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The Dynamic Response of Housing Values to a Forest Invasive Disease: Evidence from a Sudden Oak Death Infestation

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Abstract "Sudden Oak Death" (*Phytophthora ramorum*) is a non-indigenous forest pathogen which causes substantial mortality of coast live oak (*Quercus agrifolia*) and several other oak tree species on the Pacific Coast of the United States. We estimated the time path of residential property values subject to oak mortality using a dataset that spans more than two decades—including a decade of transactions before-and-after the invasion. The findings suggest moderate, persistent property value discounts (3–6%) for homes located near infested oak woodlands subject to continuous post-invasion declines in forest health. The most severe discounts (8–15%) occurred where dying oaks were distributed both within residential neighborhoods and in nearby woodlands. Various hedonic modeling specifications were tested and compared to assess their ability to control for bias associated with unobserved spatial effects.

Keywords Difference-in-differences · Spatial hedonic · Invasive diseases · Sudden oak death

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1 Introduction

Recent ecological and economic disruptions caused by nonnative forest pests and pathogens in the United States have heightened public awareness of the dangers posed by forest invasive species. Despite the fact that, in 2005, the US Congress passed the Healthy Forests Restoration Act to provide additional funding for the management of forest pests and pathogens, little is known about the magnitude or distribution of economic damages from forest invasive species. Rigorous assessments of the economic impacts of forest invasive species are needed to provide credible, theoretically sound information that can be used both by policy-makers and natural resource management agencies. Although it has been suggested that much of the economic impact of forest invasive species may be due to the loss of non-market values such as aesthetics and recreational quality, as well as the provision of other ecosystem services (Holmes et al. 2009), little effort has been focused on obtaining estimates of non-market impacts.

The goal of this study is to estimate the time path of residential property values in response to a virulent forest disease—"Sudden Oak Death", (caused by the exotic pathogen *Phytophthora ramorum*)—in Marin County, California. This is accomplished using a quasi-experimental hedonic property value method that measures change in property value over time relative to a base, pre-outbreak level. Sudden Oak Death (SOD) causes substantial mortality of several oak tree species on the Pacific Coast, and is believed to have entered the United States on nursery stock (Ivors et al. 2006). The first mortality from SOD in the oak woodlands of Marin County was recognized in the mid-1990s. The data for the analysis cover more than 30,000 property transactions spanning more than two decades (1983–2008) across 56 communities within Marin County, California. The time span of the dataset encompasses the before (1983–1997) and after (1998–2008) period of the invasion when oaks in several study communities died from SOD. This unique dataset permits a dynamic analysis of property values discounts from the disamenity effects of SOD for each year of the invasion from 1998 to 2008.[1] These results should prove useful for elucidating and quantifying the damages caused by this forest pathogen and helpful to policy makers trying to understand the impacts of forest invasive diseases.

Two strategies are used for identifying the disamenity effect of SOD. First, for the early period of the invasion (1998–2003), cross-sectional spatial econometric models are used. These models control for spatial dependence with nearest-neighbor weighting matrices specified for spatial lag dependence and autocorrelation. Second, for a longer period (1983–2008) with transactions before-and-after the invasion, quasi-experimental difference-in-differences hedonic models are used with fixed-effects specified for communities and parcel 'repeat sales'. The spatial difference-in-differences model exploits the natural experiment inherent in the long study period, which spans twenty-five years, to control for unobservable spatial effects.

The problem of spatially-correlated unobservable effects arises when property values associated with SOD are influenced by neighborhood characteristics not observed by the analyst (e.g., home owner preferences, omitted landscape features). The pathogen may be spread between properties by wind-blown rain, the movement of nursery plants, or intra-city hikers, creating a direct link between the spread of the pathogen, homeowner preferences, and the nursery planting and recreation decisions of homeowners and their neighbors. However, these

[1] The identification of the disamenity effect of SOD is enhanced by the quasi-random nature of the invasion. Homeowners do not know if their property will be affected by SOD since there is no exact knowledge of how disease spreads. The effects associated with the invasion are unlikely to be diluted by previous expectations about such an event.

homeowner preferences are difficult to quantify and therefore, unobservable to the analyst. Thus, cross-section OLS estimation of the hedonic models during the invasion will likely produce biased estimates of SOD effects on property values.

Several hedonic studies have been conducted that evaluate the contribution that healthy trees make to residential property values (for a review, see, Holmes et al. 2010). In general, this literature suggests that trees increase residential property values in the range of 1–5%. This general result is echoed in recent studies finding that street trees in Portland, Oregon increase residential property values by roughly 1–3.5% (Netusil et al. 2010; Donovan and Butry 2010). Very few studies, however, have evaluated the impact of invasive species, in general, or tree decline, in particular, on property values. Holmes et al. (2010) report a discount of 1–2% for properties in the Highlands region of New Jersey with dying hemlock trees due to a non-native forest insect, the hemlock wooly adelgid. In a study of the effect of an aquatic invasive species on residential property values in Wisconsin, Horsch and Lewis (2009) find a decrease in land values of 13%.

2 Estimating the Effects of Sudden Oak Death Damage in Hedonic Models

Larger sample sizes and advances in computing power now permit the use of spatial econometrics (Kim et al. 2003) and spatial fixed-effects (Horsch and Lewis 2009; Pope 2008a,b) for hedonic modeling. Further, the increasing availability of pooled cross-section and panel data have allowed researchers to exploit quasi-experiments to purge omitted variables (Chay and Greenstone 2005; Greenstone and Gallagher 2008; Linden and Rockoff 2008). Kuminoff et al. (2010) update the well-known Cropper et al. (1988) study of misspecification bias in hedonic models to examine how the recent advances in hedonic models compare. Among their findings is that the quasi-experimental difference-in-difference estimators reduce the bias from spatial omitted variables, and are also effective in the presence of time-varying omitted variables if used in conjunction with spatial fixed-effects. Also, spatial fixed-effects have greater success in averting misspecification bias than the use of spatial weighting matrices.

We apply these recent advances in our hedonic models. The spatial econometric model imposes structure through weighting matrices. The estimates are consistent if unobservables are parcel-specific and follow the weighting matrices' pattern. The spatial difference-in-differences models use knowledge of the before-and-after effects of the disamenity to control for spatial observables. Spatial fixed-effects are included to further purge unobservables shared either by the community or parcel 'repeat sales', and which are potentially correlated with the disamenity. The advantage of the fixed-effects specification is that there is no (potentially false) structure imposed on the spatial dependence.

3 Sudden Oak Death (*Phytophthora ramorum*)

"Sudden Oak Death" is an emerging forest disease caused by a non-native pathogen (*Phytophthora ramorum*) in the United States (California and Oregon) and Europe (Great Britain and the Netherlands.)[2] *Phytophthora ramorum* causes both lethal and non-lethal

[2] Up to date information on *P. ramorum* is available from the California Oak Mortality Task Force at http://www.suddenoakdeath.org/ and the United Kingdom's Food and Environment Research Agency at http://www.fera.defra.gov.uk/plants/plantHealth/pestsDiseases/pRamorum.cfm.

infections in plants. The lethal form of the disease infects the branches and stems of several ecologically important tree species including tanoak (*Lithocarpus densiflora*), coast live oak (*Quercus agrifolia*), canyon live oak (*Quercus chrysolepsis*), California black oak (*Quercus kellogii*), and Shreve's oak (*Quercus parvula var. shrevei*). Except for tanoak, these tree species cannot transmit the disease to other host plants. In contrast, the non-lethal form of the disease, called ramorum blight, infects the leaves or twigs of host species, known as foliar hosts, some of which act as reservoirs of inoculum which can transmit the pathogen to other host species.

In California, SOD was first identified in the mid 1990s, and spread rapidly to reach epidemic proportions in oak forests along the California coast (Rizzo and Garbelotto 2003) and in a few isolated locations in southern Oregon. Since then, more than 23 plant species in 12 families have been identified as hosts in North American forests (Hansen et al. 2005). In England and Wales, from 2002 to 2008, there have been outbreaks at 198 sites in locations other than nurseries, with 152 ongoing cases subject to containment measures. In the UK, evergreen rhododendron (*Rhododendron ponticum*) is the main sporulating host in woodlands, with beech and some oak species particularly at risk (Sansford et al. 2009).

4 Study Area and Data

This study focuses on the property value effects of SOD on parcels in Marin County, California (Fig. 1). As of 2008, the county had a population of 248,794. Marin County is located just north of San Francisco and is known for its natural beauty, liberal politics, and affluence. The interior is mountainous, forested, and largely undeveloped, while the eastern county along Highway 101 is suburban residential. Marin County has a per capita income of $51,950 and a median household income of $83,732, among the highest in the United States (American Community Survey 2006).

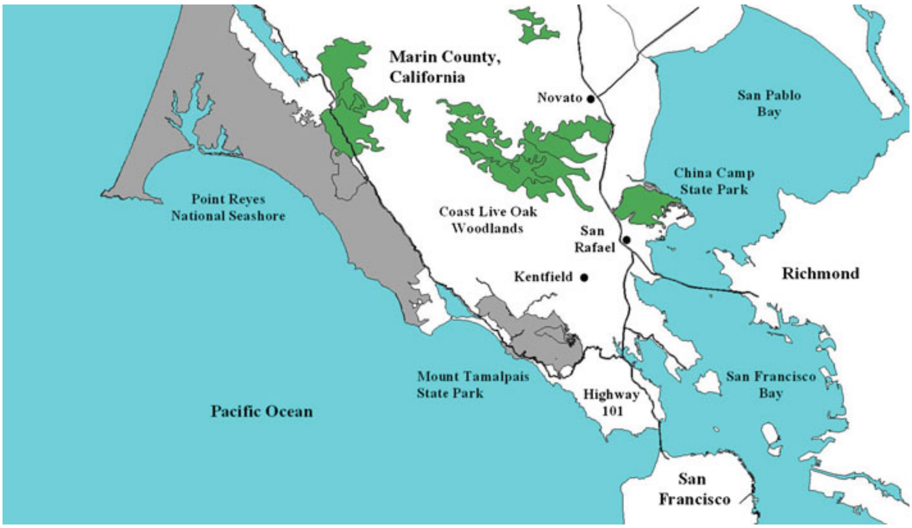

Fig. 1 Map of study area

4.1 Data Sources and Variable Specification

The data for this study are compiled from a variety of sources. Data on arms-length detached single-family home transactions were purchased from CD-DATA, one of the largest providers of real estate information in California, which obtain data from County Assessors. The data include the sale prices of the three most recent transactions for every property in Marin County, in addition to lot and structure characteristics of every property. Our hedonic model ultimately makes use of a subset of property transactions for the years 1983–2008. The entire panel of data represents 30,907 transactions of single-family homes in Marin County. The median sale price of the homes in inflation adjusted 2,008 dollars is $807,467.

Although the received literature does not provide complete guidance on the selection of variables or functional form in hedonic models, property prices are generally determined by characteristics of the lot, structure and neighborhood (Table 1). The dependent variable in all models is the observed arms-length transaction price adjusted to real dollars with the US urban housing consumer price index for the San Francisco-Oakland-San Jose metro area (2,008 dollars). Lot and structural characteristics include the age of the structure in years, the number of bedrooms (*BEDRMS*), the number of full bathrooms (*BATH*), the number of fireplaces (*FIREPL*), the acres of the lot area (*LOT*), the square footage of the building area (*BLDG*), indicator variables for the presence of a pool, more than one building, a garage, and central heating in the home, and an index for the quality of the structure of the home judged by the Assessor (*QUAL*).

County GIS spatial data are from MarinMap, a consortium of public agencies (local governments, special districts) organized under the Marin General Services Authority. [3] To alleviate omitted variable bias, a variety of neighborhood variables are calculated from these data. We identify fifty-six distinct communities [4] in Marin County as defined by the Community Development Agency of the County of Marin. [5] The cross-sectional hedonic models include an indicator variable for each community, and the panel identifier for the community fixed-effects difference-in-differences model are the fifty-six communities.

Constructed neighborhood variables include the distance from the Golden Gate Bridge (which links Marin County with San Francisco), the closest town center, including interaction variables with indicator variables for ten large towns in Marin County, [6] and the second closest town center, including interaction variables with indicator variables for the same ten towns.

Additional neighborhood variables include indicator variables for i) quarter-mile proximity to major roadways, bus routes, noise contours, libraries (*DLIB)*, highways (*DHWY*), historic sites (includes the closest and second closest), ii) half-mile proximity to an airport,

[3] For more information, see http://marinmap.org.

[4] These communities are Belvedere, Larkspur, Mill Valley, Novato, San Rafael, Sausalito, Corte Madera, Fairfax, Ross, Tiburon, San Anselmo, Dillon Beach, Tomales, Northern tip of Eastshore, Eastshore, Forest Knolls, Olema, Pt. Reyes Station, Inverness, San Geronimo Village, Muir Beach, Woodacre, Muir Woods Park, Alto, Lucas Valley, Country Club, Point San Pedro, Los Ranchitos, Homestead, Waldo Point, Paradise Cay, Unincorporated Fairfax, Santa Venetia, Greenbrae Boardwalk, Bayside Acres, California Park, San Quentin, Unincorporated Tiburon, Marin City, Almonte, Tamalpais, Strawberry, Sleepy Hollow, Bel Marin Keys, Loma Verde, St. Vincent's, Kentfield, Stinson Beach, Lagunitas, San Geronimo Valley, Sun Valley, Black Point, Bolinas, Nicasio, Indian Valley, North Novato, South Novato, Lucas Valley Environs, Marinwood.

[5] The Current Planning Division of the Community Development Agency of the County of Marin administers and enforces zoning and subdivision regulations in accordance with the Marin Countywide Plan and applicable state laws. http://www.co.marin.ca.us/depts/CD/main/comdev/CURRENT/index.cfm.

[6] Belvedere, Larkspur, Mill Valley, Novato, San Rafael, Sausalito, Corte Madera, Fairfax, Ross, and Tiburon (San Anselmo omitted) each have populations greater than 2,000.

Table 1 Description of non-SOD variables

Variable name	Mean	SD	Variable description
PRICE	958,355	568,799	Selling price of the property in real dollars (2008)
Attributes of the property			
LOT	0.365	1.064	Size (in acres) of the property
BLDG	2.148	921	Size (in square feet) of the structure on the property
BATH	2.449	0.868	Number of full bathrooms
BEDRMS	3.348	0.875	Number of bedrooms
FIREPL	1.175	0.603	Number of fireplaces
QUAL	7.409	0.914	Index for the quality of the structure of the property judged by the assessor
REPTWO	0.363	–	= 1 if the property sold twice
REPTHREE	0.404	–	= 1 if the property sold thrice
Attributes of the neighborhood			
DHWY	0.079	–	= 1 if quarter-mile from a highway
DFERY	0.015	–	= 1 if half-mile from a ferry hub
DLIB	0.046	–	= 1 if quarter-mile from a library
PRECIP	28	–	Inches of precipitation
ELEV	184	–	Elevation of the property above sea level
DMCINN	0.278	–	= 1 if mile from McInnis County Park
DCHINA	0.073	–	= 1 if mile from China Camp State Park
DGNRA	0.343	–	= 1 if mile from golden gate national recreation area
Temporal attributes			
TIME			
1992	0.019		= 1 if the property transaction took place in one of the given years (1995 is the omitted year)
1997	0.033	–	
2002	0.088		
2007	0.067		
NORTH			
2000	0.025	–	= 1 if the property transaction took place in the North[a] in one of the given years
2005	0.029		
SOUTH			
2000	0.024	–	= 1 if the property transaction took place in the South[b] in one of the given years
2005	0.024		

Number of observations: 30,907

Note: A full set of descriptions of the variables in the models is available on request

[a] North includes the communities of Novato, Bel Marin Keys, Black Point, Indian Valley, Loma Verde, North Novato, and South Novato

[b] South includes the communities of Belvedere, Mill Valley, Sausalito, Tiburon, Almonte, Alto, Homestead, Marin City, Muir Woods, Paradise Cay, Strawberry, Tamalpais, and Unincorporated Tiburon

ferry hubs (*DFERY)*, county facilities, district offices, park 'n rides, fire stations, schools, medical facilities, non-economical mineral deposits, and iii) within a dam inundation zone, a floodplain, school districts (includes four variables for the districts, with the San Rafael District omitted), landslides zones (includes four variables of landslide frequency, with water area omitted), earthquake zones (includes five liquefaction[7] potential zones, with wave liquefaction omitted).

Relevant natural amenity variables include the number of inches of precipitation (*PRECIP)*, the elevation of the property about sea-level (*ELEV*), indicator variables for (i) quarter-mile proximity to the ocean, streams, rivers, lagoons, lakes, neighborhood parks, ridge way greenbelt, federal parks, redwood woodlands, (ii) half-mile proximity to wetlands (estuarine, palustrine, emergent, forest, unconsolidated, farmed, with marine omitted), neighborhood parks, ridge way greenbelt, federal parks, and (iii) mile proximity to neighborhood parks, ridge way greenbelt, federal parks, McInnis County Park (*DMCINN*), China Camp State Park (*DCHINA*), and the Golden Gate National Recreation Area (*DGNRA*).

Sub-regions of Marin County may experience different housing market conditions over time. For instance, the southern portion of the County may have a faster price increase, while the northern portion may experience a slower price increase. An indicator variable for the northern communities (*DNORTH*) is interacted with indicator variables for the years 1996–2008 (*DNORTH00, DNORTH05*). Also, an indicator variable for the southern communities (*DSOUTH*) is interacted with indicator variables for the years 1996–2008 (*DSOUTH00, DSOUTH05*).[8]

Most properties sold more than once during the study period from 1983 to 2008. Since properties selling more than once may have different characteristics than properties selling only once, indicator variables for properties that sold twice (11,204 transactions) or thrice (12,486 transactions) during the study period are included. Since the study period includes the 2000–2006 housing boom in the United States, when there was significant speculative behavior, the indicator variables for the properties that sold twice or three times are interacted with time dummies for 1996–2008.

4.2 Sudden Oak Death Variable Specification

Indicators for the presence/abundance of SOD infections (Tables 2 and 3) are constructed to include (i) a three-twentieths, three-tenths, and nine-twentieths of a mile indicator and log-distance variables for proximity to coast live oak woodlands (*OAKWOOD*), and three-tenths of a mile indicator variables for proximity to (ii) confirmations of SOD infections of coast live oak (*CONFIRM*), (iii) oak mortality from a 2005 aerial survey by the US Forest Service (*AERIAL*),[9] and (iv) arborist's records of neighborhoods in Novato, San Rafael, and Kentfield with heavy damage from SOD (*ARBOR-NV, ARBOR-SF, ARBOR-KF*). Generic reference to any one of the SOD indicators is *SODID*.

Oak mortality in the woodlands (*OAKWOOD*) causes reduced aesthetic, ecosystem service, and recreation values, in addition to posing a physical hazard. *CONFIRM* and *AERIAL*

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[7] Liquefaction describes the behavior of soils that suddenly transition from a solid state to a liquefied state, such as during earthquakes.

[8] The northern communities include Novato, Bel Marin Keys, Black Point, Indian Valley, Loma Verde, North Novato, and South Novato. The southern communities include Belvedere, Mill Valley, Sausalito, Tiburon, Almonte, Alto, Homestead, Marin City, Muir Woods, Paradise Cay, Strawberry, Tamalpais, and Unincorporated Tiburon.

[9] California GIS maps of SOD confirmations and aerial surveys of oak mortality are publicly available on the OakMapper. For more information, see http://oakmapper.org/.

Table 2 Description of the indicators for SOD infections in the oak woodlands

Distance band to nearest woodland (mile)	*OAKWOOD*		*OWIMPACT 2000*		*OWIMPACT 2004*	
	= 1 if within specified distance band of coast live oak woodland		= 1 if within specified distance band of coast live oak woodland for the year 2000		= 1 if within specified distance band of coast live oak woodland for the year 2004	
	Number of houses	Mean distance to woodland (mile)	Number of houses	Mean distance to woodland (mile)	Number of houses	Mean distance to woodland (mile)
0.15	1,670	0.08	165	0.08	166	0.07
0.30	3,512	0.15	335	0.15	387	0.16
0.45	5,366	0.23	498	0.22	636	0.24

Number of observations: 30,907

are a concern to homeowners because isolated dying oak trees are on an adjacent neighbor's property. Homeowners in heavily damaged neighborhoods (*ARBOR-NV, ARBOR-SF, ARBOR-KF*) confront dying trees on their own property, adjacent neighbor's properties, and in nearby oak woodlands.

County GIS data for the location of coast live oak woodlands and confirmations of SOD infections are from the University of California, Berkeley's Geospatial Innovation Facility.[10] County GIS data for the 2005 aerial survey are from the Pacific Southwest Region, US Forest Service.[11] The location of neighborhoods with heavy oak mortality is from a 2008 telephone survey of arborists in Marin County.[12] The arborist's records do not indicate the years when the oak mortality occurred. However, the 2001–2002 and 2005–2007 aerial surveys approximate when the oak mortality in the neighborhoods occurred.

Coast live oak woodlands shown in Fig. 1 are principally in the central and eastern regions of the County near San Rafael, but there are also woodlands in the northern region near Novato. Mortality in the coast live oak woodlands began in late 1998 and continues to this day. As of 2008, there were 33 SOD confirmations throughout the neighborhoods of Marin County, and nearly all of the confirmed samples were taken in 2000 and 2001.[13] Aerial surveys of oak mortality by the US Forest Service are available for the years 2001–2002 and 2005–2007, but the oak mortality from the years other than 2005 is either too coarse (2001, 2002) or too far away from most of the property transactions (2006, 2007) to be useful in this study. There are 29 distinct patches of aerially observed oak mortality in 2005, with the largest patches in the

[10] For more information, see http://giifserv.cnr.berkeley.edu/website/OakMapper/metadata/species.htm and California Gap Analysis, and http://giifserv.cnr.berkeley.edu/website/OakMapper/metadata/sod.htm and the Kelly Research and Outreach Lab.

[11] For more information, see http://www.fs.fed.us/r5/spf/fhp/fhm/sod/index.shtml. We thank Zachary Heath for supplying this data.

[12] The information about the neighborhoods with heavy oak mortality came mostly from Bartlett Tree Service in Marin County. For more information, see http://www.bartlett.com/index.cfm. The tree services polled their arborist for the top spots in each of their geographically based areas of work.

[13] Although there are 33 confirmations, these are only the places where samples were taken to test for the presence of SOD and the disease was found. Many other places surely have infections though no samples were taken to confirm it was SOD.

Table 3 Description of SOD indicators for the dynamic response of property values to the SOD invasion, for 3/10 of a mile

Variable name	Number of houses	Mean distance to woodland (mile)	Variable description
SOD infections in oak woodlands			
OAKWOOD	3,512	0.15	= 1 if coast live oak woodland
OWIMPACT			
2000	335	0.15	= 1 if coast live oak woodland, for the years 1996–2008, only three years shown
2004	387	0.16	
2008	113	0.15	
Patches of SOD infections on homeowner properties			
CONFIRM	803	0.20	= 1 if confirmed SOD infection
CFIMPACT			
1998–1999	50	0.20	= 1 if confirmed SOD infection, for two-year intervals from 1996 to 2008, only two intervals shown
2002–2003	129	0.19	
AERIAL	2,805	0.17	= 1 if aerially observed oak mortality, based on the 2005 Forest Service aerial survey
AEIMPACT			
2006	207	0.17	= 1 if aerially observed oak mortality, based on the 2005 Forest Service aerial survey, for the years 1996–2008, only two years shown
2008	54	0.16	
Neighborhoods of SOD infections			
ARBOR-NV	1,132	0.15	= 1 if heavily damaged Novato neighborhoods
ARIMPACT-NV			
2002	69	0.15	= 1 if heavily damaged Novato neighborhoods, for the years 1996–2008, only two years shown
2006	92	0.10	
ARBOR-SR	1,142	0.14	= 1 if heavily damaged San Rafael neighborhoods
ARIMPACT-SR			
2000	121	0.13	= 1 if heavily damaged San Rafael neighborhoods, for the years 1996–2008, only 3 years shown
2004	150	0.14	
2008	28	0.15	
ARBOR-KF	271	0.13	= 1 if heavily damaged Kentfield neighborhoods
ARIMPACT-KF			
2005	19	0.11	= 1 if heavily damaged Kentfield neighborhoods, for the years 1996–2008, only 2 years shown
2008	9	0.15	

Number of observations: 30,907

central and southern regions near San Anselmo, Fairfax, San Rafael, Tiburon, and Sausalito but also smaller patches in the northern region near Novato.

The neighborhoods with heavy damage from SOD are based on sections of streets in the towns of Novato, San Rafael, and Kentfield where arborists identified significant tree removals due to SOD.[14] The neighborhoods in Novato and San Rafael with heavy damages due to SOD are tangential to large tracts of infected oak woodlands, while the neighborhoods in Kentfield are not. We suspect heavy damages in the neighborhoods of Novato, San Rafael, and Kentfield starting in 1998, 2002, and 2005, respectively, based on the aerial surveys indicating oak mortality near those neighborhoods in those years.

OWIMPACT is the interaction of *OAKWOOD* and year-specific dummies from 1996 to 2008. The coefficient estimates for *OWIMPACT* indicate the premium/discount to property values of proximity to *OAKWOOD* from 1996 to 2008. Two years prior to the 1998 invasion are included to examine what premium/discount exists before the invasion. The vector of variables *CFIMPACT* is the interaction of *CONFIRM* and dummies for two-years intervals from 1996 to 2008. The dummies are in two-years intervals because the limited number of property transactions in *CONFIRM* prevent accurate statistical estimation for each year.

AEIMPACT is the interaction of *AERIAL* and year-specific dummies for 1996–2008, although there is no expectation of SOD infections in *AERIAL* prior to the 2005 aerial survey. *ARIMPACT-NV, ARIMPACT-SF*, and *ARIMPACT-KF* are interactions of *ARBOR-NV, ARBOR-SF, ARIMPACT-KF* and year-specific dummies for 1996–2008. SOD infections are expected in those neighborhoods in 1998, 2002, and 2005, respectively, based on the Forest Service aerial surveys.

Households taking preventative steps to reduce oak infections may moderate property value discounts. Available preventative steps include the removal of California bay laurel trees to reduce the likelihood of pathogen spread, the purchase of homeowner's insurance, and the application of the chemical spray Agri-Fos® (Garbelotto and Schmidt 2009). The locations where homeowners take preventative steps are not known, although homeowners near heavily damaged neighborhoods may take preventative action, which may moderate the discounts.

5 Methods

A number of functional forms were considered for the hedonic models. The first was a linear-linear model, and the second was an inverse semi-logarithmic model, in which the dependent variable is transformed using the natural log operator and the independent variables are linear in the parameters, as found in many hedonic applications in the literature. In addition, non-linear forms and a variety of Box-Cox models were estimated to add flexibility to the functional form, given the absence of a priori information on the structure of the hedonic price function.

All specifications have a very similar fit, with the linear Box-Cox (constant lambda transformation on non-binary independent variables) fitting just slightly better than a semi-logarithmic model. We chose the semi-logarithmic model because of its prevalence in the literature and ease of interpretation. Pair-wise correlation analysis and variance inflation factors fail to indicate that multicollinearity is a serious problem. Lastly, standard errors

[14] The Novato locations include Indian Valley Rd., Wild Horse Valley Rd., Ignacio Blvd., Pacheco Creek Rd., Oak Forrest Rd., and the Alameda del Prado. The San Rafael locations include Convent Ct., Oakdale Dr., North San Pedro Rd., and Bret Harte Rd. The Kentfield locations include Woodland Rd., Upland Rd., and Crown Rd.

are clustered at the community level (observations are independent across communities but not necessarily within communities) to account for potential heteroskedasticity.

Structural differences in the housing market are tested for southern (*DSOUTH*) and northern (*DNORTH*) sub-regions (Chow 1960). The coefficient estimates for the characteristics of the house structure *LOT, BLDG, QUAL, BEDRMS*, and *BATH* are used to judge whether the sub-regions are statistically different. No evidence of structural difference is found in the southern communities except the intercept, and the variable *DSOUTH* accounts for this. In addition, no evidence of a structural difference is found for the northern communities for *BLDG* and *QUAL*, although *LOT, BEDRMS*, and *BATH* show weak statistical differences. The inclusion of *DNORTH* accounts for most of this observed difference.

5.1 Cross-Section Hedonic Model During the SOD Invasion

We begin estimation by exploring the effects of SOD on property values with cross-sectional hedonic models during the early period of the SOD invasion in Marin County. For each year between 1998 and 2003, three cross-sectional models are estimated: ordinary least squares, the spatial lag dependence model, and a general spatial model, with spatial lag dependence and spatial autocorrelation.

Three cross-sectional models are estimated using the following inverse semi-logarithmic model specification:

$$\begin{aligned} \ln P_i &= \rho \mathbf{W}_{\mathbf{1i}}' \mathbf{lnP} + \mathbf{X}_{\mathbf{i}}' \boldsymbol{\beta} + \phi SODID_i + \varepsilon_i \\ \varepsilon_i &= \lambda \mathbf{W}_{\mathbf{2i}}' \varepsilon_i + u_i \end{aligned} \tag{1}$$

where $\mathbf{X_i}$ is a Kx1 vector of variables specific to parcel i, $SODID_i$ identifies the effect of SOD, $\{\beta, \phi\}$ is a set of K + 1 parameters to be estimated, $\{\rho, \lambda\}$ is a set of the spatial lag operator and the coefficient on the spatially correlated errors, $\mathbf{W}_{\mathbf{1i}}'$ and $\mathbf{W}_{\mathbf{2i}}'$ are Nx1 vectors from the weighting matrices corresponding to spatial lag dependence and spatial autocorrelation, ε_i is a spatially correlated error term, and u_i is an independent and identically distributed error term.

The SOD presence/abundance indicator is *OAKWOOD*. The estimate for *OAKWOOD* indicates how proximity to oak woodlands, for three indicator variables and three interactive indicator and continuous log-distance variables (three-, six-, and nine-twentieths of a mile), influences property values in each of the 6 years from 1998 to 2003 during the early period of the invasion.

Estimation of spatial econometric models requires the calculation of weighting matrices. The weighting matrices represent spatial dependence within the dependent variable and the unobserved error term.[15] There is little formal evidence supporting choice of weighting matrices, and is determined by the researcher and the particulars of the data set (Anselin 2002). The weighting matrices considered include Delauny contiguity, inverse distance, and the *k*-nearest-neighbors of a property. The benefit of *k*-nearest-neighbors weighting matrices (as opposed to contiguity or inverse distance) is that they eliminate the possibility of islands, or observations having no neighbors (Anselin and Bera 1998).

Following the procedure suggested by Anselin (2005), estimation of (1) begins using ordinary least squares. Next, a series of robust Lagrange multiplier tests (LM) for ρ and λ determine the spatial specification, spatial lag dependence or spatial autocorrelation

[15] MATLAB code for generating the spatial weighting matrices and the spatial econometric models is found in the Spatial Econometrics Toolbox by James LeSage. The toolbox and documentation are available for download at http://www.spatial-econometrics.com.

(Anselin et al. 1996). Robust LM tests are computed on the basis of the specification under the null, provide indications of multiple types of misspecification, have clear asymptotic properties, and have power even if both types of spatial dependence are present. The robust LM tests indicate both spatial lag dependence and spatial autocorrelation are present in our data.

To ensure our estimates are robust to the choice of weighting matrix, we perform estimation of (1) for the Delauny contiguity, inverse distance, and the two-, four-, and eight-nearest-neighbor weighting matrices for spatial lag dependence and spatial autocorrelation processes. The parameter estimates do not differ notably across the weighting matrices,[16] though the k-nearest-neighbor weighting matrices fit better (based on the robust LM tests), with the strongest fit for the spatial lag dependence weighting matrix $\mathbf{W}'_{\mathbf{1i}}$ being the two nearest-neighbors for 1998 and the eight nearest-neighbors for 1999–2003, and for the spatial autocorrelation weighting matrix $\mathbf{W}'_{\mathbf{2i}}$ being the two nearest-neighbors for 1998–2003.

5.2 Spatial Difference-in-Differences Hedonic Model

The difference-in-differences model uses the study period 1983–2008. Our quasi-experimental strategy exploits the substantial spatial and temporal variation present in this longer study period that includes transactions before-and-after the SOD invasion.

The full dataset for the longer study period consists of a total of 30,907 observations, spanning 56 communities. The price of parcel i on community j in time t take the following forms:

Ordinary Least Squares (OLS):[17]

$$\ln P_{it} = \mathbf{X}'_{\mathbf{i}}\boldsymbol{\beta} + \mathbf{Z}'_{\mathbf{it}}\boldsymbol{\varphi} + \delta_1 SODID_i + \mathbf{IMPACT}'_{\mathbf{it}}\boldsymbol{\delta_2} + \mathbf{T}'_{\mathbf{t}}\boldsymbol{\delta_3} + \varepsilon_{it} \quad (2)$$

Community Fixed-Effects:

$$\ln P_{it} = \mathbf{X}'_{\mathbf{i}}\boldsymbol{\beta} + \mathbf{Z}'_{\mathbf{it}}\boldsymbol{\varphi} + \delta_1 SODID_i + \mathbf{IMPACT}'_{\mathbf{it}}\boldsymbol{\delta_2} + \mathbf{T}'_{\mathbf{t}}\boldsymbol{\delta_3} + \alpha_{j(i)} + \varepsilon_{it} \quad (3)$$

A subset of the full dataset consists of 23,690 transactions of only the properties that sold more than once during the period of 1983–2008.

Parcel Fixed-Effects 'Repeat Sales':

$$\ln P_{it} = \mathbf{Z}'_{\mathbf{it}}\boldsymbol{\varphi} + \mathbf{IMPACT}'_{\mathbf{it}}\boldsymbol{\delta_2} + \mathbf{T}'_{\mathbf{t}}\boldsymbol{\delta_3} + \alpha_{i(t)} + \varepsilon_{it} \quad (4)$$

where $\mathbf{X_i}$ is a Kx1 vector of time-constant variables specific to parcel i, $\mathbf{Z_{it}}$ is a Lx1 vector of time-varying variables specific to parcel i, $\mathbf{T_t}$ is a Jx1 vector of year-specific dummy variables, and $SODID_i$ and $\mathbf{IMPACT_{it}}$ identify the difference-in-differences effect of SOD (discussed below). In (3), $\alpha_{j(i)}$ is a community specific fixed-effect, potentially correlated with the regressors, associated with community j where parcel i is located. In (4), $\alpha_{i(t)}$ is a parcel specific fixed-effect, potentially correlated with the regressors, associated with parcel i occurring at time t.

The spatial difference-in-differences specification estimates the effects of SOD on property values from the year the invasion starts, which varies depending on SOD indicator, to the end of the study period in 2008. The coefficient for $SODID_i\,(\delta_1)$ is the premium/discount of properties in places eventually affected by SOD, before the invasion begins. The coefficients on $\mathbf{IMPACT_{it}}\,(\boldsymbol{\delta_2})$[18] specify the discount to the values of properties affected by

16 Results for other weighting matrices are shown in Tables 10 and 11 of the Appendix.

17 Estimation of a community random-effects model yields results identical to ordinary least squares.

18 $IMPACT_{it}$ is a vector of interaction variables of the $SODID_i$ indicator and year-specific dummies for the years 1996–2008.

SOD just before and after the invasion is underway. The coefficients estimates ($\boldsymbol{\delta_2}$) are the difference-in-differences components of interest.[19]

Fixed-effects are not present in the error term, and so consistent parameter estimates are possible even if correlation exists between the fixed-effects and the independent variables. The definition of the spatial fixed-effect is typically political and demographic boundaries similar to those of census tracts (e.g., Pope 2008a,b).[20] In our application, the most plausible argument for the spatial relationship between properties is that of the community defined by the Community Development Agency of Marin County. One would expect error terms to be correlated within a community because of shared community-specific characteristics.

Parcel fixed-effects are a true panel approach, often referred to as 'repeat sales', that uses houses that have sold multiple times over the study period. Most of this unique dataset consists of properties that sold twice (11,204 transactions) or three times (12,486 transactions) during the study period. The ability to observe the transaction price of the same house in differing time periods increases the flexibility of the researcher for controlling unobserved spatial heterogeneity.[21] The parcel fixed-effects specification has fewer variables than the community fixed-effects model because any time-constant parcel variable is absorbed by the fixed-effect. Only variables that vary over time for the parcel are estimated.

The final econometric issue to discuss is the use of a twenty-five year time-series of property sales.[22] To account for basic temporal dependency, we include a vector of dummy variables T_t to specify the year a given transaction takes place. To control for price-differentials over time across sub-regions, we include interaction terms of the indicator variables *DNorth* and *DSouth* and year-specific dummies for 1996–2008.[23] To account for time-varying speculative behavior during the housing boom, we include interaction terms of indicator variables for properties that sold twice or three times and year dummies for 1996–2008.

The likelihood of a confounding event occurring concurrent to the various years of the SOD invasion on each community is highly unlikely. Also, identification of the effect of SOD is enhanced by the quasi-random nature of the SOD invasion. Homeowners from 1998 to 2008 do not know for certain if their property will be affected by SOD since there is no exact knowledge of how the disease spreads. Therefore, the effects associated with an invasion are unlikely to be diluted by any previous expectations about such an event.[24]

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[19] To see this, suppose two time periods and two infestation levels. $\ln P_{T,YI}$ is the price of a property in proximity to an eventual SOD infestation (T for treatment) and in a year of the infestation (YI), and $\ln P_{C,YN}$ is the price of a property not in proximity to an eventual SOD infestation (C for control) and in a year prior to the infestation (YN). The difference-in-differences component of interest is: $(\ln P_{T,YI} - \ln P_{T,YN}) - (\ln P_{C,YI} - \ln P_{C,YN}) = ((\delta_1 + \delta_2 + \delta_{3,YI}) - (\delta_1 + \delta_{3,YN})) - ((\delta_{3,YI}) - (\delta_{3,YN})) = \delta_2$.

[20] A challenge lies in determining the appropriate geographic resolution for the spatial fixed-effects. If the geographic resolution is too coarse, the fixed-effects may fail to absorb meaningful variation in the omitted variables. If they are too small, they may absorb most of the variation in the characteristic of interest (Kuminoff et al. 2010).

[21] See Palmquist (1982) for a general discussion repeat sales data for estimating the property value effects of environmental characteristics.

[22] The sensitivity of the difference-in-difference results to shorter time frames (1994–2001 and 1992–2003) of the transaction data are shown in Table 12 of the appendix. Similar signs and magnitudes of parameter estimates for the SOD effect are observed.

[23] Initially, flexible community-year interaction indicators were included in the estimation. However, the collinearity introduced with the SOD-year interaction indicators made the precise measurement of the effect of SOD on property values difficult.

[24] The use of the fungicide Agri-Fos® and the purchase of homeowner insurance could be correlated with the expectation and severity of an infestation, thereby affecting the discount of the property values. We thank an anonymous referee for pointing this out.

The SOD indicators, generically called *SODID* in (2 and 3), (*OAKWOOD, CONFIRM, AERIAL, ARBOR-NV, ARBOR-SF, ARBOR-KF*) offer alternative perspectives of the dynamic discount to property values from the invasion. For *OAKWOOD*, discounts are ongoing because oaks continuously die in the woodlands, once the woodland is infected. For *CONFIRM* and *AERIAL*, the discounts are likely (i) less severe since these are isolated dying oaks on the adjacent homeowner's property, and (ii) more transitory since homeowners remove the dying oaks from their property.

ARBOR-NV, ARBOR-SF, and *ARBOR-KF* offer another look at the invasion, where an entire neighborhood is infected, and in the case of the San Rafael and Novato neighborhoods, nearby oak woodlands are also infested. Although homeowners remove the dying oaks on their properties, there is a greater quantity of dying oaks both within the neighborhood and in the nearby woodlands. Thus, *ARBOR-NV, ARBOR-SF*, and *ARBOR-KF* likely detect more severe and long-lasting damages than *OAKWOOD, CONFIRM*, and *AERIAL* detect.

6 Results

6.1 Results for the Period of the SOD Invasion

Results from estimating (1) with ordinary least squares ($\rho = 0, \lambda = 0$), spatial autoregressive ($\lambda = 0$), and general spatial model that allows for both spatial lag dependence and spatial autocorrelation are presented in Tables 4 and 5. The coefficients reflect the marginal percent change in selling price resulting from a one-unit change in a given attribute, holding all else constant. In general, the parameter estimates for the non-SOD variables (Table 4) conform reasonably well to expectations, and the estimated magnitudes are robust across the three models. Most non-SOD variables are generally significant from zero at the 95% confidence level or higher, including *BLDG, BEDRMS, QUAL, DHWY, DLIB*, and *PRECIP* variables. The high statistical significance of ρ and λ lends support for the general spatial model (that the robust LM tests preferred) of spatial lag dependence and spatial autocorrelation.

Table 5 indicates the effect on property values of proximity to (with three indicator distance variables) and distance from (with three interactive indicator and log-distance variables) infested coast live oak woodlands for three-twentieths, six-twentieths (or three-tenths), and nine-twentieths of a mile. Parameter estimates for the indicator and interactive log-distance variables are similar (since confidence intervals overlap) across the three cross-sectional estimation approaches.

The effect of SOD is difficult to detect in this cross-sectional setting. The parameter estimates for the indicator variables fluctuate between positive and negative from 1998 to 2003 for each of the three proximities to the infested coast live oak woodlands. The parameter estimates for the interactive log-distance variables are generally positive when significant for the years 2000 and 2003 for select proximities to the infested coast live oak woodlands, but there is also fluctuation between positive and negative from 1998 to 2003. There is little intuition for why no discount would be observed for properties affected by SOD, and despite the inclusion of an unusually rich set of control variables, these results are likely due to the presence of unobservable characteristics correlated with the SOD indicator.

Table 4 Cross-section results for non-SOD variables for the year 2000

	OLS		Spatial autoregressive SAR		General spatial model SAC	
	Coef.	Robust t-stat	Coef.	t-stat	Coef.	t-stat
Constant	10.50**	29.36	–		–	
LOT	6.60e-8	0.17	5.93e-8	0.18	3.48e-8	0.30
BLDG	1.98e-4**	8.37	0.16e-3**	8.46	0.15e-3**	8.54
BATH	−0.02	0.83	−0.01	0.47	−0.01	0.63
BEDRMS	0.03*	2.28	0.04**	3.57	0.04**	3.61
FIREPL	−0.01	0.71	−0.01	0.85	−0.01	0.87
QUAL	0.13**	7.19	0.15**	9.37	0.15**	9.65
DHWY	−0.15**	3.99	−0.11**	3.19	−0.11**	3.36
DFERY	0.10	1.19	0.09	1.26	0.09	1.32
DLIB	0.06*	1.90	0.02	0.54	0.02	0.64
PRECIP	0.01	0.52	0.01**	2.42	0.01**	2.47
ELEV	2.27e-5	0.27	7.44e-5	1.05	6.35e-5	0.92
DMCINN	0.11	0.85	0.07	0.54	0.06	0.49
DCHINA	−0.13	1.21	−0.12	1.24	−0.12	1.29
DGNRA	0.02	0.16	0.06	0.54	0.05	0.46
R^2	0.75		0.72		0.72	
Rho	–		0.49**	26.5	0.50**	27.1
Lambda	–		–		−0.06**	81.87

Number of observations: 1,484
Note: *, ** significance at the 95 and 99% levels. Models use the semi-log functional form. Median home sale price in real 2008$ is $927,973. Spatial weights matrices, W_1 is the kth nearest neighbor, where $k = 2$ for 1998 and $k = 8$ for 1999–2003, and W_2 is the kth nearest neighbor, where $k = 2$ for 1998–2003

6.2 Spatial Difference-in-Differences Results

Tables 6 and 7 summarize results from the spatial difference-in-differences model, where the community (Eq. 3) and parcel (Eq. 4) fixed-effects specifications control for community and parcel specific effects, and are shown after the ordinary least squares specification (Eq. 2). The results are similar across the estimations with ordinary least squares having a slightly better fit because all time-constant variables are included. The stability of coefficients across the various specifications indicates a degree of model robustness.

The coefficients of the non-SOD variables such as *LOT, BLDG, QUAL, DHWY*, and all the *TIME* variables are nearly identical and of the same order of statistical significance across the three specifications (Table 6). *PRECIP* and *DCHINA* are controls of interest because rainfall is a pathway of spread for SOD and China Camp State Park was an early epicenter for SOD infections in Marin County. The coefficients for these variables are robust, statistically significant, and have their expected sign across the models. Prior to the invasion, the *OAKWOOD* coefficient indicates proximity to coast live oak woodlands (within three-tenths of a mile) has a positive and statistically significant premium on property values of 3– 4%. This is consistent with the belief that the woodlands are a source of recreational and aesthetic value.

Table 5 Cross-section results during the period of the SOD invasion -SOD indicator (*OAKWOOD*)

	Distance to nearest oak woodland (mile)					
	0.15		0.30		0.45	
	Indicator	Log-distance	Indicator	Log-distance	Indicator	Log-distance
Ordinary least squares						
1998	−0.14	0.12e-3	−0.10	-0.10e-3	−0.05	0.40e-4
	(1.52)	(0.48)	(1.26)	(1.23)	(0.65)	(0.89)
1999	0.07	0.63e-4	0.09	0.13e-5	0.11	−0.32e-4
	(0.78)	(0.23)	(1.19)	(0.02)	(1.24)	(0.77)
2000	0.02	0.20e-3**	0.04	0.52e-4	0.08*	−0.34e-4*
	(0.13)	(2.88)	(1.04)	(1.49)	(2.08)	(1.67)
2001	0.03	−0.88e-4	−0.01	0.25e-5	−0.01	0.73e-5
	(0.08)	(0.84)	(0.18)	(0.08)	(0.21)	(0.36)
2002	0.02	−0.57e-5	0.01	−0.98e-5	−0.01	−0.21e-5
	(0.54)	(0.76)	(0.29)	(0.28)	(0.10)	(1.01)
2003	0.01	−0.53e-4	−0.01	0.19e-4	0.02	0.42e-4*
	(0.02)	(0.76)	(0.51)	(0.76)	(0.54)	(2.30)
Spatial autoregressive, SAR						
1998	−0.13	0.98e-4	−0.09	−0.12e-3	−0.03	0.32e-4
	(1.11)	(0.34)	(0.84)	(1.18)	(0.27)	(0.61)
1999	0.02	0.52e-4	0.02	0.36e-4	0.05	0.12e-4
	(0.18)	(0.21)	(0.26)	(0.46)	(0.54)	(0.23)
2000	−0.05	0.19e-3**	0.02	0.61e-4	0.01	−0.53e-5
	(1.24)	(2.31)	(0.66)	(1.60)	(0.19)	(0.24)
2001	−0.01	0.31e-4	−0.01	0.14e-4	0.01	0.31e-5
	(0.27)	(0.28)	(0.02)	(0.36)	(0.02)	(0.12)
2002	0.03	−0.50e-4	0.02	−0.17e-4	−0.01	−0.19e-4
	(0.61)	(0.52)	(0.48)	(0.40)	(0.13)	(0.79)
2003	−0.03	0.22e-4	−0.04	0.41e-4	−0.01	0.56e-4**
	(0.72)	(0.22)	(0.89)	(1.02)	(0.01)	(2.36)
General spatial model, SAC						
1998	−0.08	−0.73e-4	−0.07	0.89e-4	-0.03	0.26e-4
	(0.82)	(0.26)	(0.83)	(1.05)	(0.36)	(0.58)
1999	0.01	−0.75e-4	0.01	0.39e-4	0.01	0.25e-4
	(0.15)	(0.30)	(0.02)	(0.53)	(0.13)	(0.51)
2000	−0.05	0.19e-3**	−0.02	0.61e-4*	0.01	−0.42e-5
	(1.28)	(2.34)	(0.66)	(1.65)	(0.19)	(0.20)
2001	−0.01	0.39e-4	−0.01	0.16e-4	−0.01	0.39e-5
	(0.33)	(0.35)	(0.09)	(0.42)	(0.10)	(0.16)
2002	0.03	−0.49e-4	0.02	−0.16e-4	−0.01	−0.19e-4
	(0.61)	(0.52)	(0.48)	(0.39)	(0.10)	(0.85)
2003	−0.03	0.27e-4	−0.03	0.44e-4	0.01	0.55e-5**
	(0.79)	(0.29)	(0.94)	(1.17)	(0.09)	(2.52)

Number of observations for 1998–2003 is 428, 490, 1484, 1202, 1438, and 1245
Note: *, ** significance at the 95 and 99% levels. The t-statistics are shown in parentheses. Models use the semi-log functional form. Spatial weights matrices, W_1 is the kth nearest neighbor, where $k = 2$ for 1998 and $k = 8$ for 1999–2003, and W_2 is the kth nearest neighbor, where $k = 2$ for 1998–2003

Table 6 Spatial Difference-in-Differences Results for non-SOD Variables (1983–2008)

	OLS		Community fixed-effects		Parcel fixed-effects "Repeat Sales"	
	Coef.	Robust t-stat	Coef.	Robust t-stat	Coef.	Robust t-stat
Constant	12.30**	85.56	11.90**	73.23	13.20**	847.11
LOT	4.40e-7**	5.23	3.97e-7**	4.51	–	–
BLDG	1.85e-4**	23.19	1.81e-4**	23.52	–	–
BATH	0.01	0.80	0.01	0.47	–	–
BEDRMS	0.02**	3.59	0.02**	3.60	–	–
FIREPL	0.01	0.55	0.01	1.21	–	–
QUAL	0.12**	16.70	0.11**	16.09	–	–
DHWY	−0.01**	0.19	−0.03**	2.18	–	–
DFERY	0.01	0.20	0.02	0.75	–	–
DLIB	0.03	1.57	0.02	1.55	–	–
PRECIP	−4.35e-3**	2.99	−2.03e-3**	1.93	–	–
ELEV	−1.79e-5	0.67	−2.05e-5	0.69	–	–
DMCINN	0.01	0.10	0.08**	2.40	–	–
DCHINA	0.09**	2.36	0.08*	1.98	–	–
DGNRA	−0.02	0.76	−0.01	0.10	–	–
TIME						
1992	0.08**	4.35	0.08**	4.47	0.09**	5.35
1997	0.03	1.14	0.03	1.09	0.03	1.00
2002	0.52**	22.32	0.52**	21.52	0.51**	17.35
2007	0.74**	27.49	0.74**	27.04	0.85**	21.94
DNORTH	0.05	1.24	–	–	–	–
2000	−0.10**	4.31	−0.11**	4.49	−0.11**	4.43
2005	−0.05**	2.52	−0.05**	2.13	−0.09**	3.35
DSOUTH	−0.02	0.63	–	–	–	–
2000	0.10**	2.68	0.10**	2.61	0.12**	2.65
2005	0.01	0.31	0.01	0.28	0.01	0.19
REPTWO	0.03**	5.65	0.03**	5.44	–	–
REPTHREE	0.06**	5.28	0.06**	5.14	–	–
OAKWOOD	0.03*	1.74	0.04**	2.94	–	–
N	30,907		30,907		23,690	
R^2	0.75		0.68		0.70	
Panel ID	–		56 Communities		9,764 Parcels	
Rho	–		0.336		0.776	

Note: *, ** significance at the 95 and 99% levels. Models use the semi-log functional form. Median home sale price in real 2008$ is $807,467

Properties that sold two or three times during the study period (*REPTWO*, *REPTHREE*) receive a premium over properties with only one sale. This indicates the 'repeat-sales' model may represent another type of housing market, with more speculative behavior, that is more susceptible to time-varying trends from the US housing boom. The community fixed-effects model appears to resolve issues of bias and inefficiency from unobserved spatial variables, while providing some resistance to trends from the boom, since homes that sold only once

Table 7 Spatial difference-in-differences results during the period of the SOD invasion—SOD indicator (*OWIMPACT*)

	Distance to nearest oak woodland (mile)					
	0.15		0.30		0.45	
	Indicator	Log-distance	Indicator	Log-distance	Indicator	Log-distance
Ordinary least squares						
1998	0.01	−0.01e-2**	−0.008	−0.06e-3**	−0.03	−0.04e-3**
	(0.38)	(2.41)	(0.30)	(2.42)	(1.23)	(3.33)
1999	−0.03	−0.07e-3	−0.04	−0.04e-3	−0.07**	−0.06e-3**
	(0.84)	(1.06)	(1.10)	(1.51)	(2.42)	(2.86)
2000	−0.03	−0.05e-3	−0.03	−0.03e-3	−0.06*	−0.05e-3**
	(0.94)	(0.75)	(0.96)	(1.04)	(2.09)	(3.10)
2001	−0.03	−0.01e-2*	−0.05*	−0.08e-3**	−0.06*	−0.04e-3**
	(0.94)	(2.04)	(1.76)	(3.22)	(2.31)	(2.9)
2002	−0.02	−0.01e-2*	−0.03	−0.05e-3**	−0.06**	−0.05e-3**
	(0.90)	(1.90)	(1.39)	(2.64)	(3.39)	(4.15)
2003	−0.04	−0.01e-2	−0.05**	−0.05e-3**	−0.04**	−0.02e-3
	(1.43)	(1.56)	(2.45)	(3.16)	(2.70)	(1.61)
Community fixed-effects						
1998	0.03	−0.01e-2**	0.009	−0.05e-3*	−0.01	−0.03e-3**
	(0.99)	(2.44)	(0.35)	(2.13)	(0.54)	(3.28)
1999	−0.03	−0.07e-3	−0.04	−0.05e-3*	−0.07**	−0.06e-3**
	(0.80)	(1.01)	(1.11)	(1.72)	(2.52)	(3.04)
2000	−0.02	−0.05e-3	−0.03	−0.03e-3	−0.05*	−0.05e-3**
	(0.82)	(0.76)	(0.88)	(1.07)	(1.96)	(3.00)
2001	−0.01	−0.01e-2*	−0.03	−0.08e-3**	−0.05*	−0.05e-3**
	(0.43)	(1.94)	(1.29)	(2.95)	(1.95)	(2.87)
2002	−0.02	−0.01e-2*	−0.03	−0.05e-3*	−0.06**	−0.05e-3**
	(0.58)	(1.72)	(1.13)	(2.78)	(3.04)	(4.24)
2003	−0.04	−0.01e-2*	−0.04*	−0.05e-3**	−0.04**	−0.02e-3*
	(1.41)	(1.69)	(2.32)	(3.44)	(2.53)	(1.73)
Parcel fixed-effects 'Repeat Sales'						
1998	0.02	−0.02e-2**	0.05e-2	−0.05e-3	−0.02	−0.03e-3**
	(0.59)	(3.42)	(0.02)	(1.61)	(0.73)	(2.40)
1999	−0.05*	−0.01e-2**	−0.07**	−0.09e-3**	−0.09**	−0.07e-3**
	(1.73)	(2.67)	(2.75)	(4.14)	(4.23)	(4.06)
2000	−0.04*	−0.01e-1	−0.05	−0.05e-3	−0.07**	−0.05e-3**
	(1.66)	(1.26)	(1.57)	(1.30)	(2.80)	(3.28)
2001	−0.02	−0.08e-3	−0.05	−0.09e-3**	−0.08**	−0.07e-3**
	(0.56)	(0.68)	(1.57)	(3.53)	(3.40)	(3.66)
2002	−0.006	−0.02e-2*	−0.02	−0.07e-3**	−0.05**	−0.06e-3**
	(0.17)	(2.14)	(0.79)	(2.72)	(2.46)	(6.94)
2003	−0.05	−0.02e-2**	−0.07**	−0.08e-3**	−0.08**	−0.05e-3**
	(1.57)	(3.99)	(2.81)	(4.59)	(3.54)	(3.80)

Number of observations for the OLS and community fixed-effects procedure is 30,907 and for the parcel fixed-effects "Repeat Sales" procedure are 23,690. *, ** significance at the 95 and 99% levels. Robust (clustered) t-statistics are in parentheses. Models use the semi-log functional form. Median home sale price in real 2008$ is $807,467 are included. Due to this potential advantage, only the results of the community fixed-effects model are displayed for the other SOD indicators.

The results for *OWIMPACT* (Table 7) have more consistent signs over time, compared to the cross-section model results (Table 5) which fluctuate between positive and negative, during the period of the SOD invasion. The results of *OWIMPACT* are generally stable across specifications (Eqs. 2–4) in sign and magnitude. The parameter estimates of the indicators become more negative later in the invasion, likely due to the greater number of dying trees in the woodlands, and the negative parameter estimates of the interactive log-distance variables[25] indicate that property values are lower for homes farther from the oak woodland. Property value discounts at the beginning of the invasion may be due to uncertainty about how much damage the disease could cause. The greater discount for homes farther from the oak woodland (observed in the indicator and interactive log-distance variables) may be due to increased visibility of SOD infected oaks on surrounding woodland hillsides.

Tables 8 and 9 displays the results for the difference-in-differences community fixed-effects model for the discount to property values over time, for each of the SOD indicators. Given the twenty-five year study period, we are able to estimate the dynamic path of the discount to property values of proximity to a SOD indicator, by year, for more than a decade. The italicized of each column of Tables 8 and 9 indicates the year the SOD indicator is expected to show discounts to property values from the invasion. Two (or more) years of results prior to the year of expected detection are shown to compare results before and after the invasion.

OWIMPACT results indicate a discount of 3–6% for every year from 1998 to 2008,[26] with these discounts significant within three-twentieths of a mile (Table 8) in the year 2006 and the three-tenths of a mile (Table 9) in the years 2003–2008. In 1996, prior to the invasion, there is a premium of 4–6% suggesting discounts deeper than 3–6% may have occurred. The continually dying oaks in the woodlands have an ongoing effect on the discount to property values. This likely persists until no further dying oaks are in the vicinity of the homes.

CFIMPACT results indicate a 5% discount, though statistically insignificant, for the three-twentieths of a mile and a positive 0.5% premium, also insignificant, for three-tenths of a mile in the years of 1998 and 1999.[27] The lack of statistical significance is likely because these are isolated dying trees and because a small numbers of transactions occur near the locations confirmed to have SOD. The magnitude of the discount fades in subsequent years for the three-twentieths of a mile indicator though recurs for the three-tenths of a mile indicator, possibly because the disease has spread to adjacent trees in the area. Note that the presence of a premium prior to invasion for *CFIMPACT* means the discount may be larger than 5%. The 2006 coefficient for *AEIMPACT* indicates a discount of 1–3%, though not statistically significant, for homes near oak mortality observed in the 2005 aerial survey.[28] The discounts

25 The estimates for the interactive log-distance variables are the counterpart of the *OWIMPACT* estimates for the indicator variables. That is, the results for the interactive log-distance variables represent the estimates for the interaction of the indicator distance variable within three-twentieths, six-twentieths (or three-tenths), and nine-twentieths of a mile, the log-distance variable, and the indicator year variable.

26 For coefficients estimates with small magnitudes, the Halvorsen and Palmquist (1980) corrected coefficient to percentage is nearly identical to the raw coefficient.

27 For 230 of the samples collected at locations in Marin County and later confirmed to be positive for SOD, 204 of those samples were collected in 2000 and 2001. The trees likely exhibited symptoms of SOD before being tested for the disease.

28 The negative estimates prior to 2005 suggest that the disease may have been observed in the area before the Forest Service aerial survey.

Table 8 Dynamic response of property values to the SOD invasion by SOD indicator, for 3/20 of a mile

Year	Coast oak woodland (*OW IMPACT*)	SOD confir-mations (*CF IMPACT*)	2005 Aerial Survey Mortality (*AE IMPACT*)	Novato neighborhoods (*ARIMPACT-NV*)	San Rafael neighborhoods (*ARIMPACT-SF*)	Kentfield neighborhoods (*ARIMPACT-KF*)
1996	0.06*	0.17*	−0.09	0.15**	0.05	−0.11**
	(1.88)	(1.66)	(1.00)	(4.69)	(0.89)	(4.18)
1997	−0.02		−0.07	0.11**	−0.08**	0.06**
	(1.03)		(1.35)	(4.27)	(2.33)	(2.64)
1998	**–0.03**	**–0.05**	−0.02	−0.03	**–0.06***	−0.13**
	(**0.99**)	(**1.17**)	(0.37)	(0.42)	(**1.89**)	(4.66)
1999	−0.03		0.06	−0.03	−0.06*	−0.02
	(0.80)		(1.19)	(0.38)	(1.64)	(0.74)
2000	−0.02	0.02	0.01	0.04*	−0.10**	0.15**
	(0.82)	(0.18)	(0.21)	(2.11)	(5.06)	(5.15)
2001	−0.01		0.04	0.12**	−0.13**	0.23**
	(0.43)		(0.83)	(5.87)	(2.72)	(11.18)
2002	−0.02	0.01	−0.03	**0.01****	−0.09**	0.06**
	(0.58)	(0.17)	(0.95)	(**5.87**)	(4.73)	(2.52)
2003	−0.04		−0.02	−0.04**	−0.11**	0.07**
	(1.41)		(0.51)	(4.89)	(2.75)	(3.33)
2004	−0.02	0.05	−0.01	−0.03**	−0.12**	0.09**
	(0.98)	(0.57)	(0.51)	(2.39)	(2.92)	(3.85)
2005	−0.03		**0.009**	−0.08**	−0.08**	**–0.16****
	(1.03)		(**0.34**)	(5.39)	(3.23)	(**5.56**)
2006	−0.05**	0.01	−0.01	−0.01	−0.09**	−0.10**
	(3.05)	(1.41)	(0.50)	(0.47)	(2.63)	(3.95)
2007	−0.02		−0.01	0.06**	−0.11**	0.01
	(0.54)		(0.32)	(2.79)	(3.36)	(0.20)
2008	−0.03		−0.02	0.12**	−0.17**	0.23**
	(1.04)		(0.28)	(3.33)	(3.63)	(5.82)
R^2	0.68					
Panel ID	56 Communities					
Rho	0.33					

Number of observations: 30,907

Note: *, ** significance at the 95 and 99% levels. These are the community fixed-effects difference-in-difference hedonic models. Robust (clustered) t-statistics are in parentheses. Italicized indicate the year when visibly dying trees are expected to first appear for each of the indicators

fade and eventually switch to a not statistically significant premium in 2008 for the three-tenths of a mile indicator. This suggests property values may rebound after the dying oaks are removed near a homeowner's property.

Another explanation for SOD variable sign reversals is a pattern of tree mortality driven by extreme weather events. Heavy rains in warm periods produce inoculum and spread the disease. Infected trees' capacity to manage water declines, but the trees survive until high

Table 9 Dynamic response of property values to the SOD invasion by SOD indicator, for 3/10 of a mile

Year	Coast oak woodland (*OW IMPACT*)	SOD confirmations (*CF IMPACT*)	2005 Aerial survey mortality (*AE IMPACT*)	Novato neighborhoods (*ARIMPACT-NV*)	San Rafael neighborhoods (*ARIMPACT-SF*)	Kentfield neighborhoods (*ARIMPACT-KF*)
1996	0.04*	0.04	−0.02	0.08**	0.02	0.02
	(1.64)	(0.92)	(0.30)	(2.70)	(0.37)	(0.51)
1997	−0.02		−0.008	0.10**	−0.06**	0.008
	(1.10)		(0.23)	(4.34)	(2.67)	(0.35)
1998	**0.009**	**0.005**	−0.02	0.003	**–0.05**	−0.14
	(**0.35**)	(**0.15**)	(0.73)	(0.15)	(**1.38**)	(1.09)
1999	−0.04		0.04	−0.02	−0.09	0.06**
	(1.11)		(0.88)	(0.56)	(1.59)	(2.46)
2000	−0.03	0.03	0.004	0.02	−0.08**	0.16**
	(0.88)	(0.99)	(0.12)	(0.69)	(4.60)	(2.73)
2001	−0.03		0.01	0.06**	−0.10**	0.13**
	(1.29)		(0.27)	(3.27)	(2.56)	(6.57)
2002	−0.03	−0.03	−0.02	**0.01**	−0.07**	0.10**
	(1.13)	(0.82)	(1.00)	(**0.70**)	(3.43)	(4.41)
2003	−0.04*		−0.006	−0.02	−0.08**	0.11**
	(2.32)		(0.23)	(0.38)	(3.38)	(5.54)
2004	−0.06**	0.006	−0.03	0.01	−0.09**	0.01
	(3.72)	(0.19)	(1.41)	(0.57)	(3.83)	(0.48)
2005	−0.06**		**–0.01**	−0.03*	−0.07**	**–0.14****
	(3.42)		(**0.80**)	(1.68)	(4.15)	(**5.05**)
2006	−0.06**	−0.06	−0.03	−0.01	−0.07**	−0.11**
	(3.75)	(0.17)	(1.34)	(0.25)	(3.18)	(3.97)
2007	−0.05*		−0.01	0.05*	−0.10**	0.09**
	(2.13)		(0.41)	(1.84)	(5.40)	(2.72)
2008	−0.09*		0.004	0.08*	−0.20**	0.15*
	(2.25)		(0.07)	(1.95)	(5.97)	(2.17)
R^2	0.68					
Panel ID	56 Communities					
Rho	0.33					

Number of observations: 30,907

Note: *, ** significance at the 95 and 99% levels. These are the community fixed-effects difference-in-difference hedonic models. Robust (clustered) t-statistics are in parentheses. Italicized indicate the year when visibly dying trees are expected to first appear for each of the indicators

temperatures and extended dry periods overwhelm the trees' impaired vascular capability and large numbers die (Frankel 2010). Recognizing this pattern of tree mortality, positive signs for the SOD variables could occur when the trees are alive and display minimal infection, but then switch suddenly negative when trees die in a drought several years later.

The results for *ARIMPACT-NV, SF,* and *KF* indicate heavily damaged neighborhoods produce large and often ongoing discounts of nearby property values.[29] For the Novato neighborhoods, the discounts, generally between 3–8%, last for four years following the invasion, and are statistically significant for three of the years. The premium in Novato prior to the invasion suggests the discount may be more severe after the invasion. The discount for the San Rafael neighborhoods, generally between 6 and 13%, last to the end of the study period, and are all statistically significant. The 1997 discount indicates damages may have become apparent earlier in the San Rafael since an early impacted area of Marin County was in the nearby China Camp State Park. Two large discounts in the Kentfield neighborhoods, between 10–16%, coincide with the expected invasion date, and the premium prior to the invasion suggests the discount may be still more severe. Since the discounts are larger for three-twentieths of a mile than three-tenths of a mile, the damaged neighborhood discounts appear to be localized to the immediate area where the damages occur.

The length of time a discount persists in a neighborhood is related to its proximity to infested oak woodlands, how severely infested the oak woodlands are, and how long the woodlands are infested. The San Rafael neighborhoods are in proximity to China Camp State Park where homeowners have observed severe SOD-related mortality on the hillsides for a decade. The Novato neighborhood is also in close proximity to oak woodlands although the infestation began later and was less severe than in China Camp State Park. The Kentfield neighborhoods are not in close proximity to open areas of oak woodlands, but are close to the more severe SOD-related tanoak mortality in the redwood forest interior of Marin County.

7 Discussion

This study finds dynamic effects on property values in Marin County, California from an invasion by the forest invasive disease, Sudden Oak Death. Evidence is provided through different SOD variables, hedonic model specifications, and statistical estimation approaches of a causal link that could exist between SOD-related tree mortality and property values in particular circumstances. A quasi-experimental hedonic model for the study period 1983–2008, with the first large wave of SOD mortality in Marin County in late 1997, indicates proximity to dying trees in oak woodlands, on the properties of homeowners, and in heavily damaged neighborhoods could relate to property value discounts. Properties within a three-tenths mile from SOD infested oak woodlands experience a 3–6% discount, and this discount is ongoing since oaks are continually dying in the woodlands. If an isolated dying oak is on an adjacent homeowner's property, we observe discounts of 1–5%, although this discount is transitory and diminishes or completely disappears within a couple of years as the dying trees are removed. The most severe discounts of 8–15%, which can last for several years, occur where dying oaks are located throughout a neighborhood and in nearby woodlands.

Government spending on invasive species management is significant, despite the general lack of rigorous economics estimates of the damages (Olson 2006). Our results indicate that government spending on the management of SOD in oak woodlands where

[29] The year discounts begin correspond to when oak mortality is observed in the US Forest Service aerial surveys.

homeowner response is unlikely could mitigate property value discounts.[30] Property value discounts are most severe and long lasting for heavily damaged neighborhoods near infested oak woodlands, where dead and dying oaks are left standing, and these discounts could have been avoided or mitigated by management actions to reduce the spread the SOD (e.g. the removal of bay laurel) or by faster removal of the dead and dying oaks.[31]

The cross-sectional parameter estimates for the ordinary least squares and the spatial econometric hedonic models appear unstable when only limited post-invasion transaction data are available. For the difference-in-differences hedonic models, which include before-and-after-invasion transaction data, the results for the property value discounts are closest to a priori expectations. Further, these data represent all the available transactions, and the model specification flexibly accounts for spatial dependence with community fixed-effects. For these reasons, this model is preferred for accurately identifying the effect of SOD on residential property values. The 'repeat sales' estimation method has the most potential for mitigating bias from unobserved spatial variables, but this subset of transactions is also susceptible to bias from speculative behavior during the US housing boom.

Many natural hazards (e.g. wildfires, floods, and invasive species) have long-lasting effects on property values, and more studies examining the dynamic response of property values to natural hazards are needed. Understanding how natural hazards cause economic damages over time is important for improving the government response with education and management. More generally, tracking the dynamic responses that people make to changes in resource conditions can illuminate how they value resources over time and, thus, broadly inform long-run policies affecting them.

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Appendix

See Tables 10, 11 and 12.

[30] Thanks to Susan Frankel for pointing out that although people may have information about the symptoms of SOD they are often unable or unwilling to take action.

[31] Since infected oaks do not spread the pathogen and the cost of the removal of oaks is high, many dead and dying oaks are left-standing in the oak woodlands.

Table 10 Cross-section results during the period of the SOD invasion -two-nearest neighbor weighting matrix

	Distance to nearest oak woodland (mile)					
	0.15		0.30		0.45	
	Indicator	Log-distance	Indicator	Log-distance	Indicator	Log-distance
Spatial autoregressive, SAR						
1998	−0.13	0.11e-3	−0.09	0.12e-3	−0.02	0.31e-4
	(1.11)	(0.37)	(0.83)	(1.21)	(0.22)	(0.58)
1999	−0.01	0.12e-3	0.01	0.64e-4	0.04	0.71e-5
	(0.01)	(0.43)	(0.06)	(0.74)	(0.44)	(0.12)
2000	−0.01	0.16e-3*	0.01	0.38e-4	0.04	−0.27e-4
	(0.12)	(1.80)	(0.49)	(0.96)	(1.16)	(1.18)
2001	0.05	−0.25e-4	0.07*	−0.49e-4	0.08*	−0.39e-4
	(1.23)	(0.21)	(1.66)	(1.15)	(1.74)	(1.42)
2002	0.09*	−0.89e-4	0.09*	−0.55e-5	0.07*	−0.52e-4*
	(1.98)	(0.85)	(2.16)	(1.23)	(1.74)	(2.03)
2003	−0.04	0.91e-5	−0.04	0.44e-5	0.78e-3	0.57e-4*
	(0.88)	(0.86)	(0.85)	(1.03)	(0.02)	(2.20)
General spatial model, SAC						
1998	−0.09	0.94e-5	−0.06	0.89e-4	−0.01	0.26e-4
	(0.85)	(0.03)	(0.67)	(1.00)	(0.15)	(0.56)
1999	−0.01	−0.59e-4	−0.03	0.69e-4	−0.01	0.22e-4
	(0.13)	(0.22)	(0.36)	(0.90)	(0.10)	(0.43)
2000	−0.01	0.14e-4*	0.01	0.39e-4	0.03	−0.22e-4
	(0.41)	(1.9)	(0.35)	(1.19)	(1.16)	(1.17)
2001	0.05	0.30e-4	0.07*	−0.44e-4	0.07*	−0.40e-4*
	(1.44)	(0.28)	(1.87)	(1.17)	(1.89)	(1.67)
2002	0.06*	−0.74e-5	0.06*	−0.33e-4	0.04	0.39e-4*
	(1.76)	(0.85)	(1.81)	(0.87)	(1.39)	(1.91)
2003	−0.04	0.72e-4	−0.03	0.50e-4	0.01	0.49e-4**
	(1.04)	(0.80)	(1.04)	(1.51)	(0.14)	(2.53)

Number of observations for 1998–2005 is 428, 490, 1484, 1202, 1438, 1245, 1807, and 1669
Note: *, ** significance at the 95 and 99% levels. Models use the semi-log functional form. The t-statistics are shown in parentheses. Spatial weights matrices, W_1 is the kth nearest neighbor, where $k = 8$ for 1998 and $k = 2$ for 1999–2005, and W_2 is the kth nearest neighbor, where $k = 2$ for 1999–2005

Table 11 Cross-section results during the period of the SOD invasion—delauny contiguity weighting matrix

	Distance to nearest oak woodland (mile)					
	0.15		0.30		0.45	
	Indicator	Log-distance	Indicator	Log-distance	Indicator	Log-distance
Spatial autoregressive, SAR						
1998	−0.13	0.10e-3	−0.09	0.11e-3	−0.03	0.34e-4
	(1.09)	(0.35)	(0.85)	(1.17)	(0.29)	(0.65)
1999	0.01	0.14e-3	0.03	0.23e-4	0.06	−0.31e-5
	(0.16)	(0.54)	(0.39)	(0.28)	(0.66)	(0.06)
2000	−0.02	0.17e-3*	0.01	0.57e-4	0.04	−0.19e-4
	(0.50)	(2.03)	(0.19)	(1.47)	(1.22)	(0.89)
2001	0.03	−0.26e-4	0.03	−0.18e-4	0.04	−0.13e-4
	(0.67)	(0.23)	(0.80)	(0.46)	(0.88)	(0.51)
2002	0.05	−0.95e-4	0.05	−0.27e-4	0.03	−0.24e-4
	(1.19)	(0.97)	(1.11)	(0.63)	(0.83)	(0.97)
2003	−0.05	0.58e-4	−0.05	0.55e-4	−0.01	0.61e-4**
	(1.17)	(0.58)	(1.31)	(1.37)	(0.38)	(2.53)
General spatial model, SAC						
1998	−0.09	−0.86e-6	−0.07	0.88e-4	−0.02	0.33e-4
	(0.88)	(0.01)	(0.78)	(1.01)	(0.29)	(0.73)
1999	0.01	−0.70e-4	0.01	0.29e-5	0.01	0.56e-5
	(0.16)	(0.29)	(0.09)	(0.41)	(0.13)	(0.12)
2000	−0.02	0.17e-3*	0.01	0.58e-5	0.04	−0.18e-4*
	(0.66)	(2.12)	(0.20)	(1.60)	(1.32)	(1.86)
2001	0.02	−0.98e-5	0.03	−0.14e-4	0.03	−0.13e-4
	(0.59)	(0.09)	(0.75)	(0.37)	(0.77)	(0.52)
2002	0.05	−0.95e-4	0.05	−0.27e-4	0.03	−0.20e-4
	(1.19)	(1.02)	(1.11)	(0.63)	(0.79)	(0.90)
2003	−0.05	0.62e-5	−0.05	0.59e-4*	−0.01	0.59e-4**
	(1.32)	(0.67)	(1.47)	(1.66)	(0.35)	(2.82)

Number of observations for 1998–2005 is 428, 490, 1484, 1202, 1438, 1245, 1807, and 1669

Note: *, ** significance at the 95 and 99% levels. Models use the semi-log functional form. The t-statistics are shown in parentheses. Spatial weights matrices, W_1 and W_2, are the Delauny contiguity

Table 12 Sensitivity of the spatial difference-in-differences results to the time frame

	Distance to nearest oak woodland (mile)					
	0.15		0.30		0.45	
	Indicator	Log-distance	Indicator	Log-distance	Indicator	Log-distance
Time frame—1994–2001						
1998	0.04	−0.06e-3	0.02	−0.04e-3*	−0.02e-1	−0.02e-3*
	(1.51)	(0.79)	(0.69)	(1.85)	(0.07)	(1.68)
1999	−0.02	−0.05e-3	−0.04	−0.05e-3	−0.06*	−0.06e-3**
	(0.73)	(0.41)	(1.10)	(1.35)	(2.11)	(2.63)
2000	−0.02	−0.01e-3	−0.02	−0.03e-3	−0.04	−0.04e-3**
	(0.44)	(0.12)	(0.63)	(0.72)	(1.35)	(2.39)
2001	0.003	−0.09e-3	−0.03	−0.07e-3*	−0.04	−0.04e-3**
	(0.11)	(0.88)	(1.10)	(2.25)	(1.56)	(2.54)
Time frame—1992–2003						
1998	0.04	−0.08e-3	0.008	−0.05e-3*	−0.07	−0.02e-3*
	(1.03)	(1.62)	(0.28)	(2.03)	(0.30)	(2.16)
1999	−0.03	−0.06e-3	−0.05	−0.06e-3*	−0.07	−0.05e-3**
	(0.99)	(0.72)	(1.46)	(1.77)	(0.30)	(2.55)
2000	−0.03	−0.03e-3	−0.04	−0.03e-3	−0.05	−0.04e-3*
	(0.74)	(0.36)	(0.84)	(0.94)	(1.45)	(2.02)
2001	−0.02	−0.01e-2	−0.04	−0.08e-3**	−0.05**	−0.04e-3*
	(0.54)	(1.40)	(1.42)	(2.47)	(2.39)	(2.09)
2002	−0.02	−0.09e-3	−0.03	−0.05e-3**	−0.06**	−0.05e-3**
	(0.80)	(1.20)	(1.51)	(2.46)	(2.39)	(2.97)
2003	−0.04	−0.07e-3	−0.05**	−0.05e-3**	−0.03*	−0.09e-4
	(1.53)	(1.29)	(2.82)	(3.37)	(1.44)	(0.56)

Number of observations for the community fixed-effects model for the time frame of 1994–2001 is 10,569 and the time frame of 1992–2008 is 16,675

Note: *, ** significance at the 95 and 99% levels. Robust (clustered) t-statistics are in parentheses. Models use the semi-log functional form. Median home sale price in real 2008$ for the time frame of 1994–2001 is $821,453 and the time frame of 1992–2008 is $862,602

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