes built on relatively large lots that have been developed to the full legal limit. For these dwellings, it is likely that zoning is the limiting factor to redevelopment, rather than location quality.

The redevelopment option may be in the money for smaller homes on large lots near the fully developed properties, both sold within the same time period. Neighborhood dummies and clustered standard errors deal with unobservable location issues, any remaining endogeneity in the level of the zoning limit and any cross-location differences regarding the degree to which the legal development limit is economically binding.

Technically, we select all sales of fully developed properties on lots with sizes above the median lot size and pair them with all transactions within a circle with a half mile (804 m) radius¹⁹ that occurred in the same 3-year band (1978-1980, 1981-1983, ... , 2005-2007) as the reference point. We use this approach since we need temporal proximity of sales to make sales prices comparable, and the 3-year period is the result of a trade-off between maximizing temporal proximity and data density: shorter periods gave noisy coefficient estimates. Requiring this temporal proximity besides spatial proximity makes our analysis robust to possible changes in Berlin's spatial equilibrium caused by the big bang events starting in 1990, and to changes in variance or other underlying parameters.

We exclude neighborhoods that have fewer than 9 comparables in the reference circle and time period. In total, 487 fully developed homes on large lots remain in our sample,

¹⁹ A similar setup to match properties by location was used by Piet Eichholtz, Nils Kok and John Quigley (2010).

augmented with 6,256 neighboring transactions. For each of the 487 areas (i.e., neighborhoods), we define a dummy variable. The comparables are not exclusive, as observations can be located in the intersections of the half-mile circles.

Figure 2 visualizes the distribution of the sample within West Berlin and its neighborhoods (shaded in light grey). Each location of a single-family home transaction is marked by a small black dot. The vast majority of these homes are located in Berlin's periphery: the city center is dominated by multi unit rental buildings. The 487 circles are marked by white dots surrounded by dark grey circles with a radius of half a mile. Overall, the circles cover 35 of the 49 western neighborhoods and adequately represent the geographic distribution of the full sample.

Finally, we refine the modeling of location within each circle by adding spatial variables such as distances to rivers or open space, primary school or kindergarten, public transport hubs or railway tracks. To calculate these distances, we first translate the street address into longitude and latitude coordinates using Google Maps.²⁰ Locations of railway tracks, parks, lakes, rivers, and other open spaces are derived from free GIS maps supplied by the OpenStreetmap project²¹, while the complete list of subway-, railway-, and light rail-stations was obtained from the Berlin transportation authorities. We calculate the fastest route to the center, which is a combination of the walking time to these public transport hubs and the subsequent commuting time to the center. We look up the commuting time on a Monday morning to Berlin central station for each of the public transport stations in the 2009 transportation schedules.²² The school administration's official address list

²⁰ Detailed information on how to use the Google Maps toolbox for geocoding can be obtained from the authors on request.

²¹ www.openstreetmap.org

²² The new central station is located in what can be considered the center of the united Berlin, close to government quarters and parliament. It is Berlin's central transportation hub. During the cold war, Berlin Zoo station served as interim main station. It is about 4 train-minutes west of the new center.

reveals the location of all of primary schools and kindergartens. In addition, we define dummy variables for the distances to the (formerly) fortified East-West border.

Comparing Fully Developed to High Development potential Sales, Same Neighborhood

Fully developed sales account for 26.3 percent of our sample. For these sales the option to add space has little or no value even during the boom because zoning prohibits additional space. We divide the remainder of the sample into two groups: transactions of dwellings with high development potential, and transactions with low development potential. We define high development potential as the upper 26.3rd percentile of the distribution of development potential in order to implement our idea of pairing fully developed properties with those that have development potential. It is these high development properties where we expect value to be increased most by the presence of the option after controlling for hedonic characteristics as suggested by figure 1. The remaining 47.4 percent of the dwellings in the sample are expected to have relatively low option value (sector I, figure 1).

Table 1 presents the summary statistics of the final sample, the subsample of matched dwellings in the half-mile circles, and the subsamples of high, low, and no development potential dwellings. Average transaction values for single-family homes, at 2007 consumption prices, were roughly between € 350,000 and € 375,000. Comparing the matched sample with the full sample shows that dwellings in the matched subsample have higher selling prices, larger lot sizes and somewhat higher replacement values as required by our selection of neighborhoods likely to have in-the-money redevelopment options. This sets up the need for the robustness tests discussed below.

Next, we compare the descriptive statistics for high development potential properties to those for fully developed properties, columns 3 and 5, table 1. The average sales prices (in 2007 Euros) for the two samples are almost identical. By construction, the high development potential sales are on larger lots and have less interior area. Not surprisingly, they have lower replacement value; the magnitude of the difference suggests that building age and depreciation are adequately captured by replacement value.

The location variables suggest that the half-mile radius circles successfully control for neighborhood. For example, both types of property are, on average, just over 25 minutes from the city center by train (excluding the walking time from the home to the nearest train station). Moreover, the standard deviation of this time is very similar. Likewise, comparisons of distance to water and distance to green space do not show a statistically significant difference. About 12 percent of dwellings in both subsamples are located within 200 meters of a railroad track and each has 6-7 percent of dwellings located within 200 meters of the former border (e.g., the Wall) between East and West Berlin. This suggests that we have adequately matched the locations of the two types of property.

Regression Model

In order to empirically investigate the effect of option value on the value of existing dwellings we propose an empirically testable form of equation (3):

$$\ln P_i = \alpha + B_x X_i + B_s S_i + B_y Y_i + \beta_d \ln(D_i) + \beta_{dh} \ln(D_i) HighD_i + \beta_f Fulldev_i + \beta_h HighD_i + \varepsilon_i \quad (4)$$

where i indexes properties sold at time t ; the time subscript is suppressed to emphasize the essential cross-sectional nature of the regression.²³ The vector of standard hedonic characteristics is given by X_i ;²⁴ location (neighborhood dummies and distance variables) is represented by the vector S_i ; and time dummies – one for each of the 3-year bands – by the vector Y_i . The coefficients on $\ln(D_i)$ can now be interpreted as the elasticity of house

²³ The empirical estimates shift coefficients over time to allow option value to vary, and time dummies account for time variation within the cross-section. The assumption of linearity or log linearity of the use value portion of equation (4) is supported by a large empirical literature: see, for example, Maureen Cropper, Leland Deck and Kenneth McConnell (1988) and Jill McCluskey and Gordon Rausser (2003). Joseph Aldy and Kip Viscusi (2008) use a hedonic model similar to equation (4) to identify the nonlinear effects of age. We will test the linearity assumption for our data.

²⁴ The B_x coefficients represent the present value of implicit rents for these characteristics. Most hedonic regressions omit the option value terms: if option value is present, this practice raises questions about the interpretation of the B_x coefficients. Large changes will be apparent when we present regression results.

price with respect to development potential. We allow for the nonlinearity illustrated by figure 1 with two dummy variables: *Fulldev* is one if $\ln(D_i)$ is zero, otherwise zero; *HighD_i* is one for the sales with relatively high values for $\ln(D_i)$ (e.g., upper 25th percentile), otherwise zero.²⁵ Interaction of $\ln(D_i)$ and *HighD_i* controls for the curvature characteristic of option value. ε_i is a noise term modeled with robust standard errors and neighborhood clustering. Concerns regarding potential correlations between ε_i and omitted location variables are addressed by pairing high development potential properties with neighboring fully developed properties sold within the same three year window.

Equation (4) is estimated by ordinary least squares (OLS) with Huber-White robust standard errors clustered for each of the 487 neighborhoods²⁶.

Results

In order to test H1 and H3, we need to split our full 30-year sample into sub-periods based on housing market circumstances. We base these sub-periods on house price changes, so to demarcate the sub-periods we need to estimate a house price index for Berlin. Before presenting the regression results of equation (4), we provide this index.

Berlin House Price Index, Figure 3

Based on our data set of single-family homes we estimate a standard hedonic price index from 1978 through 2007.²⁷ We estimate time dummy coefficients for a standard hedonic

²⁵ The log linear transformation given by equation (4) is highly robust whereas a maximum likelihood estimation of the nonlinear form of equation (A.3) may not converge. Convergence is most problematical during periods with low option value, when the last term of the equation might plausibly be omitted.

²⁶ Colin Cameron, Jonah Gelbach and Douglas Miller (2008) suggest that 487 neighborhoods provide enough variation to obviate the need for bootstrap methods.

²⁷ Ours is the first West Berlin constant quality index based on a standard hedonic regression. Indeed, it is the first city-level transaction-based hedonic index in Germany. The index is available at <http://www.lindenthal.eu>. See Johannes Hoffmann and Andreas Lorenz (2006), The Committee for Land Price Valuation (Gutachterausschuss, 2008), and Rainer Schulz *et al.* (2003) for discussions of earlier estimates.

functional form with no development potential variables and with constant coefficients on all property characteristics. We take the exponent of these coefficients and normalize to 100 in 1978. The resulting price index is plotted in figure 3.

The graph suggests that the Berlin housing market has experienced roughly three phases for the 30 years covered by the index. The first period, between 1978 and 1989, can be characterized by steady growth. The average nominal house price increase over this time period was 5 percent per annum. In real terms, the annual growth rate was 1.9 percent.

The great expectations after the fall of the Wall fueled price increases, peaking in 1994 with nominal prices being 47 percent above 1989 values. The average annual price increase for this period was 8.1 percent in nominal terms, and 4.6 percent in real terms.

In 1995, house prices decreased slightly followed by a much larger drop in 1996. In 2007, house prices were back at 1989 levels – in nominal terms. In real terms, however, prices had plummeted to 55 percent of their 1994 values, and 84 percent of their 1978 values. The average price fall between 1994 and 2007 was 2.3 percent per annum in nominal terms and 2.9 percent in real terms. The weak performance of the local economy, adverse demographic trends and the fading out of the Berlin subsidies, combined with low growth for German house prices in general (Thies Lindenthal and Piet Eichholtz, 2011) are likely reasons for the disappointing price performance in the Berlin housing market after 1994.

Testing the Static Option Value Model, Table 2

We first analyze redevelopment option value for the full sample period, using the regression model given by equation (4). Regressions 1a, 2a and 3a exclude distance variables, relying on our matching of fully developed sales ($\ln(D_i) = 0$) with less developed ($\ln(D_i) > 0$) sales within half a mile to control for omitted location variables; moreover, we include 487 neighborhood dummies in all regressions. We also estimate every regression including further variables controlling for location based on geographic information systems (regressions 1b, 2b, and 3b).

The first two columns of table 2 provide the regression results for the standard hedonic model – i.e., omitting development potential variables. This model captures the cross sectional variation in Berlin house prices rather well, as the R-squared is around 0.9. The results are robust to adding the distance variables as additional controls for location, regression 1b. Most of these variables are not statistically significant, suggesting that the 487 neighborhoods do a good job of controlling location. Within these neighborhoods, value is significantly reduced by increased distance to the nearest public transit station. Value increases with longer time to the center of Berlin reflecting Berlin’s industrial origins with factories and working class quarters in the center and higher quality buildings for the better off in the green belt around it.

Next, we introduce option value into the model by the log of the variable D measuring development potential. Again, we use a specification with hedonics alone and one that also includes location effects. As before, time and spatial dummies are included in both setups. We have adequately captured option value only if estimates are non-negative (hypothesis H1). The results presented in columns 2a and 2b show that we cannot reject H1: the estimated elasticity of house value with respect to development potential is 16.0 percent for the model with hedonics only, and 15.3 percent for the full hedonic model, both significant at the 1 percent level.

We investigate the effect of option value by introducing dummies for dwellings with high development potential, $HighD$ in equation (4), and with zero development potential ($Fulldev$), and by including an interaction term of the development potential with the dummy for high development potential. The coefficients for these variables allow for curvature of the option value with respect to the development potential illustrated by figure 1. The results are provided in columns 3a and 3b of table 2. The curvature with respect to the development potential axis is as predicted by figure 1 and H2. The results show that the elasticity of house value with respect to development potential is about 23.5 percent ($= 0.045 + 0.190$) for the 1,767 sales with the highest development potential. These are the smaller structures on large lots in neighborhoods where the option is likely to be in-the-money. The statistically significant 2.8 percent premium for fully developed

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properties controls for a residual location effect: better located properties are likely to be developed first.

The significant -9.3 percent coefficient on the high development potential dummy does not mean that high development potential homes carry a discount. This negative intercept is more than offset by the coefficient for $\ln(D_i)$. Multiply this coefficient estimate ($0.045 + 0.190$) with the minimum value for $\ln(D_i)$ for high development potential sales (0.58) to get 0.136 and add -0.093. In other words, the high development potential properties start at a 4.4 percent addition to property value and increase to a mean of 10.0 percent. For the 75th percentile, the value is 14.7 percent. The sale with the largest development potential has 80.4 percent of property value in the redevelopment option.

Our matched sample is considerably smaller than our complete sample of 19,825 observations, and our results could possibly be affected by sample selection bias. That is why we have done an additional estimation of models 1a, 2a, and 3a to check for the robustness of our analysis. The estimation results are reported in table 3, and they suggest that sample selection bias plays a very small role, if any. The coefficients for the three hedonic variables (lot size, interior space, and replacement value) are nearly identical to those we found for the matched sample when we include an option value term (compare regressions 2a with 2c, 3a with 3c). At the same time, the coefficients on the option variables change according to expectations: option value is relatively high in our matched sub-sample, since it is composed of dwellings around houses that are fully developed. Including the remainder of the sample in the regression is therefore likely to decrease the economic and statistical significance of the option value variables, and it does.

We perform a further robustness test for the functional form of our model. In line with the literature on hedonics, we use a double-log specification for the use value variables, and attribute the curvature in the model to the option value component. We want to investigate whether the curvature we find may be attributable to the hedonics rather than the options variables, and we do that by estimating model 3a using alternative functional forms for the use value variables. More specifically, we test H1 and H2 when we (1)

assume quadratic terms for the hedonics, or (2) assume a semi-parametric functional form in which we use dummies for high quantiles of lot size, interior space, and replacement value. This semi-parametric approach is commonly applied (see Ed Coulson, 2010). The results for the semi-parametric approach, which are not reported here, still show significant option curvature, both statistically and economically.²⁸ The sizes of the coefficients are not significantly different than those reported for model 3a.

Option Value During the Boom and Bust Years, Table 4

The two pronounced phases of boom and bust evident in the graph of Berlin house prices depicted in figure 2 provide for a natural experiment. We expect substantial option value to be created during the boom years, while much of this should dissipate during the bust.

To test whether option value goes up in the boom and down in the bust, we estimate a hedonic model in which we approximate the boom period with a dummy variable for the six years from 1990 through 1995, and the bust with a dummy for the years from 1996 through 2007. The left out time period is the “quiet” period preceding the Big Bang events: the period from 1978 through 1989.

The baseline hedonic model includes dummies for the boom and bust years and spatial dummies (table 4, model 1). To investigate the influence of option value on cyclical house price movements – and to test H3 – model 2 includes development potential in the regression, and it is interacted with the market phase dummies. The regression results for the option coefficient show that we cannot reject H3: redevelopment potential has a significantly positive effect on value in the relatively quiet first period, and this effect goes up during the boom. The change in the option value coefficient is not significant because of high option value (elasticity of .23) during the quiet period. This might reflect

²⁸ Because of collinearity, the quadratic model produces an insignificant positive coefficient for $\ln D$ interacted with high development potential. It puts more weight on $\ln D$ by itself: it has a significant .087 coefficient..

substantial subsidies to West Berlin when the Wall was still up, or it might indicate that the fall of the Wall was anticipated.

During the boom, the elasticity of house value with respect to development potential is 0.272 (model 2), even exceeding the elasticity on the high development potential properties in the static regressions (table 2, models 3a and 3b). The redevelopment option elasticity shows a statistically significant decline of more than 0.15 in the subsequent bust. During the bust the elasticity was roughly half what it was during the quiet period, indicating a very substantial decline in option value over the market cycle. This confirms predictions based on theory.

To check for robustness of the results, we try a number of alternative specifications of the model with the time-dependent redevelopment option. First, we investigate the effect of the redevelopment option by only letting the redevelopment option for dwellings with high redevelopment potential be time-dependent, keeping the mid-range of development potential constant. The results, model 3 of table 4, do not materially differ from model 2.

Models 4 and 5 provide tests of hypotheses H2 and H3. These models shift the elasticity with the dummy for high development potential and allow all elasticity coefficients to shift over the three sub-periods. Again, H2 and H3 cannot be rejected: the coefficients on the interaction term in all three periods are significantly positive. In both specifications, the coefficient for development potential in the boom is statistically and economically significant, but the difference with the coefficient for the quiet period is not statistically significant. For the bust, we do find a statistically significant negative difference with the preceding periods. For high development potential properties, the elasticity is over 0.478 ($= 0.144 + 0.334$) during the boom; it declines by two thirds, to 0.151 during the bust. Interestingly, high development potential properties retain a significant positive elasticity

even during the bust. For low development potential properties the elasticity of 0.144 goes to zero during the bust phase.²⁹

A possible concern with the results presented in table 4 is that we hold the standard hedonic coefficients constant over the three different periods, while it is likely that use value will be positively associated with the boom/bust cycle in house prices. To analyze the importance of this, we adjusted model specification 2 in table 4, allowing first the land coefficient and then the interior area coefficient to change over the three periods (results not shown). The elasticities of house value with respect to development potential are 0.22, 0.27 and 0.12 during the quiet, boom and bust periods in the original setting. When we allow the land coefficient to shift, these elasticities are 0.23, 0.29 and 0.11, respectively, and when we allow the interior area coefficient to do so, they are 0.21, 0.27 and 0.13. Since the elasticities remain virtually unchanged, we conclude that our inferences are robust to allowing additional flexibility in coefficients.

The Share of Option Value over the Cycle, Table 5

To establish the economic significance of the elasticity estimates in table 4, we convert them into amounts of option value over time for low and for high development potential sales.³⁰ In table 5, we focus the discussion on models 3, 4 and 5. Model 3 allows no variation over the cycle in elasticity of low development potential properties, so it is included here only for baseline comparison.

²⁹ Adding the high development potential dummy confirms H1 since the minimum (25th percentile) of $\ln(D_i)$ for these properties is 0.58 (0.68). This implies that option value as a percentage of property value is a minimum of 6 percent during the quiet and boom periods and 3.7 percent during the bust. For the 25th percentile property these numbers are about 10 percent and 5 percent. Note that fully developed properties have a 3 percent premium during all phases of the cycle.

³⁰ This is done by multiplying the point estimates of elasticities by the appropriate mean values of the development potential variable (table 1): 0.27 for the 3,189 low development potential sales and 0.87 for the 1,767 high development potential sales. Then the coefficient on the appropriate dummy for high development potential is added: the exponent of the result is option value as a percentage of property value.

Table 5 suggests that the share of option value in transaction prices increased by between 15 and 20 percent during the boom for both low and high development potential properties: e.g., from 18.3 percent to 22.0 percent. During the bust, option value dropped to less than half of its pre-boom percentage for high development potential properties, and the 4 percent option premium for properties with low development potential disappears. The relative magnitude of the change was uniform across the low and high development potential segments, and it is robust across the models.

Translating these relative numbers into Euro amounts visualizes the economic magnitude of the real option component in home values. Model specifications 3 through 5 imply that the option to add more space to the building is worth between € 91,000 and € 98,000 for the high development potential sales during the boom. These high development potential properties experience an increase in elasticity during the boom: this increase implies that roughly 40 percent of the change in house value from the quiet period was associated with change in option value. During the bust, about 50 percent of the decline in value was associated with changes in option value. Of the properties with low development potential (nearly half of the sales we examined) option value is positively associated with the average rate of change in house prices. This is especially true during the bust, when about 12 percent of the decline in value is associated with change in option value.

Conclusions

This paper provides the first empirical evidence of the relation between redevelopment options and the dynamics of house prices. The analysis is based on a theoretical model where option value is additive to the use value of the existing characteristics vector. In our hedonic model, implicit market prices measure the value of rents from existing property characteristics, while additionally, a market premium may be paid for the option to tear down and replace the existing property.

Theory implies that any redevelopment option value is a function of unrealized development potential for the dwelling. Property value and option value are simultaneously determined; the nonlinear functional form characteristic of option value,

together with zoning limits and spatial proximity, allows identification of the proportion of value due to option value in any cross-sectional equilibrium. The effect of option value on property value is expected to increase during periods of high volatility and/or rising house prices, and to decrease in periods with falling house prices or low volatility. The nonlinearity of option value implies that changes in the redevelopment option of existing dwellings magnify the amplitude of cyclical house price movements, but only for properties not at the zoning limit.

We identify potentially high option value properties with the ratio of maximum structure allowed by zoning to existing structure size. We identify neighborhoods with potentially high option value by sales of fully developed properties on lots above median size. The presence of neighboring properties with unrealized development potential establishes the possibility of measuring option value after controlling for location.

An unexplored database consisting of West Berlin house sales spanning the years 1978 through 2007 allows us to analyze the effects of the redevelopment option over different phases in a housing market cycle. The main prediction of theory is confirmed: the elasticity of house value with respect to development potential is 15 percent on average over our full sample period; for homes with high development potential, the elasticity increases significantly, to 23 percent. This result is robust for alternative specifications of the hedonic model.

The time period covered in the dataset includes Berlin's Big Bang between the end of 1989 and 1994 when house prices boomed, followed by a prolonged bust. The constant quality house price index presented in this paper shows that average house prices fell every year in the 10 years after 1994, losing 55 percent in real terms from their peak. By the end of 2007, real house prices stood at 84 percent of their 1978 values.

For high development potential homes, about 40 percent of the price increase during the boom years is associated with changes in the value of the redevelopment option, while about 50 percent of the subsequent fall in prices can be attributed to reductions in option

value, as predicted by the nonlinearity of option value. For low development potential homes, the effects of the redevelopment option are less pronounced but still economically significant: 12 percent of the decline in real value of these dwellings is associated with change in option value.

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Appendix A: One solution to equation (3)

To provide an example of equation (3), we use an option model with zoning restrictions on the density of redevelopment. The model was first developed by Titman (1985) and extended by Joseph Williams (1991) and by Jyh-Bang Jou and Tan Lee (2007). Since this paper does not add to theory, but instead empirically tests predictions from existing theory, this Appendix is confined to sketching the solution given by Williams (1991) and by Jou and Lee (2007). In addition, we provide details on a numerical example illustrated in figure 1.

We begin with assumptions in addition to a constant discount rate, ρ :

1. The cost function is given by $x_{2i}(q_i^n)^\gamma$ where $\gamma > 1$ is the elasticity of cost with respect to the new hedonic quantity.

2. The x_{it} follow standard correlated geometric Brownian motion processes.
3. Risk adjusted drift rates for the two stochastic processes are given by v_i , $i = 1, 2$.
4. The hedonic quantity may be limited by a zoning constraint, $\delta < q_i^n$ where q_i^n is optimally chosen.

Then the price per unit, equation (2) is: $p(x_{2t}, \rho, v_2) = E_t \left[\int_t^\infty x_{2s} e^{-\rho(s-t)} ds \right] = \frac{x_{2t}}{\rho - v_2} < \infty$.

Given that asset value is linearly homogeneous in the x_{it} then Williams (1991) and Jou and Lee (2007) show that the valuation equation for the existing asset is given by:

$$W(y_t) = \frac{1}{\rho - v_2} q_i^0 y_t + A_1 y_t^\eta \quad (\text{A.1})$$

Where asset value W is scaled by x_{1t} , A_1 is a constant, y_t is the ratio $\frac{x_{2t}}{x_{1t}}$ and $\eta > 1$ is the

larger root of a quadratic equation:

$\eta = -[(v_2 - v_1) / \omega^2 - .5] + \text{Sqrt}\{[(v_2 - v_1) / \omega^2 - .5]^2 + 2(\rho - v_1) / \omega^2\}$ where ω^2 is the variance of the normalized stochastic process.

They derive closed form solutions giving optimal timing, y_t^* and optimal quantity, q_i^* :

See equation (13) in Jou-Lee (2007).³¹

Zoning is an important part of our identification strategy. We use solutions for a binding zoning limit proved in Jou and Lee (2007) for figure 1:

$$q_i^* = \delta \text{ and } y_t^* = \frac{\eta \delta^\gamma / (\eta - 1)}{(1 / (\rho - v_2)) (\delta - q_i^0)}, \text{ s.t. } q_i^0 < \delta; \rho > v_2; \gamma, \eta > 1. \quad (\text{A.2})$$

³¹ Jou and Lee (2007) use a parameter β for q_i^0 . We change notation to emphasize our focus on cross sectional variation in q_i^0 . Moreover, we avoid confusion by using ρ for the risk free rate.

Note that the time of redevelopment indexed by y^* is a positive function of q_i^0 . The intuition is that houses with less development potential will have longer expected lives before redevelopment. Houses with greater potential are likely to be redeveloped sooner.

The valuation equation displayed in figure 1 is:

$$W(y_t) = \frac{1}{\rho - v_2} q_i^0 y_t + \max \left[\frac{\delta}{\eta - 1} \left(\frac{y_t}{y^*} \right)^\eta, 0 \right] \quad (\text{A.3})$$

The variable in a cross-sectional hedonic model is q_i^0 as indicated by the x-axis in figure 1. The characteristic curvature of option value is given by the power function and the inverse function of q_i^0 , equation (A.2). Next we illustrate the minimum value of q_i^0 required by the high contact and smooth pasting conditions.

Numerical solutions in figure 1

The following values of parameters were chosen:

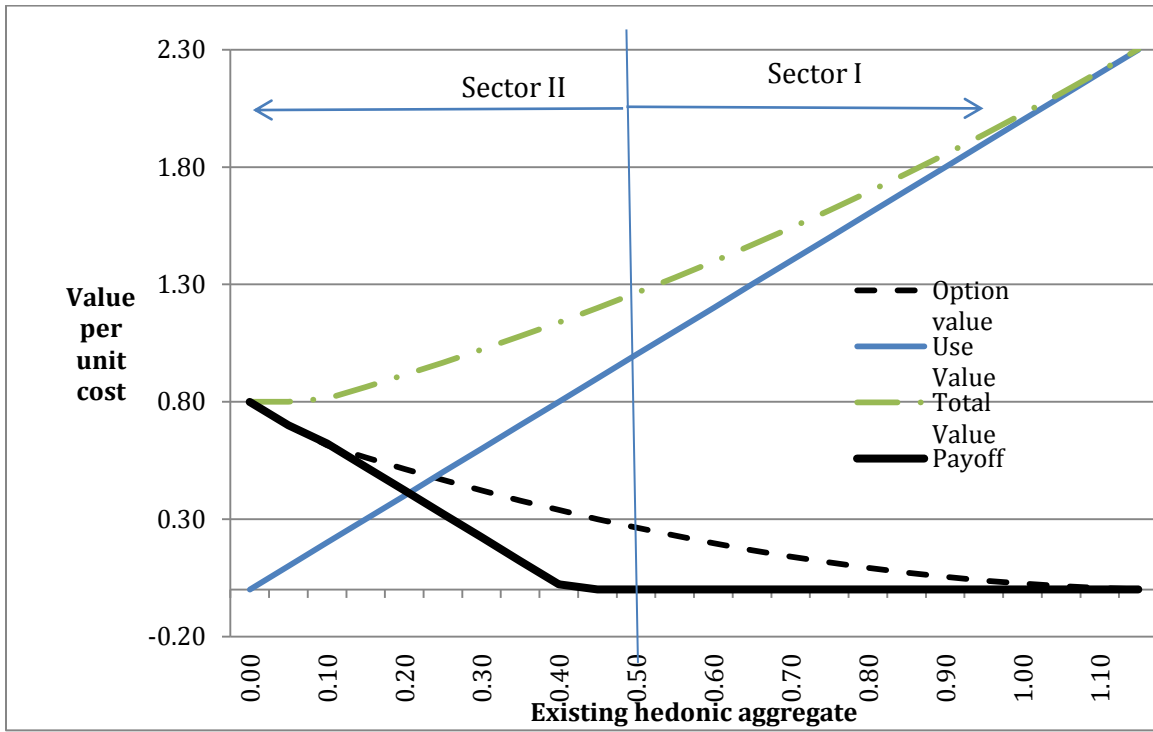
$$\rho = .1; \gamma = 2.5; \delta = 1.2; y = .18; v_1 = 0.0; v_2 = 0.01; \omega^2 = .1.$$

This gives solutions:

$$\eta = 1.87; \pi = \frac{1}{\rho - v_2} = 11.10; y^*(\delta | q_i^0 = .5) = .34; q^* - \text{unconstrained} = 2.14$$

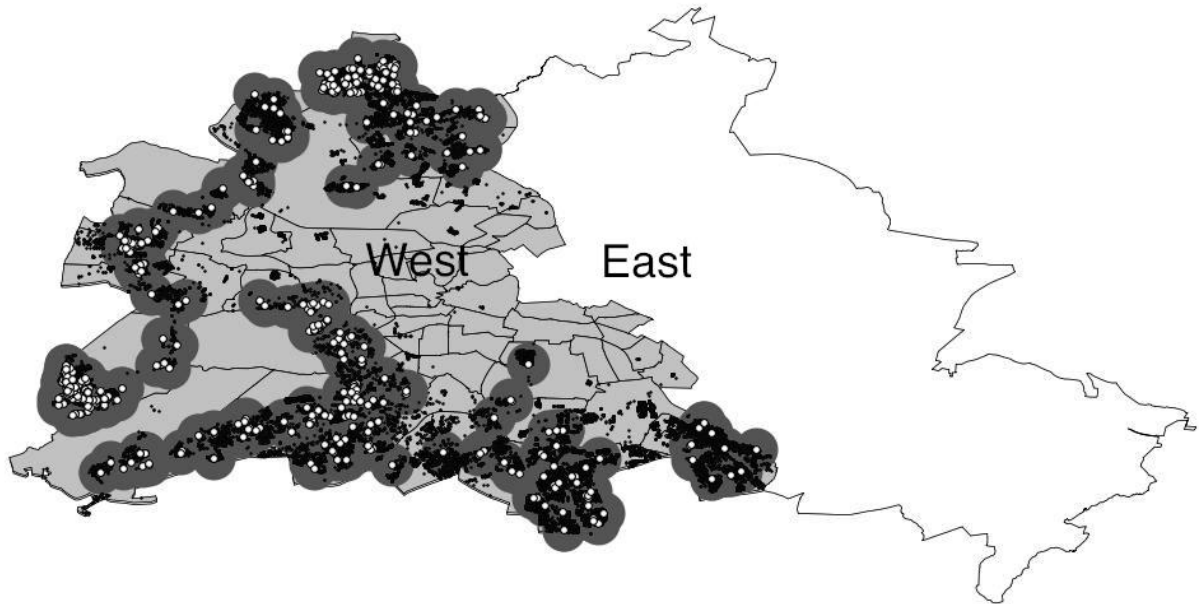
We plugged these values into equation (A.3) and let q_i^0 vary to produce figure 1. Note that the high contact point is $q_i^0 = .10$. Owners with houses smaller than this should rationally exercise.

Figure 1
Use Value, Option Value and Total House Value, Equation (A.3)



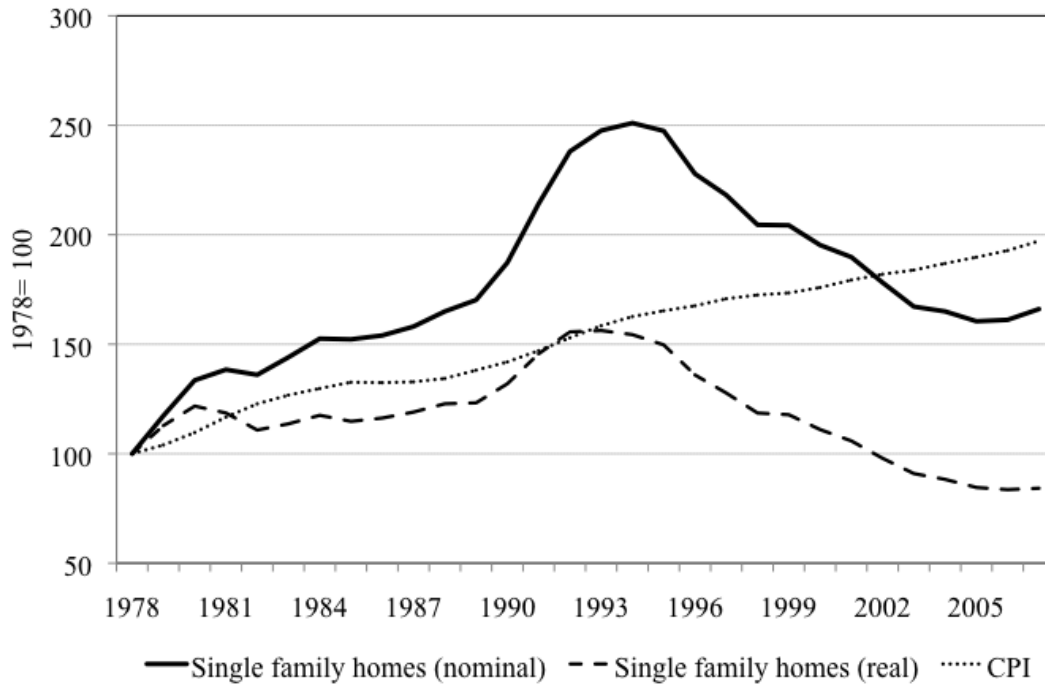
Notes: This plots a numerical example of a solution to equation (A.3), the hedonic model with option value and a zoning constraint. In Sector I, the value of the option to redevelop is small and the standard hedonic model applies. In Sector II, the curvature typical of option value allows identification of the portion of total value due to option value.

Figure 2
Geographic Distribution of Single-family Housing
Transactions in West Berlin



Notes: The map shows the boundaries of Berlin and West Berlin's official neighborhood classifications (shaded in light grey). Each location of a single-family home transaction is marked by a small black dot. The vast majority of these homes are located in Berlin's periphery, while rental apartment buildings dominate the city center. We match sales of fully developed buildings which have large lots (represented by white dots) with all sales that are within a half-mile circle (surrounding dark-grey circles) to control for the location of the buildings. All matched properties must be sold within a 3 year window of the fully developed property. The matching process resulted in 487 neighborhoods where we have sales of houses with development potential and sales without such potential.

Figure 3
West Berlin House Price Index



Note: Hedonic indices for single-family homes were estimated based on a standard hedonic model with annual time dummies. The CPI index is provided by the German central bank (available online at http://bundesbank.de/statistik/statistik_zeitreihen.en.php?lang=en&tr=UJFB99).

Table 1
Summary Statistics
Complete Sample; Matched Sample; No, Low, High Development Potential Samples
Variable means and standard deviations (in parentheses)

	<i>Full sample</i>	<i>Matched sample</i>	<i>No Dev. Potential</i>	<i>Low Dev. Potential</i>	<i>High Dev. Potential</i>
N	19825	6723	1767	3189	1767
Price (inflated to 2007 Euros)	345 (211)	377 (247)	365 (195)	392 (241)	364 (299)
Lot size (m ²)	515 (269)	572 (280)	383 (184)	569 (232)	767 (304)
Interior floor space (m ²)	146 (53)	155 (59)	167 (68)	162 (56)	128 (47)
Replacement value (2007 Euros)	153 (121)	164 (136)	218 (124)	171 (125)	96 (139)
Distance to water (m)	2963 (1757)	2860 (1637)	2856 (1789)	2926 (1614)	2747 (1510)
Distance to green space (m)	1734 (1477)	1504 (1298)	1500 (1284)	1514 (1320)	1490 (1269)
Distance to kindergarten (m)	583 (396)	593 (378)	594 (396)	595 (375)	590 (364)
Distance to primary school (m)	650 (330)	652 (336)	683 (363)	637 (329)	650 (316)
Distance to transportation hub (m)	1392 (1239)	1730 (1630)	1866 (1681)	1723 (1652)	1607 (1526)
Minutes to center from hub	26 (8)	26 (8)	26 (8)	26 (8)	27 (9)
Rail tracks < 200m	0.10 (0.31)	0.12 (0.33)	0.12 (0.32)	0.12 (0.32)	0.13 (0.34)
Border < 200m	0.07 (0.25)	0.07 (0.25)	0.07 (0.26)	0.06 (0.25)	0.06 (0.24)
Dummy fully developed	0.23 (0.42)	0.26 (0.44)	1 (0)	0 (0)	0 (0)
Dummy high development potential	0.28 (0.45)	0.26 (0.44)	0 (0)	0 (0)	1 (0)
ln(Development potential)	0.38 (0.38)	0.36 (0.37)	0 (0)	0.27 (0.16)	0.87 (0.25)

Note: Dummy fully developed is defined as 1 for all observations for which development potential is 0, 26.3% of the sample. The dummy for high development potential is defined 1 for all observations with development potential > 0.58 (demarcating the upper 26.3rd percentile of this variable) and 0 otherwise. We choose the upper 26.3rd percentile in order to pair fully developed properties with those in the same neighborhood that have development potential.

Table 2
Regression Coefficients for Static Regressions

ln(price)	Model					
	<i>1a</i>	<i>1b</i>	<i>2a</i>	<i>2b</i>	<i>3a</i>	<i>3b</i>
ln(lot size)	0.474*** (0.011)	0.477*** (0.012)	0.361*** (0.017)	0.368*** (0.018)	0.399*** (0.019)	0.406*** (0.020)
ln(interior space)	0.243*** (0.016)	0.238*** (0.017)	0.368*** (0.021)	0.360*** (0.022)	0.344*** (0.023)	0.335*** (0.024)
ln(replacement value)	0.229*** (0.007)	0.229*** (0.007)	0.234*** (0.007)	0.233*** (0.007)	0.233*** (0.007)	0.233*** (0.007)
<i>Logarithm of distance to ...</i>						
Green space		-0.009* (0.005)		-0.009* (0.005)		-0.009* (0.005)
Water		-0.012 (0.010)		-0.011 (0.010)		-0.009 (0.010)
Kindergarten		-0.004 (0.006)		-0.001 (0.006)		-0.002 (0.006)
Primary school		-0.001 (0.006)		0.001 (0.006)		0.001 (0.006)
Public transport hub		-0.026*** (0.008)		-0.018** (0.008)		-0.020** (0.008)
Minutes hub to center		0.092*** (0.024)		0.091*** (0.024)		0.087*** (0.024)
Border < 200m		-0.011 (0.014)		-0.012 (0.014)		-0.012 (0.013)
Rail < 200m		-0.010 (0.010)		-0.005 (0.010)		-0.006 (0.010)
ln(D_i)			0.160*** (0.021)	0.153*** (0.021)	0.045* (0.026)	0.038 (0.027)
ln(D_i) • Dummy high development potential					0.190*** (0.045)	0.188*** (0.045)
Dummy fully developed					0.028*** (0.008)	0.028*** (0.008)
Dummy high development potential					-0.093*** (0.034)	-0.091*** (0.034)
Neighborhood dummies	Y	Y	Y	Y	Y	Y
Time dummies	Y	Y	Y	Y	Y	Y
Constant	-1.398*** (0.084)	-1.328*** (0.156)	-1.422*** (0.084)	-1.435*** (0.152)	-1.534*** (0.083)	-1.537*** (0.151)
R-squared	0.903	0.904	0.905	0.906	0.907	0.908

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors (clustered for each of 487 neighborhoods) in parentheses, N = 6,688. Years covered: 1978-2007.

The natural logarithm of sales price (inflated to 2007 Euros) is regressed against a set of hedonics (lot size, interior floor space, replacement value of building), location variables and variables describing the real option to extend the building. The location variables are defined as distances (in meters) to urban amenities. Development potential is defined as the ratio of maximum home size allowed under current zoning divided by existing size. Time effects are controlled for by dummies for three year periods: 1978-80 ... 2005-07. Fully developed sales with lot size greater than the median (523 square meters) are matched with sales within a three year period and within half a mile to construct the 487 neighborhoods; a dummy is included for each neighborhood.

Table 3
Robustness Test, Regression Coefficients for Complete Sample

	Model		
	1c	2c	3c
ln(price)			
ln(lot size)	0.424*** (0.016)	0.351*** (0.025)	0.390*** (0.025)
ln(interior space)	0.292*** (0.021)	0.373*** (0.029)	0.348*** (0.029)
ln(replacement value)	0.230*** (0.007)	0.233*** (0.007)	0.233*** (0.007)
ln(D _i)		0.107*** (0.027)	0.017 (0.024)
ln(D _i) • Dummy high development potential			0.059 (0.057)
Dummy fully developed			0.050*** (0.008)
Dummy high development potential			0.030 (0.048)
Neighborhood dummies	Y	Y	Y
Time dummies	Y	Y	Y
Constant	-1.035*** (0.080)	-1.148*** (0.086)	-1.216*** (0.082)
R-squared	0.858	0.859	0.863

Notes: *** p<0.01, ** p<0.05, * p<0.1, Robust standard errors in parentheses (clustered for 45 neighborhoods). N=19825. Years covered: 1978-2007.

Table 4
Regression Coefficients for Time-varying Option Value Models

Variable	Model				
	1	2	3	4	5
ln(lot size)	0.480*** (0.012)	0.364*** (0.018)	0.399*** (0.020)	0.401*** (0.020)	0.399*** (0.020)
ln(interior space)	0.250*** (0.017)	0.378*** (0.023)	0.355*** (0.024)	0.354*** (0.024)	0.356*** (0.024)
ln(replacement value)	0.228*** (0.007)	0.233*** (0.007)	0.232*** (0.007)	0.232*** (0.007)	0.232*** (0.007)
Period = boom (1990-1995)	0.099*** (0.017)	0.100*** (0.016)	0.101*** (0.016)	0.101*** (0.016)	0.101*** (0.019)
Period = bust (1996-2007)	-0.062*** (0.010)	-0.057*** (0.010)	-0.059*** (0.010)	-0.056*** (0.010)	-0.055*** (0.011)
ln(D_i)			0.060** (0.028)		
• Quiet		0.220*** (0.029)		0.130*** (0.045)	0.127*** (0.044)
• Boom		0.272*** (0.029)		0.154*** (0.041)	0.144*** (0.046)
• Bust		0.118*** (0.025)		0.000 (0.033)	0.008 (0.034)
ln(D_i) • Dummy high development potential					
• Quiet			0.231*** (0.045)	0.178*** (0.051)	0.259*** (0.068)
• Boom			0.274*** (0.043)	0.200*** (0.048)	0.334*** (0.068)
• Bust			0.146*** (0.048)	0.196*** (0.048)	0.143** (0.059)
Dummy high development potential			-0.094*** (0.033)	-0.097*** (0.033)	
• Quiet					-0.168*** (0.052)
• Boom					-0.217*** (0.054)
• Bust					-0.051 (0.041)

Table 4 (continued)
Regression Coefficients for Time-varying Option Value Models

Dummy fully developed			0.029***	0.029***	
			(0.008)	(0.008)	
• Quiet					0.032
					(0.020)
• Boom					0.032**
					(0.014)
• Bust					0.027**
					(0.011)
Neighborhood dummies	Y	Y	Y	Y	Y
Constant	-1.052***	-1.077***	-1.187***	-1.196***	-1.194***
	(0.084)	(0.082)	(0.082)	(0.082)	(0.085)
R-squared	0.899	0.903	0.905	0.905	0.905

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. N = 6,688. Years covered: 1978-2007.

The natural logarithm of sales price (inflated to 2007 Euros) is regressed against a set of hedonics (lot size, interior floor space, replacement value of building) and variables describing the real option to extend the building. Development potential is defined as the ratio of maximum home size allowed under current zoning divided by existing size. Fully developed sales with lot size greater than the median (523 square meters) are matched with sales within a three year period and within half a mile to construct the 487 neighborhoods. A dummy is included for each neighborhood. Robust standard errors (clustered for each neighborhood) in parentheses.

Table 5
Share of Option Value in Total Home Value in Boom and Bust Period

	Model		
	3	4	5
<i>Share of option value in total value of home</i>			
Low development potential homes			
Quiet	1.6%	3.6%	3.5%
Boom	1.6%	4.2%	4.0%
Bust	1.6%	0.0%	0.2%
High development potential homes			
Quiet	17.3%	18.6%	18.3%
Boom	21.7%	23.5%	22.0%
Bust	8.9%	7.5%	8.4%
<i>Value of development option (in Euros inflated to 2007 values)</i>			
Low development potential homes			
Quiet	€ 5,545	€ 12,128	€ 11,843
Boom	€ 6,838	€ 17,777	€ 16,600
Bust	€ 4,601	€ 0	€ 609
High development potential homes			
Quiet	€ 58,576	€ 63,297	€ 62,035
Boom	€ 90,955	€ 98,347	€ 92,119
Bust	€ 25,059	€ 21,227	€ 23,575
<i>Change in value of development option in absolute terms</i>			
Low development potential homes			
Quiet to boom	€ 1,293	€ 5,649	€ 4,756
Boom to bust	-€ 2,237	-€ 17,777	-€ 15,991
High development potential homes			
Quiet to boom	€ 32,379	€ 35,050	€ 30,084
Boom to bust	-€ 65,896	-€ 77,120	-€ 68,544
<i>Change in value of development option/change in total home value</i>			
Low development potential homes			
Quiet to boom	1.6%	7.1%	6.0%
Boom to bust	1.6%	13.0%	11.7%
High development potential homes			
Quiet to boom	40.9%	44.3%	38.0%
Boom to bust	48.1%	56.3%	50.0%

Notes: All calculation are based on coefficients from table 3, models 3 through 5. As an example of percentages consider model 5, high development potential during the quiet period: 18.3% = $\exp((0.127+0.259)*0.87 -0.168)$, where 0.87 is the mean value for $\ln(D_i)$ from table 1. To convert the percentages into Euros, we used the median transaction prices in 2007 Euros for each phase in our sample: For the quiet period, the median price was € 339,500, for the boom phase € 418,700 and for the bust phase € 281,700.