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Real option value over a housing market cycle

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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 nonlinear functional form for option value and zoning limits provides identification of changes in option value over the cycle. For homes with high development potential, our results show that about 40% of the price increases during the boom years after the fall of the Berlin Wall were related to increased option value. In the subsequent bust about 50% of their price decline was associated with decreased option value. For dwellings with low redevelopment potential 12% of the decline in real value can be attributed to changing option value.

1. Introduction

In theory, real options contribute to price volatility in the market for residential real estate. This paper analyzes the extent to which house price dynamics are amplified by real options embedded in the existing housing stock.

Much of the literature on the value of the development option ponders over the relatively straightforward case of vacant land.[1] Owners of already developed dwellings, however, can execute a wide array of different real options, ranging from tearing down and rebuilding to less drastic choices like renovating, adding additional rooms or better amenities, improving the energy efficiency or changing other physical characteristics of the building. This study focuses on the economically most relevant real option: the possibility to add space, either incrementally or by demolishing and rebuilding.

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

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 relative to the existing structure. This is equivalent to dividing the maximum allowed floor area ratio by the actual ratio, holding lot size constant.[2] If the existing configuration of the

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[1] Undeveloped land value includes a call option: the right but not the obligation to put a structure on the land. See, for example, Titman (1985), Quigg (1993), Capozza and Li (1994), and Grenadier (1996).

[2] Dye and McMillen (2007) motivate a similar variable, the ratio of existing building area to land area, by zoning regulations in Chicago. They find that this variable has the expected negative sign in probit models of teardown exercise.

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dwelling and the land it stands on is close to the maximum, then the strike price of the option to exchange the existing for the optimal 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 employ a spatial matching process in which we compare houses with little or no development potential with houses in the same neighborhood 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 segmented pairings between heterogeneous groups of agents.[3] Several recent empirical studies are related to our approach. Aldy and Viscusi (2008) model age cohorts as separate equilibria, allowing identification of a highly nonlinear response of valuation to age. 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 term additive to a standard vector of hedonic characteristics. Spatially narrow neighborhoods are constructed to control for omitted variables.

Several housing studies use the hedonic model to value the option to redevelop. They capture option value with a wide variety of variables, including demolition and construction permits, the ratio of interior space to lot size, the ratio of interior space to neighboring new construction, the ratio of assessed building value to assessed land value, structure age relative to tract average, and renovation expenditures. We discuss some of these methods next.

Dye and McMillen (2007) correct for sample selection with a probit model of demolition permits.[4] Then they use a hedonic model to show that the vector of hedonic coefficients on structural characteristics is not significantly different from zero for properties identified as near the point of teardown, suggesting that they are selling for land value. Our paper differs by applying a hedonic model with option value to all sales, many of which are far from the point of option exercise.

McMillen and O'Sullivan (2013) study the effect of possible future teardowns on house prices, allowing the hedonic coefficients to vary with the hazard rate of demolition. They find that hedonic coefficients vary as predicted by the option value model: e.g., lower estimated coefficient on interior space if the probability of demolition is high. We find a different effect when we compare a hedonic regression including a variable designed to capture option value with a regression omitting that variable: the coefficient on interior space is biased downward by the omission of an option value term.[5]

Our approach is based on Clapp et al. (2012), who show that the hedonic model can be extended to include an option value term. They derive the implications of option value for a cross sectional hedonic equilibrium, where value equals use value (the present value of the existing vector of hedonic characteristics) plus option value (the right to exchange the existing vector for a new one at some cost). From this point of view, the existing literature on real option exercise is dealing with the special case where the sale of a house has near 100% option value.[6] They show that smaller older houses have a greater percentage of value in option value, and that the cross sectional valuation equation has the highly nonlinear curvature well-known from the financial economics literature. Their simulations suggest that introducing even a small percentage of option value can influence the hedonic coefficients on existing structural characteristics.

Clapp and Salavei (2010) apply this model to data from Greenwich, Connecticut. They show that the coefficient on option value measured by the ratio of assessed building value over assessed land value is greater than zero, confirming a prediction of the model, and that a few sales (less than .1% of their sample) have nearly 100% option value, whereas the median sale has only 1.8% option value. Their findings are robust when assessed values are replaced with a logit model of demolition permits, or with the ratio of structure size to new construction in the same neighborhood.

Munneke and Womack (2013) apply the Clapp et al. (2012) model to Florida data, and they add a selection model based on Dye and McMillen (2007). They develop both models by introducing spatial probit and spatial hedonic models. They use option value variables similar to those in Clapp and Salavei (2010), but all these variables enter simultaneously into their probit model. Also they use a buffer zone to control boundary effects, a well-known problem for spatial models. This allows for spatial clustering of option exercise.

The literature has established a highly uneven spatial distribution of option exercise, and, by implication, embedded option value. Helms (2003) demonstrates that a few neighborhoods have a lot of renovation investment and others little. Observable differences in housing stock and demographics explain most of the spatial clustering; however, a few neighborhoods cannot be explained by observables. Likewise, Dye and McMillen (2007) show that certain wards in Chicago have a lot of option exercise, and location near mass transit or near Lake Michigan significantly increase the probability of teardown. We control for spatial clustering by constructing a large number of small neighborhoods consisting of a few blocks each. Within each neighborhood, we measure option value by comparing sales of houses that are developed to the zoning maximum (no extension option left) with those that have some option value. We only include neighborhoods containing at least one house that has been developed to the maximum size allowed, which ensures that the zoning is economically binding. This pairing method is inspired by the boundary models discussed above.

Bostic et al. (2007) point out that volatility over a housing market cycle is higher for properties with higher land value relative to structure value, i.e., higher "land leverage." In the model of Bourassa et al. (2011), land value is equal to sales price less construction costs plus depreciation. Our option model similarly allows for leverage related to construction costs, with additional leverage from use value of the existing structure; option value is influenced by underlying parameters (e.g., variance, expected appreciation and interest rates).[7] With these modifications, we agree that properties with a higher percentage of value in the option (i.e., less in the existing use value) will display more volatility over the housing market cycle, and our findings confirm this.

We focus on identification of option value over a housing boom and bust cycle. In contrast to Clapp and Salavei (2010) this paper uses estimates of cross sectional hedonic equilibria over different phases of the cycle to determine the contribution of option value to the cycle.

To investigate this, we use unexplored data from the West Berlin housing market. There are two reasons why these data are uniquely fit

[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 (Bajari and Benkard, 2005). Likewise, Viscusi and 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 Ekeland et al. (2004) for discussion of a hedonic envelope composed of pairings between supply and demand segments. By way of contrast, Rosen (1974) suggested that agents differ in a continuously variable parameter such as tastes or technology.

[4] Their selection model allows for misclassification; a significant percentage of demolition permits is never used. This improves on earlier work by Rosenthal and Helsley (1994), who model the point of option exercise, when property value is equal to land value.

[5] The standard hedonic model is nested within our model. Omitted variable bias predicts that the omission of option value will bias the coefficient downward because option value decreases with interior space. By way of contrast, McMillen and O'Sullivan (2013) allow coefficients to vary across space.

[6] The model assumes that option value is less than 100% of the value of the house until the demolition process makes the house uninhabitable: i.e., the option is irrevocably exercised. For example, a negative economic shock after purchase (and perhaps after obtaining a demolition permit) might delay option exercise.

[7] The cost of exercising the exchange option in our model is equal to sacrificed use value as well as construction costs, defined to include demolition costs. At the point of exercise, the value of the optimal structure less demolition and construction cost is land value.

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 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% to the growth in real house value. In the subsequent bust, option value accounted for about 50% 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% 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.[8]

These results are intuitive, given that options provide a form of leverage. Our method, however, provides a new perspective and empirical evidence on the amplifying effect of real options on the boom and bust cycle 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 relevant 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.

2. Real option value in existing dwellings

We use 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.[9] The main empirical implication of the model is the addition (to a standard hedonic vector) of a nonlinear term for option value. If that option term is not significant, the model reduces to a standard hedonic model of house prices. So in effect, the standard hedonic model can be regarded a nested version of our more general hedonic model that accounts for option value.

2.1. Embedded option value

The hedonic model with a non-negative option value term was first proposed by Clapp et al. (2012) and provides the framework for Clapp and Salavei (2010) and for Munneke and Womack (2013):

$$\ln P_{it} = B_0 + B_x X_{it} + B_s S_{it} + B_y Y_i + f\left(q_i^0\right) + \varepsilon_{it}. \quad (1)$$

Here, P_{it} is the observed market price of the asset i sold at time t; the vector of standard hedonic property characteristics is given by X_{it}; location (neighborhood dummies and distance variables) is represented by the vector S_{it}; and time dummies by the vector Y_i. The scalar q_i^0 is intensity, an aggregate index of existing ($t = 0$) hedonic property characteristics per unit land, and $f(q_i^0)$ is the non-negative option value term with the curvature characteristic of option value. A disturbance term, ε_{it} arising from negotiations between buyers and sellers, will be modeled empirically with spatial clustering. $\boldsymbol{B}$ is a vector of parameters to be estimated.

Brueckner (1980) and Capozza and Li (1994) model intensity as the capital–land ratio. Clapp and Salavei (2010) and Munneke and Womack (2013) measure intensity in several ways: as the square footage of the existing dwelling divided by the square footage of nearby new construction; as assessed building value divided by assessed land value and by the probability of redevelopment. These studies assume that the economically optimal space addition to a dwelling is unconstrained by regulation. We introduce binding zoning constraints, a characteristic of our West Berlin data. The model with zoning constraints is based on Jou and Lee (2007):

$$\ln P_{it} = B_0 + B_x X_{it} + B_s S_{it} + B_y Y_i + B_\delta \left(\delta_i^0 - q_i^0\right)^\eta + \varepsilon_{it}, s.t. q_i^0 \le \delta_i^0. \quad (2)$$

Here, δ_i^0 is a zoning constraint specific to each house at the time of sale ($t = 0$) and $\eta > 1$ is the larger root of a quadratic equation. A technical appendix, available on request, gives the details of the derivation of the last term in Eq. (2). The proof is omitted here because it follows Jou and Lee (2007) closely. Our paper only requires the nonlinear function characteristic of many option value models.[10]

The empirical implications of the last term in Eq. (2) are that option value increases in the binding zoning constraint and decreases in the intensity of the existing vector. Option value can be near zero when the parameters captured by B_δ are such that the option is deep out of the money, as when houses are selling far below replacement cost: in this case $B_\delta \approx 0$. When the existing vector equals the zoning maximum, then option value is zero regardless of the state of the economy or the B_δ parameter. The well-known option value curvature comes from $\eta > 1$.

The model is summarized in Fig. 1, which plots a solution given model parameters fixed in cross-sectional hedonic equilibrium. Most importantly, a draw from the stochastic process on spot rents is fixed, as are other parameters of the option model, so variation comes from use value (the standard hedonic value) relative to a property-specific

[8] Ortalo-Magné and Rady (2006) show that "trade-up" homes exhibit more pronounced price volatility than "starter" homes caused by house price overreaction in response to income shocks. This effect does not account for the price volatility we find in our sample. Buildings in the most volatile market segment tend to have a smaller interior floor space and low replacement values, which is typical for starter homes.

[9] Arnott et al. (1983) analyze the profit-maximization problem of a landlord who chooses the quality of her building not only at the time of construction but also during the lifetime of this building through the degree of maintenance or potential upgrades.

[10] The constants $B_\delta \ge 0$ and $\eta > 1$ include all the parameters typical of option value equations. The most important of these are the drift and variance of the stochastic process, the cost of exercise and the riskless rate. They also include a draw from the stochastic process; this random outcome is fixed in the cross-section.

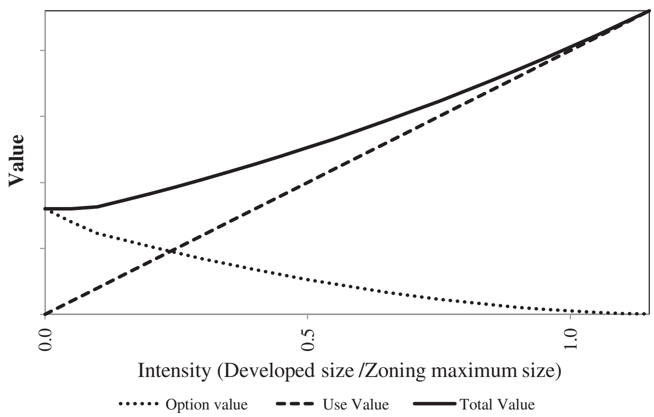

Fig. 1. Use value, option value and total house value. Notes: This plots a numerical solution based on theory by Clapp et al. (2012) for a hedonic model with option value and a zoning constraint. At the right half of the graph, the value of the option to redevelop is small and the standard hedonic model applies. At the left, however, the curvature typical of option value allows identification of the portion of total value due to option value. Option value is defined as gross value, which includes the value of the delay option and the net value of the new structure: value new less the sacrificed value of the existing structure and the costs of demolition and new construction.

zoning constraint; this intensity is measured on the horizontal axis. The vertical axis breaks property value into the net option payoff (value at the point of exercise), the value of the delay option (option value in Fig. 1 is the sum of these two) and use value, the 45 degree line.[11] We propose to use the highly nonlinear function characteristic of option value, together with the zoning constraint specific to each property, to identify the percentage of total value due to option value.

We need an empirical counterpart to the intensity variable ($\delta_i^0 - q_i^0$) in Eq. (2) and on the horizontal axis, Fig. 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 new and old quantities by the maximum size of a house (in square meters) allowed on each lot by binding 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.[12] A large development potential ratio suggests that the last term in Eq. (1) 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 $\ln(D_i)$ have negative signs.

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

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 boom period and lower before and after that time.

One of the coefficients of B_x is for log of interior space, typically the most influential structural characteristic for a standard hedonic equation. The aggregate index of hedonic characteristics, q_i^0, will increase with interior space, and the option value term in Eq. (2) decreases with q_i^0. If the option value term is omitted from the hedonic equation, and option value is present ($B_\delta > 0$ and $\delta_i^0 > q_i^0$ for a significant share of properties in the market) then it follows that the coefficient on interior space is biased downward: i.e., it is not a consistent estimator of the marginal value of additional structure.[13]

H4. The coefficients for ln(*interior space*) will be biased downward when the option value term is omitted from the hedonic regression, provided that option value is greater than zero in the local market.

3. Events and data

3.1. 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." [14]

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 politburo announced the end of the border controls and in the very same night thousands of East Germans crossed the border into West Berlin (Schmemann, 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 re-united, including 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 9000 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% 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

[11] Note that we define option value as gross option value. In terms of Capozza and Li (1994) our concept of gross option value includes agricultural value and access value (distance to the central business district) as well as the value of the delay option.

[12] 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.

[13] See Clapp et al. (2012) for details on omitted variable bias, and for simulation results showing considerable bias even for small amounts of option value.

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

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% (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.[15]

3.2. The dataset

Micro-data for housing transactions are difficult to obtain in Germany, as house sales are treated as private information. This is why empirical studies of German house prices are so very rare. Every transaction of land or buildings, however, needs to be certified by a notary, who sends the title deed to the local land register. In addition, the deeds are sent to the local committees for land price valuation (*Gutachterausschuss für Grundstückswerte*) who use this 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.[16] We use the 19,825 transactions that contain information on sales price, date of sale, interior space, lot size, replacement value and maximum floor space allowed by zoning.[17] 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.

International readers might be surprised by the seemingly low number of transactions for a city of several million inhabitants. Berlin's low homeownership rate of 12.1% in 1998 (16.2% in 2008) and the low share of single family homes in the housing stock explain the relatively modest size of the data set (Ahlfeldt and Maennig, 2010; Lindenthal and Eichholtz, 2011). Still, the data comprise the full universe of transactions with complete information.

4. Empirical approach

4.1. Measuring real option value

Based on the ratio of maximum interior space allowed by zoning[18] to the current interior floor space, we calculate the unrealized space potential at the dwelling level. More than one quarter of our sample has a development potential ratio of one, which means that these dwellings are fully developed. This is not surprising in a densely populated urban area with strict density limits. Still, 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% of the upper boundary, while those in Reinickendorf have only 43% 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 were 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 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.[19]

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 owners. Zoning variances for individual homes are very rare in Berlin.

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 single-family homes, the total developable area increases slowly in time — by approximately 0.1% per year. There is hardly any variation across neighborhoods, and there is no significant change in the time trend over the cycle.

4.2. 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.

Our empirical strategy to control for spatial heterogeneity is first to compare sales of fully developed properties with sales of neighboring properties that may or may not be fully developed. We focus on areas where our measure of development potential has economic meaning by identifying recent 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. For each of these sales, we identify a small geographic area containing neighboring sales of less-than-fully developed properties.[20]

Our method allows for an in-the-money redevelopment option for smaller homes on large lots near the fully developed properties,

[15] A recent paper by Glaeser and 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 events surrounding the fall of the Berlin wall with the creation and destruction of option value.

[16] Schulz et al. (2003) and Schulz and Werwatz (2004) are the only papers we know of that use (subsets of) these data. Ahlfeldt and Maennig (2010) use a dataset of Berlin condominium prices.

[17] Filters were used to eliminate a few transactions with outlying values for interior space and lot size.

[18] Two areas of zoning rules are relevant in this context. The second section (§ection 16–§ection 21) of *Baunutzungsverordnung* (BauNVO, 2012) defines ceilings for developable space, while §ection 34 of *Baugesetzbuch* (BauBG, 2012) imposes detailed requirements on building features and characteristics of any space that is developed.

[19] 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.

[20] We first used administrative demarcations to control for location specific quality differences. Berlin's districts, however, contain relatively large and diverse areas and therefore proved to be poor spatial control variables for our study.

both sold within the same time period. Neighborhood dummies and Huber–White clustered standard errors (for each neighborhood) deal with unobservable location issues, and 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. This approach follows a well-established method for controlling unobserved heterogeneity by identifying off of variation within small neighborhoods.[21]

Technically, we select all sales of fully developed properties with lot sizes above the median and pair them with all transactions within a circle with a half mile (804 m) radius that occurred in the same 3-year band (1978–1980, 1981–1983, …, 2005–2007).[22] We select transactions with large lot sizes because we want zoning limits to constrain the optimal house, not lot size. The 3-year period reflects 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 cataclysmal events starting in 1990, and to changes in variance or other underlying parameters.

We exclude neighborhoods that have fewer than 9 comparable sales in the reference circle and time period. In total, 487 fully developed homes on large lots are at the centers of the half mile circles, augmented with 6236 neighboring transactions. Of these, there are an additional 1280 fully developed homes on smaller lots.[23] 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. Each sale enters the estimation only once, even if it is assigned to multiple neighborhoods.

Fig. 2 visualizes the distribution of the sample within West Berlin and its neighborhoods (shaded in light gray). 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 gray 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.[24] Locations of railway tracks, parks, lakes, rivers, and other open spaces are derived from free GIS maps supplied by the OpenStreetmap (2009) project, 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.[25] The school administration's official address list 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.

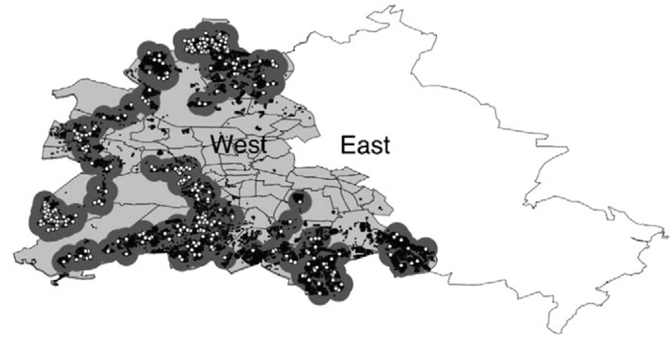

Fig. 2. Geographic distribution of single-family housing transactions in West Berlin. Notes: The map shows the boundaries of Berlin and West Berlin's official neighborhood classifications (shaded in light gray). Each location of a single-family home transaction is marked by a small black dot. The vast majority of these homes are located in Berlin's periphery, while rental apartment buildings dominate the city center. We compare 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-gray circles) to control for the location of the buildings. All paired properties must be sold within a 3 year non-overlapping window from the fully developed property sale: 1978–80 … 2005–07. This process resulted in 487 neighborhoods where we have sales of houses with development potential and sales without such potential.

4.3. Comparing zero to high development potential sales, same neighborhood

Fully developed sales account for 26.3% 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[26] 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 in Fig. 1. The remaining 47.4% of the dwellings in the sample are expected to have relatively low option value.

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 (USD 480,00–515,000). 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

[21] A seminal paper is by Black (1999). Citing Black and others, Abbott and Klaiber (2011) note that "as long as the fixed effect is specified at a geographical scale at or below the scale of variation of the omitted variables and the assumptions already noted are satisfied, fixed-effects estimates pose a simple nonparametric solution to the omitted variables problem (p. 1331)". We use these small neighborhoods to control for the clustering of redevelopment noted by Dye and McMillen (2007), Helms (2003) and Munneke and Womack (2013).

[22] A similar setup to match properties by location was used by Eichholtz et al. (2010).

[23] The paired subsample of sales consists of 1767 ($=487+1280$) fully developed ($lnD=0$), 1767 with the highest values for the development potential (high lnD) and 3189 sales with lower development potential (lnD greater than zero but less than the high subset). The total subsample is 6723 ($=1767\times 2+3189$) sales.

[24] Detailed information on how to use the Google Maps toolbox for geocoding can be obtained from the authors upon request.

[25] 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. Ahlfeldt and Wendland (2011) show the significance of transport infrastructure for land prices in Berlin.

[26] We pick the top 26.3% in terms of option value to have as many observations in the high potential segment as in the 26.3% of houses without any space potential left. We tried different percentiles as cut-off points and found consistent results.

Table 1
Summary statistics complete sample; matched sample; no, low, high development potential sample variable means and standard deviations (in parentheses).

	Full sample	Matched sample	No dev. potential	Low dev. potential	High dev. potential
N	19,825	6723	1767	3189	1767
Price (thousands, inflated to 2007 EUR)	345	377	365	392	364
	(211)	(247)	(195)	(241)	(299)
Lot size (m^2)	515	572	383	569	767
	(269)	(280)	(184)	(232)	(304)
Interior floor space (m^2)	146	155	167	162	128
	(53)	(59)	(68)	(56)	(47)
Replacement value (thousands, 2007 EUR)	153	164	218	171	96
	(121)	(136)	(124)	(125)	(139)
Distance to water (m)	2963	2860	2856	2926	2747
	(1757)	(1637)	(1789)	(1614)	(1510)
Distance to green space (m)	1734	1504	1500	1514	1490
	(1477)	(1298)	(1284)	(1320)	(1269)
Distance to kindergarten (m)	583	593	594	595	590
	(396)	(378)	(396)	(375)	(364)
Distance to primary school (m)	650	652	683	637	650
	(330)	(336)	(363)	(329)	(316)
Distance to transportation hub (m)	1392	1730	1866	1723	1607
	(1239)	(1630)	(1681)	(1652)	(1526)
Minutes to center from hub	26	26	26	26	27
	(8)	(8)	(8)	(8)	(9)
Rail tracks < 200 m	0.10	0.12	0.12	0.12	0.13
	(0.31)	(0.33)	(0.32)	(0.32)	(0.34)
Border < 200 m	0.07	0.07	0.07	0.06	0.06
	(0.25)	(0.25)	(0.26)	(0.25)	(0.24)
Dummy fully developed	0.23	0.26	1	0	0
	(0.42)	(0.44)	(0)	(0)	(0)
Dummy high development potential	0.28	0.26	0	0	1
	(0.45)	(0.44)	(0)	(0)	(0)
ln(Development potential)	0.38	0.36	0	0.27	0.87
	(0.38)	(0.37)	(0)	(0.16)	(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. All pairing is for sales within the same 3-year non-overlapping window: 1978–80 … 2005–07. Replacement value (adjusted to 2007 Euros) provides us with a proxy for building age and condition. 345,000 EUR converted to approximately 473,000 USD in 2007. The average lot size of 515 m^2 translates into 5540 ft^2 while the interior floor space of 146 m^2 measures 1570 ft^2.

potential sales are on larger lots and have less interior space. Not surprisingly, they have lower replacement value; the magnitude of the difference suggests that building age and depreciation are adequately captured by replacement value. This is important since we do not have building age in our sample.[27]

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 min 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% of dwellings in both subsamples are located within 200 m of a railroad track and each has 6–7% of dwellings located within 200 m 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.

4.4. Regression model

We propose an empirically testable equation where use value is captured by the first three variables and the option value term is captured by the last four variables as suggested by H1, H2 and H3:

$$\ln P_i = \alpha + B_x X_i + B_s S_i + B_y Y_i + \beta_d \ln(D_i) + \beta_{dh} \ln(D_i) HighD_i + \beta_f Fulldev_i + \beta_h HighD_i + \varepsilon_i \qquad (3)$$

where i indexes properties sold at time t; the time subscript is suppressed to emphasize the essential cross-sectional nature of the regression.[28] The vector of standard hedonic characteristics is given by X_i [29]; 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 price with respect to development potential. We allow for the nonlinearity in Eq. (3) (illustrated in Fig. 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. 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.

[27] Hedonic studies of building age typically discard houses more than 100 years old because building age does not reflect renovation. From this perspective, our use of assessed building value is preferable to building age.

[28] 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 Eq. (3) is supported by a large empirical literature: see, for example, Cropper et al. (1988) and McCluskey and Rausser (2003). Aldy and Viscusi (2008) use a hedonic model similar to Eq. (3) to identify the nonlinear effects of age.

[29] The B_x coefficients represent the present value of implicit rents for these characteristics, which include the interior floor space of the unit. 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.

Eq. (3) is estimated by ordinary least squares (OLS) with Huber–White robust standard errors clustered for each of the 487 neighborhoods. Cameron et al. (2008) suggest that 487 neighborhoods provide enough variation to obviate the need for bootstrap methods.

5. 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 Eq. (3), we provide this index.

5.1. Berlin house price index

Based on our data set of single-family homes we estimate a standard hedonic price index from 1978 through 2007.[30] We estimate time dummy coefficients for a standard hedonic 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 Fig. 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% per annum. In real terms, the annual growth rate was 1.9%.

The great expectations after the fall of the Wall fueled price increases, peaking in 1994 with nominal prices being 47% above 1989 values. The average annual price increase for this period was 8.1% in nominal terms, and 4.6% 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% of their 1994 values, and 84% of their 1978 values. The average price fall between 1994 and 2007 was 2.3% per annum in nominal terms and 2.9% 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 (Lindenthal and Eichholtz, 2011) are likely reasons for the disappointing price performance in the Berlin housing market after 1994.

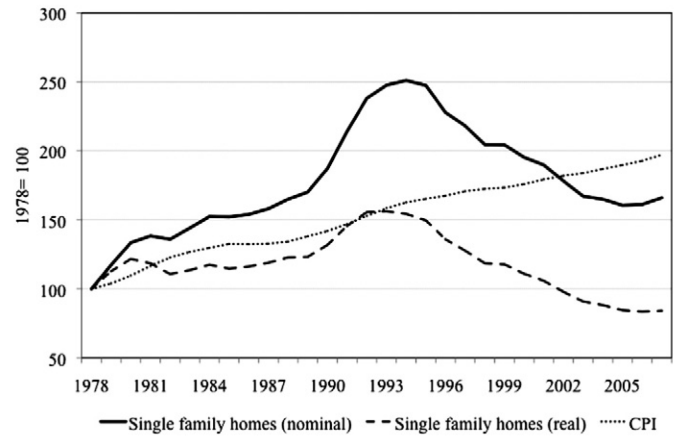

Fig. 3. West Berlin house price index. Note: Hedonic indices for single-family homes were estimated based on a standard hedonic model with annual time dummies. The CPI index is provided by the German central bank (available online at http://bundesbank.de/statistik/statistik_zeitreihen.en.php?lang=en&tr=UJFB99).

5.2. Static option value model

We first analyze redevelopment option value for the full sample period, using the regression model given by Eq. (3). Regressions 1a, 2a and 3a exclude distance variables, relying on our comparison 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 in 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 for 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 (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% for the model with hedonics only, and 15.3% for the full hedonic model, both significant at the 1% level.

We investigate the effect of option value by introducing dummies for dwellings with high development potential, *HighD* in Eq. (3), 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 in Fig. 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 in Fig. 1 and H2. The results show that the elasticity of house value with respect to development potential is about 23.5% (=.045 + .190) for the 1767 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 significant 2.8% premium for fully developed properties controls for a residual location effect: better located properties will be developed first.

The significant −9.3% 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% addition to property value and increase to a mean of 11.8%.[31] For the 75th percentile, the value is 14.7%.

[30] 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 Hoffmann and Lorenz (2006), The Committee for Land Price Valuation (Gutachterausschuss, 2008), and Schulz et al. (2003) for discussions of earlier estimates.

[31] Take the exponent of $(0.045 + 0.190) \times 0.87 - 0.093 = 0.111$, where 0.87 is the mean $\ln(D_i)$ for properties with high development potential. Note that we get more conservative estimates of option value when we pair fully developed with high development potential properties, regressions 3a and 3b compared to 2a and 2b.

Table 2
Regression coefficients for static regressions.

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

Notes: Robust standard errors (clustered for each of 487 neighborhoods) in parentheses, N = 6723. 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 m^2) are paired with sales within a three year period and within half a mile to construct the 487 neighborhoods; a dummy is included for each neighborhood. Replacement value (adjusted to 2007 Euros) provides us with a proxy for building age and condition. The asterisks ***, ** , * indicate significance at 1%, 5% and 10% confidence levels.

The sale with the largest development potential has 80.4% of property value in the redevelopment option.

We have direct evidence that options were exercised in response to high option value. We studied changes in the interior floor space of repeat sales of houses. This repeat subsample suggests a 5% addition to the total stock of interior space due to redevelopment of pre-existing houses, not new construction. About 80% of this redevelopment occurred after 1987.

Table 2 shows that the coefficient on interior space is 0.24 when an option value term is omitted and at least 0.34 when it is included. This strongly confirms H4: this coefficient is biased downward by omitted variable bias, and the amount of the bias is about 1/3rd of the value of the consistent estimator for the West Berlin data.[32] This result holds for all of our robustness tests, which are discussed next.

Our matched sample is considerably smaller than our complete sample of 19,825 observations, so our results might be affected by sample selection bias. That is why we have estimated Models 1a, 2a, and 3a using 19,825 sales. 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, and 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 which we do not report in a table. 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

[32] Table 2 suggests an upward bias in the estimated coefficient on lot size when the regression omits a term for option value. This is plausible since larger lots will allow more redevelopment possibilities, so the omitted option variable will be positively correlated with lot size. The model, Eq. (2), assumes no variation in lot size.

Table 3
Robustness test, regression coefficients for complete sample.

	Model		
ln(Price)	1c	2c	3c
ln(Lot size)	0.424***	0.351***	0.390***
	(0.016)	(0.025)	(0.025)
ln(Interior space)	0.292***	0.373***	0.348***
	(0.021)	(0.029)	(0.029)
ln(Replacement value)	0.230***	0.233***	0.233***
	(0.007)	(0.007)	(0.007)
ln(D_i)		0.107***	0.017
		(0.027)	(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***	−1.148***	−1.216***
	(0.080)	(0.086)	(0.082)
R-squared	0.858	0.859	0.863

Notes: Robust standard errors in parentheses (clustered for 45 neighborhoods). N = 19,825. Years covered: 1978–2007. The asterisks ***, ** , * indicate significance at 1%, 5% and 10% confidence levels.

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 still show significant option curvature, both statistically and economically. The sizes of the coefficients are not significantly different from those reported for Model 3a.

5.3. Option value during the boom and bust years

The two pronounced phases of boom and bust evident in the graph of Berlin house prices depicted in Fig. 3 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 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 0.23) during the quiet period. This might reflect 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

Table 4
Regression coefficients for time-varying option value models.

Variable	Model				
	1	2	3	4	5
ln(Lot size)	0.480***	0.364***	0.399***	0.401***	0.399***
	(0.012)	(0.018)	(0.020)	(0.020)	(0.020)
ln(Interior space)	0.250***	0.378***	0.355***	0.354***	0.356***
	(0.017)	(0.023)	(0.024)	(0.024)	(0.024)
ln(Replacement value)	0.228***	0.233***	0.232***	0.232***	0.232***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Period = boom (1990–1995)	0.099***	0.100***	0.101***	0.101***	0.101***
	(0.017)	(0.016)	(0.016)	(0.016)	(0.019)
Period = bust (1996–2007)	−0.062***	−0.057***	−0.059***	−0.056***	−0.055***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.011)
ln(D_i)			0.060**		
			(0.028)		
• Quiet		0.220***		0.130***	0.127***
		(0.029)		(0.045)	(0.044)
• Boom		0.272***		0.154***	0.144***
		(0.029)		(0.041)	(0.046)
• Bust		0.118***		0.000	0.008
		(0.025)		(0.033)	(0.034)
ln(D_i)·dummy high development potential					
• Quiet			0.231***	0.178***	0.259***
			(0.045)	(0.051)	(0.068)
• Boom			0.274***	0.200***	0.334***
			(0.043)	(0.048)	(0.068)
• Bust			0.146***	0.196***	0.143**
			(0.048)	(0.048)	(0.059)
Dummy high development potential			−0.094***	−0.097***	
			(0.033)	(0.033)	
• Quiet					−0.168***
					(0.052)
• Boom					−0.217***
					(0.054)
• Bust					−0.051
					(0.041)
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: Robust standard errors in parentheses. N = 6723. 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 m^2) are paired 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. Replacement value (adjusted to 2007 Euros) provides us with a proxy for building age and condition. The asterisks ***, ** , * indicate significance at 1%, 5% and 10% confidence levels.

Table 5
Robustness test: specification with all coefficients varying in time.

Estimate for period	Coeff. ln(D_i)	Robust SE	p-Value
Quiet	0.108	0.036	0.003
Boom	0.285	0.033	<0.001
Bust	0.149	0.028	<0.001

Notes: As a final test for robustness, we estimate Model 2 in Table 4 for each of the three time periods separately. Shifts in demand and supply during the three periods are captured by the time-varying coefficients for the hedonic and location variables. The table above shows the estimates for ln(D) only. Again, the coefficient for option value is significantly higher during the boom period.

redevelopment potential be time-dependent, keeping the mid-range of development potential constant. The results, Model 3 in Table 4, do not materially differ from Model 2.

Models 4 and 5 provide tests of 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.[33]

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 space 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 space 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.

As a final test for robustness, we estimate Model 2 in Table 4 for each of the three time periods separately. Shifts in demand during the three periods are captured by the time-varying coefficients for the hedonic and location variables: the coefficient on log of interior space increases from 0.25 during the quiet period to 0.40 during the boom, as expected. Table 5 presents the regression coefficients for ln(D) for each of these time-varying regressions. Again, the coefficient on ln(D) is significantly higher in the boom.

Results in Table 5 reveal substantial amounts of option value even during the quiet and bust periods, confirming casual observation that homeowners invest in renovations through all phases of the cycle. Helms (2003), Dye and McMillen (2007), Munneke and Womack (2013) and others suggest that much of this investment takes place in neighborhoods with high land value. We capture this in our model with the 487 neighborhood dummies.

Table 6
Share of option value in total home value in boom and bust period.

	Model		
	3	4	5
Share of option value in total value of home			
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%
Value of development option (in Euros inflated to 2007 values)			
Low development potential homes			
Quiet	€5179	€11,652	€11,329
Boom	€6532	€17,147	€16,330
Bust	€3954	€0	€494
High development potential homes			
Quiet	€58,595	€62,998	€61,982
Boom	€93,013	€100,728	€94,299
Bust	€26,603	€22,418	€25,108
Change in value of development option in absolute terms			
Low development potential homes			
Quiet to boom	€1353	€5494	€5001
Boom to bust	−€2578	−€17,147	−€15,836
High development potential homes			
Quiet to boom	€34,418	€37,730	€32,317
Boom to bust	−€66,410	−€78,310	−€69,190
Change in value of development option/change in total home value			
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 calculations are based on coefficients from Table 4, 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) for high option value homes (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 €323,500 for high option value homes (€338,500 for low option value), for the boom phase €408,000 (€428,500) and for the bust phase €247,000 (€299,000).

5.4. The share of option value over the cycle

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.[34] In Table 6, 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.

Table 6 suggests that the share of option value in transaction prices increased by between 15 and 20% during the boom for both high and low development potential properties: high increase 18.3% of property value to 22.0%, low from 3.5 to 4.0%. During the bust, option value dropped to less than half of its pre-boom percentage for high development potential properties, and the 4% option premium for properties

[33] 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% during the quiet and boom periods and 3.7% during the bust. For the 25th percentile property these numbers are about 10% and 5%. Note that fully developed properties have a 3% premium during all phases of the cycle.

[34] 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 3189 low development potential sales and 0.87 for the 1767 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.

with low development potential disappears. These results are robust across the models we have tested.

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 €93,000 and €101,000 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% of the change in house value from the quiet period was associated with change in option value. During the bust, about 50% 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% of the decline in value is associated with change in option value.

5.5. Generality of these results

The results in Table 6 are based on our spatially matched sample which has sales in 35 of West Berlin's 47 neighborhoods as defined by the government (see Fig. 2 for a map). We calculate that 68% of all single-family homes in the full sample of 19,825 sales have at least 10% development potential. For homes with lot sizes bigger than the median, the share increases to 90%. Moreover, the generality of our results is indicated by comparing regression 2c (Table 3) with 2a (Table 2): a given property in the full sample has about 66% (=.107/.160) as much option value as in the matched subsample.

6. 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 vector of characteristics. 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% on average over our full sample period; for homes with high development potential, the elasticity is 23%. These results are robust for alternative specifications of the hedonic model.

The time period covered in the dataset includes Berlin's reunification exuberance between the end of 1989 and 1994 when house prices boomed, followed by a prolonged sobering-up and home price 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% in real terms from their peak. By the end of 2007, real house prices stood at 84% of their 1978 values.

For high development potential homes, about 40% of the price increase during the boom years is associated with changes in the value of the redevelopment option, while about 50% 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% of the decline in real value of these dwellings is associated with change in option value.

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