Evidence of the Dynamic Response of Housing Values to a Sudden Oak Death Infestation[1]

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Abstract

Sudden oak death (SOD), caused by the non-indigenous forest pathogen *Phytophthora ramorum*, causes substantial mortality in coast live oak (*Quercus agrifolia*) and several other oak species on the Pacific Coast of the United States. Quasi-experimental hedonic models examine the effect of SOD on property values with a dataset that spans more than two decades including a decade of transactions before and after the invasion. The long study period allows for a unique contribution to the hedonic literature on natural hazards by studying the dynamic response of property values to an invasive species. The findings suggest property discounts of 2 to 5 percent for homes near infested oak woodlands, which are long lasting because of the continually dying oaks in the woodlands. Greater discounts of 5 to 8 percent occur if dying oaks are on the properties of homeowners, which are transitory because dying oaks are removed from homeowner properties. We compare recent hedonic modeling approaches including quasi-experimental, with spatial fixed-effects for a) communities, and b) parcels 'repeat sales', and spatial lag and error models to address bias from homeowner preferences, correlated with the price of a house and the proximity of a house to a SOD infection, which are not observed by the analyst.

Introduction

The recent arrival of several highly destructive forest pests and pathogens in the United States (for example, emerald ash borer, hemlock wooly adelgid, Asian longhorned beetle, and oak wilt) has increased public awareness of the dangers of forest invasive species. Reducing the damages from forest invasive species was the principal focus of the 2005 Public Land Corps Healthy Forests Restoration Act, which led to additional funding for the management of forest pests and pathogens. In particular, concern is focused on trees infected in residential areas because dying infected trees are an aesthetic and recreational dis-amenity, reduce ecosystem services (for example, screening, noise buffer, air quality, soil retention, and shade), and pose a physical hazard (for example, fire and falling trees) to nearby homes (Holmes and others 2009). There is limited information, however, of how homeowners respond to the damages over time from infestations of forest invasive species and what measures could be taken to mitigate those damages.

The goal of this study is to estimate the discounts over time to property values of an

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exotic forest pathogen (*Phytophthora ramorum*) in Marin County, California. This is accomplished with the quasi-experimental hedonic property value method. Sudden oak death (SOD) results in substantial mortality in several oak tree species on the Pacific Coast, and is believed to have entered the United States in the mid-1990s on nursery stock. The first noted mortality from SOD in the oak woodlands of Marin County was in late 1998. 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. The time span of the dataset encompasses the before (1983 to 1997) and after (1998 to 2008) period of the invasion when oaks in several study communities became infected with *P. ramorum*. This unique dataset permits a dynamic analysis of the dis-amenity effects on property values with results of the discount for each year of the invasion from 1998 to 2008. These results should prove useful in designing strategies for managing the damages of this invasion by informing extension specialists and arborists where to focus educational and removal of host plant efforts.

The hazards literature has assessed similar questions for natural disasters including other types of invasive species, wildfires, floods, and hurricanes. Horsch and Lewis (2009) used a quasi-experimental hedonic price function to examine the effect of an aquatic invasive species, and found a decrease in land values of 13 percent. Holmes and others (2006) and Huggett and others (2008) observed a discount of 1 percent and 8 percent, respectively, for properties with dying hemlock trees due to the forest invasive species, hemlock wooly adelgid. Donovan and others (2007) found that home prices are positively correlated with wildfire risk before information on wildfire risk is publicly available, whereas, afterwards, there is none. Chivers and Flores (2002) looked at the discounts associated with purchasing a home in a flood plain and found evidence of a discount only in years immediately after a flood event. Bin and Polasky (2004) observed a larger housing price discount for locating in a flood plain after Hurricane Floyd.

Study Area and Data

This study focuses on the property value effects of SOD on parcels within Marin County (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 (United States Department of Commerce, Bureau of the Census. 2008).

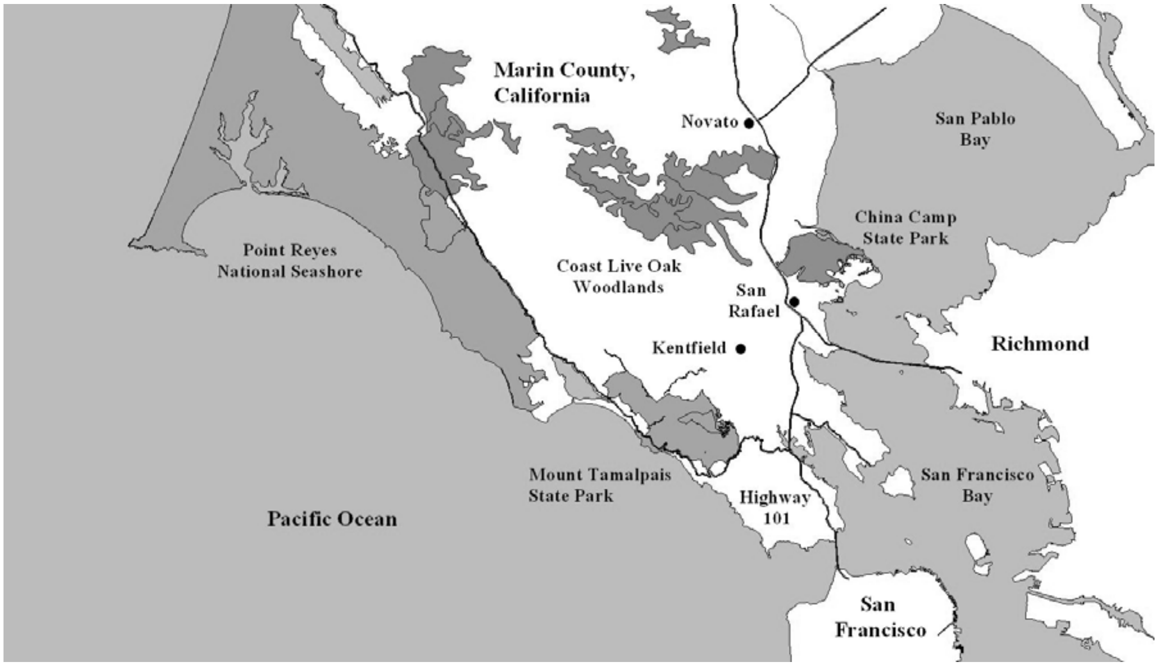

Figure 1—Map of study area.

Data and Variables for the Estimation

The data for this study are compiled from a variety of sources. Data on arms-length detached single-family home transactions are from the company 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 last three transactions for every property in Marin, in addition to lot and structure characteristics of every property. The hedonic application ultimately makes use of a subset of the property transactions for the years of 1983 to 2008. The entire panel of data represents transactions of 30,907 single-family homes in Marin County. The median sale price of the homes in inflation adjusted 2008 dollars is $807,467.

The literature does not provide complete guidance on the selection of variables or functional form in hedonic models, although in general, property prices are determined by the lot and structure and neighborhood characteristics. The dependent variable in all models is the observed arms-length transaction price adjusted to real dollars with the U.S. urban housing consumer price index (2008 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.[5] To alleviate omitted variable bias, a variety of neighborhood variables are

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

calculated from this GIS data. We identify 56 distinct communities[6] in Marin County defined by the Community Development Agency of the County of Marin.[7] The hedonic models during the period of the SOD invasion include 56 indicator variables for each community, and the panel identifier for the community fixed-effects difference-in-differences model is the 56 communities.

Neighborhood variables for location include the number of feet from the Golden Gate Bridge (which links Marin County with San Francisco), the closest town center, including interaction variables with indicator variables for 10 large towns in Marin County,[8] and the second closest town center, including interaction variables with indicator variables for the same 10 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, 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[9] 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 (*DPRK*), 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 County may have a faster price increase, while the northern County, a slower price increase. To alleviate bias of time-varying omitted variables, we control for potentially "hot/cold" regional housing markets. An

[6] 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.

[7] 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

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

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

indicator variable for the northern communities (*DNORTH*) is interacted with indicator variables for the years 1996 to 2008 (*DNORTH00, DNORTH05*). Also, an indicator variable for the southern communities (*DSOUTH*) is interacted with indicator variables for the years 1996 to 2008 (*DSOUTH00, DSOUTH05*).[10]

A unique feature of the dataset is the presence of the last three transaction prices for every property in the County. Most properties sold more than once during the study period from 1983 to 2008. Since properties selling more than once potentially have different homeowner characteristics than properties selling only once, we include indicator variables for properties that sold twice (11,204 transactions) or three (12,486 transactions) times during the study period. Since the study period includes the 2000 to 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 to 2008.

Sudden Oak Death Variables for the Estimation

We account, with SOD indicators, for the presence/abundance of SOD infections with indicator variables for quarter-mile proximity to i) coast live oak woodlands (*OAKWOOD*), ii) confirmations of SOD infections of coast live oak (*CONFIRM*), iii) oak dieback from a 2005 aerial survey by the U.S. Department of Agriculture, Forest Service (USDA FS) (*AERIAL*),[11] 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*.

Mortality in the woodlands (*OAKWOOD*) is a concern to homeowners close to the woodlands because of reduced aesthetic, ecosystem service, and recreation values, in addition to posing a physical hazard. *CONFIRM* and *AERIAL* are a concern to homeowners because dying oak trees are on a homeowner's property or an adjacent neighbor's property. Homeowners in heavily damaged neighborhoods (*ARBOR-NV, ARBOR-SF, ARBOR-KF*) cope not only with dying trees on their own property, but also on 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.[12] County GIS data for the 2005 aerial survey are from the USDA FS Pacific Southwest Region.[13] The location of neighborhoods where there was heavy oak mortality is from a 2008 telephone survey of arborists in Marin County.[14]

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[10] 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.
[11] California GIS maps of SOD confirmations and aerial surveys of oak dieback are publicly available on the OakMapper. For more information, see http://oakmapper.org/.
[12] 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.
[13] For more information, see http://www.fs.fed.us/r5/spf/fhp/fhm/sod/index.shtml. We thank Zachary Heath for supplying this data.
[14] 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.

The arborist's records do not indicate the years when the oak mortality occurred. However, the 2001 to 2002 and 2005 to 2007 aerial surveys from the USDA FS of oak dieback allow for an approximation of when the 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 smaller woodlands in the northern region near Novato. Mortality in the woodlands began in Marin in late 1998 and continues to this day. As of 2008, there were 33 SOD confirmations throughout the neighborhoods of Marin, and nearly all of the confirmed samples were taken in 2000 and 2001. Aerial surveys of oak dieback by the USDA FS are available for the years 2001 to 2002 and 2005 to 2007, but the oak dieback 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 oak dieback in 2005, with the largest patches of dieback in the 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 identify significant tree removals due to SOD.[15] The neighborhoods in Novato and San Rafael with heavy damages due to SOD are also beside large tracts of infested oak woodlands, while the neighborhoods in Kentfield are not. We suspect heavy damages in the neighborhoods of Novato, San Rafael, and Kentfield starting in 2002, 2000, and 2005, respectively, based on the USDA FS aerial surveys that indicate oak dieback near those neighborhoods starting in those years.

The vector of variables *OWIMPACT* is the interaction of *OAKWOOD* and year-specific dummies from 1996 to 2008. The coefficient estimates for the vector of variables *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 property value premium/discount exists before the invasion. The vector of variables *CFIMPACT* is the interaction of *CONFIRM* and dummies for two-year intervals from 1996 to 2008. The dummies are in 2-year intervals because of the limited number of property transactions in *CONFIRM* in each year, preventing accurate statistical estimation for *CONFIRM* interacted with year-specific dummies.

The vector of variables *AEIMPACT* is the interaction of *AERIAL* and year-specific dummies for 2004 to 2008. There are year-specific dummies for only 5 years because there is no expectation of visible SOD infections in *AERIAL* prior to the 2005 aerial survey. The vector of variables *ARIMPACT-NV*, *ARIMPACT-SF*, and *ARIMPACT-KF* is the interaction of *ARBOR-NV*, *ARBOR-SF*, *ARIMPACT-KF*, and year-specific dummies for 2000 to 2008, 1998 to 2008, and 2003 to 2008, respectively, based on aerial surveys that indicate oak dieback in those time frames.

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[15] 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.

Methods

A number of functional forms are considered for the hedonic models. 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 calculation of variance inflation factors fail to indicate that multicollinearity is a serious problem. Lastly, White's robust standard errors are used for all models, to account for potential heteroskedasticity.

The difference-in-differences model uses the study period 1983 to 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 study period 1983 to 2008 consists of a total of 30,907 observations, spanning 56 communities. The price of parcel *i* on community *j* in time *t* take forms:

Ordinary Least Squares (OLS):[16]

$$\ln\ P_{it} = X_i^{'}\beta + Z_{it}^{'}\phi + \delta_1 SODID_i + IMPACT_{it}^{'}\delta_2 + T_t^{'}\delta_3 + \varepsilon_{it} \qquad (2)$$

Community Fixed-Effects:

$$\ln\ P_{it} = X_i^{'}\beta + Z_{it}^{'}\phi + \delta_1 SODID_i + IMPACT_{it}^{'}\delta_2 + T_t^{'}\delta_3 + \alpha_{j(i)} + \varepsilon_{it} \qquad (3)$$

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 to 2008.

Parcel Fixed-Effects 'Repeat Sales':

$$\ln\ P_{it} = Z_{it}^{'}\phi + IMPACT_{it}^{'}\delta_2 + T_t^{'}\delta_3 + \alpha_{i(t)} + \varepsilon_{it} \qquad (4)$$

where X_i is a Kx1 vector of time-constant variables specific to parcel *i*, Z_{it} is a Lx1 vector of time-varying variables specific to parcel *i*, T_t is a Jx1 vector of year-specific dummy variables, and *SODID* and *IMPACT* 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 $SODID_i$ (δ_1) is the premium/discount of properties in places eventually affected by SOD, before the invasion begins. The coefficients on $IMPACT_{it}$ (δ_2)[17] specify the discount to the values of properties affected by SOD just before and after the invasion is underway.

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

[17] $IMPACT_{it}$ is a vector of interaction variables of the $SODID_i$ indicator and year-specific dummies for the years just before and after the SOD invasion begin. For *OAKWOOD CONFIRM*, *AERIAL*, *ARBOR-NV*, *ARBOR-SF*, and *ARBOR-KF*, the year-specific dummies are for the years 1996 to 2008, 1996 to 2008 (in 2-year intervals), 2004 to 2008, 2000 to 2008, 1998 to 2008, and 2003 to 2008, respectively.

The coefficients estimates (δ_2) are the difference-in-differences components of interest.[18]

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 (for example, Pope 2008a, 2008b).[19] 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 many community-specific characteristics are shared.

Parcel fixed-effects are a true panel approach, often referred to as 'repeat sales,' that uses the same 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 for unobserved spatial heterogeneity.[20] 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 last econometric issue to discuss is the use of a 25-year time-series of property sales. 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 to 2008. 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 to 2008.

Results

Table 1 summarizes the results from the spatial difference-in-differences model, where the community (3) and the parcel (4) fixed-effects forms, for control of community and parcel specific effects, are shown after ordinary least squares (2). The results are very similar across the estimations with the ordinary least squares having a slightly better fit because all time-constant variables are included. The stability of coefficients across the estimations indicates a degree of model robustness.

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[18] To see this, suppose two time periods and two infestation levels. $P_{T,YI}$ 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 $P_{C,YN}$ 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: $(P_{T,YI} – P_{T,YN}) – (P_{C,YI} – P_{C,YN}) = ((\delta_1 + \delta_2 + \delta_{3,YI}) – (\delta_1 + \delta_{3,YN})) – ((\delta_{3,YI}) – (\delta_{3,YN})) = \delta_2$.

[19] 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 and others 2009).

[20] Palmquist (1982) has a general discussion of using repeat sales data to estimate environmental characteristics.

The coefficients of the non-SOD variables are generally stable across the estimations. For instance, the coefficients on *LOT*, *BLDG*, *QUAL*, *DHWY*, and all the *TIME* variables are nearly identical and of the same order of statistical significance. *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.

The results for *OAKWOOD* and *OWIMPACT* have the expected sign and are significant, generally counter to the results for the models only using transactions for the period of the SOD invasion. Prior to the invasion, the *OAKWOOD* coefficient indicates proximity to oak woodlands has no statistically significant effect on property values.[21] After the invasion, the results for the 2000, 2004, and 2008 *OWIMPACT* coefficients indicate statistically significant discounts of 3 to 5 percent.

The results of *OWIMPACT* are generally stable across estimations (two, three, and four) in sign and magnitude. The indicator variables for properties that sell multiple times during the study period sell indicate these properties sell at a premium over properties with only one sale. This indicates the 'repeat-sales' model may represent a different type of housing market, with more speculative behavior, that is more susceptible to time-varying trends from the U.S. housing boom. The community fixed-effects model appears to resolve issues of bias and inefficiency from spatial unobservables, while providing some resistance to trends from the boom since homes that sold only once are included. Because of these advantages, only the results of the community fixed-effects model are displayed for the other SOD indicators.

[21] The community fixed-effects estimation indicates a slight premium may exist for homes beside healthy oak woodlands, which matches expectations.

	OLS		Community Fixed-Effects		Parcel Fixed-Effects "Repeat Sales"	
	Coef.	**Robust t-stat**	**Coef.**	**Robust t-stat**	**Coef.**	**Robust t-stat**
Constant	12.35**	146.66	11.88**	94.26	13.18**	1092.39
LOT	4.47e-7**	7.28	4.03e-7**	6.50	--	--
BLDG	1.86e-4**	36.67	1.82e-4**	36.47	--	--
BATH	0.01	1.35	0.01	0.81	--	--
BEDRMS	0.02**	6.89	0.02**	7.29	--	--
FIREPL	0.01	0.79	0.01	1.42	--	--
QUAL	0.12**	34.05	0.11**	31.43	--	--
DHWY	-0.03**	5.89	-0.02**	3.81	--	--
DFERY	0.01	0.43	0.02	0.92	--	--
DLIB	0.03**	3.18	0.02**	2.82	--	--
PRECIP	-4.63e-3**	11.47	-2.18e-3**	3.57	--	--
ELEV	-2.02e-5	1.27	-2.01e-5	1.21	--	--
DPRK					--	--
Mile	-0.03	0.46	0.11	0.98		
DMCINN	0.01	0.40	0.08**	2.92	--	--
DCHINA	0.09**	4.22	0.09**	3.39	--	--
DGNRA	-0.02	0.91	-0.01	0.11	--	--
TIME						
1992	0.08**	5.14	0.08**	5.24	0.09**	5.61
1997	0.02	1.18	0.02	1.21	0.03*	1.29
2002	0.52**	35.20	0.51**	36.23	0.51**	29.76
2007	0.73**	49.96	0.73**	51.19	0.84**	41.60
DNORTH	0.04	1.62	--	--	--	--
2000	-0.09**	6.61	-0.10**	7.07	-0.10**	6.43
2005	-0.04**	3.42	-0.04**	3.24	-0.08**	4.88
DSOUTH	-0.02	1.79	--	--	--	--
2000	0.10**	5.55	0.10**	5.40	0.12**	5.82
2005	0.02	1.01	0.01	0.89	0.01	0.59
OAKWOOD	-0.01	0.08	0.02	1.21	--	--
OWIMPACT						
2000	-0.05*	2.68	-0.05*	2.58	-0.04*	1.98
2004	-0.03	1.95	-0.03*	2.15	-0.03	1.32
2008	-0.05*	2.04	-0.05	1.86	-0.08**	2.77
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	

Table 1—Estimation results for spatial difference-in-differences hedonic models (1983 to 2008) – SOD indicator (*OAKWOOD*)

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

Table 2 displays the results for difference-in-difference community fixed-effects model to examine the percentage discount to property values over time, for each of the SOD indicators. Given that the study period spans 25 years, estimation is possible of the dynamic path of the discount to property values of proximity to a SOD indicator by year for more than a decade. The shaded cell of each column of Table 5 indicates the year the SOD indicator is expected to start detecting discounts to property values from the invasion. Two years of results prior to the year of expected detection are shown to compare results before and after the invasion.

Table 2—Dynamic response of property values to the SOD invasion (by percent change) for each SOD indicator

Year	Coast oak woodland (OW IMPACT)	SOD confir-mations (CF IMPACT)	2005 Aerial Survey Mortality (AE IMPACT)	Novato Neigh-borhoods (ARIMPACT-NV)	San Rafael Neigh-borhoods (ARIMPACT-SF)	Kentfield Neigh-borhoods (ARIMPACT-KF)
1996	4.50 (1.53)	-8.15 (0.80)	--	--	--	--
1997	-0.10 (0.04)		--	--	--	--
1998	-0.01 (0.03)	-3.92 (0.44)	--	--	-4.21 (1.19)	--
1999	-3.15 (1.22)		--	--	-6.67 (1.55)	--
2000	-4.30* (2.39)	-11.04 (1.49)	--	1.21 (0.36)	-8.52** (3.33)	--
2001	-1.69 (0.91)		--	4.92 (1.49)	-8.79** (2.72)	--
2002	-1.49 (0.97)	-1.78 (0.49)	--	-1.69 (0.57)	-7.69** (2.93)	--
2003	-4.21** (2.61)		--	-6.57 (1.19)	-6.85* (2.35)	1.92 (0.33)
2004	-3.15* (2.13)	-1.49 (0.52)	2.12 (0.77)	-2.27 (0.97)	-8.24** (3.18)	-4.30 (0.74)
2005	-1.78 (1.18)		-1.29 (0.48)	-8.70** (4.17)	-6.20* (2.48)	-15.46 (1.96)
2006	-3.34* (2.27)		-6.67* (2.01)	-6.76* (2.48)	-6.95** (3.03)	-17.88** (2.89)
2007	-0.80 (0.54)	5.55 (1.27)	-0.20 (0.11)	1.71 (0.58)	-10.06** (4.61)	-1.59 (0.24)
2008	-4.02 (1.68)		2.02 (0.36)	5.55 (1.27)	-15.80** (3.57)	10.74 (1.13)
R^2	0.68					
Panel ID	56 Communities					
Rho	0.33					

Number of observations: 30,907. Note: * ** indicates significance at the 95 percent and 99 percent levels. These are the community fixed-effects difference-in-difference hedonic models. Robust t-statistics are in parentheses. Shaded cells indicate the year when visibly dying trees are expected to first appear for each of the indicators.

OWIMPACT results indicate a discount of 3 to 5 percent for every year from 1998 to 2008, with these discounts significant in the years 2000, 2003, 2004, and 2006. Note that in 1996, prior to the invasion, there is a premium of 4 to 5 percent, which suggests an even deeper discount may have occurred. The continually dying oaks in the woodlands have an ongoing effect on the discount to property values. This likely persists until there are no further dying oaks in the vicinity of the homes. These discounts are less severe than if the dying oaks are located on the homeowner's property.

CFIMPACT results indicates a large, 11 percent, though statistically insignificant, discount in the years of 2000 and 2001.[22] The lack of statistical significance is likely because of the small number of transactions in quarter mile proximity to the locations confirmed to have SOD. The magnitude of the discount fades in subsequent years. Note that the presence of a discount prior to invasion for *CFIMPACT* means the discount may not be as high as 11 percent. The 2006 coefficient for *AEIMPACT* indicates a discount of 6 to 7 percent, statistically significant, on homes near oak dieback observed in the 2005 aerial survey. This discount fades and eventually switches to a statistically insignificant premium in 2008. This suggests property values rebound after the dying oaks are removed from a homeowner's property.

ARIMPACT-NV, SF, and *KF* results indicate that heavily damaged neighborhoods produce large and often ongoing discounts on nearby property values.[23] For the Novato neighborhoods, the discounts, generally between 6 to 8 percent, last for 5 years following the invasion, and are statistically significant for 2 of the years. The discounts for the San Rafael neighborhood, generally between 6 to 15 percent, last to the end of the study period, and are all statistically significant. Note that discounts are present in the San Rafael neighborhood prior to the invasion, which suggests the discounts from SOD may not be as high as 15 percent. However, two large discounts in the Kentfield neighborhoods, close to 15 percent, also coincide with the invasion.

The difference in the number of years of discounts in the neighborhoods is related to their proximity to infested oak woodlands and how long the woodlands were infested. The San Rafael neighborhood is in proximity to China Camp State Park, where SOD mortality has been severe since 1998. Homeowners have observed dying oaks on the hillsides of the park 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.

Discussion

The findings of this study indicate the dynamic effects on property values in Marin County, California from an invasion by the forest invasive species, *P. ramorum*. We use a quasi-experimental hedonic model for the study period 1983 to 2008, with the first large wave of SOD mortality in Marin County in late 1998, to detect the discounts from proximity to dying trees in oak woodlands, properties of homeowners, and heavily damaged neighborhoods. Properties within a quarter-mile from SOD infested oak woodlands experience a 2 to 5 percent discount, and this discount is ongoing since oaks are continually dying in the woodlands. If dying oaks are on a homeowner's property, we observe a greater discount of 5 to 8 percent, though this discount is transitory and significantly diminishes or completely disappears within a couple years. The most severe discounts of 8 to 15 percent occur, which can last for several years or longer, if dying oaks are throughout a neighborhood and in nearby woodlands.

[22] 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.
[23] The years of discounts closely correspond to the dates when oak dieback is observed in the USDA FS aerial surveys.

Government agencies' spending on invasive species management is significant, despite the general lack of estimates of the damages over time of the invasions, from a rigorous economic framework (Olson 2006). Our results indicate that government spending on homeowner education of the symptoms of SOD and on the removal of dying trees is crucial for mitigating property value discounts. Education about SOD helps homeowners to realize when an infestation is present and contact government or private arborists about removing infected plants before the disease grows worse and spreads to other oaks. 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 faster removal of the dead and dying oaks.[24]

Many natural hazards (for example, wildfires, floods, hurricanes, 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 damages over time is important for improving the government response with education and management. More generally, the dynamic response to changes in resources suggests how the people value resources over time and, thus, broadly informs long-run policies involving them.

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[24] Because infected oaks do not spread the pathogen and there is a high cost associated with removal of oaks, many dead and dying oaks are left standing in open oak woodlands.

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