

## CHAPTER 11

# FOREST DISTURBANCE IMPACTS ON RESIDENTIAL PROPERTY VALUES

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### 1. INTRODUCTION

Natural environments and the amenities they offer have fueled much of the population growth in the rural United States (Deller et al. 2001, English et al. 2000). In fact, the fastest growing counties in the United States during the early 1990s were non-metropolitan counties that were destinations for retirees or that offered outdoor recreation opportunities (Johnson and Beale 1994). Migration to these rural and exurban areas from urban and suburban locations, along with growth in the United States population, has resulted in an increased mixing of humans, their artifacts, and natural environments. These expanding interface and intermix areas expose more lives and property not only to desirable natural amenities, but also to natural disturbances and disamenities.

Households choose the type and amount of natural amenities, along with other structural, neighborhood, and environmental characteristics, in their location decisions. These amenities, such as access to recreation, viewshed, and air and water quality, are capitalized by housing markets into prices. Wildfires, pest outbreaks and other natural disturbances can alter the quantity and quality of amenities available to the household. Damage or destruction of the property itself or any of the surrounding amenities by natural disturbances affects that property's value and if the impacts are widespread, the broader property market is impacted as well. Even in the absence of a disturbance event, property markets respond to the presence of disturbance risk alone since this risk represents the potential for future damages to property and natural amenities. In the context of this chapter, risk will refer to both the probability of a disturbance event and the probability of the loss associated with an event.

The primary theoretical framework for studying the relationship between a property's portfolio of characteristics and its price is based on the hedonic model of Rosen (1974). The application of this theory to property markets is known as the hedonic property model (HPM). The empirical use of the HPM in the literature is extensive as it is a popular method to explain the effect of trees, forests, and

woodland on residential property markets. Morales (1980), Anderson and Cordell (1985), and Dombrow et al. (2000) examine how residential prices respond to the presence of trees. The relationship between urban forests and housing prices in Finland is treated by Tryväinen (1997) and Tryväinen and Miettinen (2000). Price response to woodland in Great Britain is the subject of work by Garrod and Willis (1992a). The effects of open space, a more general classification, on property prices are considered by Geoghegan et al. (1997), Acharya and Bennett (2001), Shultz and King (2001), and Geoghegan (2002).

Despite the depth of literature using the HPM to look at how forest and woodland amenities impact property prices, there are far fewer examples which examine the impacts of forest disturbances and the risks they represent. Price-waterhouseCoopers (2001) performed an analysis of how the Los Alamos, New Mexico real estate market responded to the 2000 Cerro Grande fire. The results report a temporary dip in prices of 3 percent to 11 percent following the fires. No insight is offered on the possible cause for this drop—a shock to the overall housing market, the loss of forest amenity, or an increased awareness of wildfire risk. Loomis (2004) estimates that house prices in Pine, Colorado decreased by approximately 15 percent following the Buffalo Creek fire due to updated risk perceptions and the loss of forest amenity. In a study of the Flagstaff, AZ property market, Wells (2001) reports that households place a higher value on medium canopy density vs. high canopy density. Lower risk of fire and increased viewshed afforded by medium canopy closure are offered as possible explanations. Donovan et al. (2007) find that the publication of a website that rated wildfire risk in the wildland-urban interface of Colorado Springs had an impact on housing price.

Payne et al. (1973) provide an accounting procedure for calculating property value losses from gypsy moth damage, which was based on a hedonic study of the contribution of trees to property value in Massachusetts (Payne and Strom 1975). Derived from the later published hedonic study, an equation was presented which describes the relationship between the number of trees on a lot and the dollar amount those trees contribute to property values. Using data on tree mortality from insect infestations, lost property value is calculated as the difference between pre-attack and post-attack valuations. However the model does not account for lost value from trees that are unsightly or unhealthy, nor does it consider the nuisance impact of gypsy moths.

Garrod and Willis (1992b) suggest that replacing mature conifers, which reduce price in their study when located within 1 km of a house, with other species would result in lower disamenities. However they offer no insight into the nature of the disamenities. Geoghegan et al. (1997), Tryväinen (1997), and Schultz and King (2001) report negative relationships between some natural amenity variables and housing prices but do not suggest the risk or realization of disturbances as a reason. The response of property prices to other natural hazards, such as earthquakes, volcanoes, and hurricanes, has received treatment by Brookshire et al. (1985), Bernknopf et al. (1990), Beron et al. (1997), and Bin and Polasky (2004).

This chapter seeks to provide a basic framework for modeling the effects of forest and other natural disturbances on property markets. The modeling section will begin by introducing the hedonic property model in a simple, accessible format. Several important modeling issues and aspects of forest disturbances that make them special in regard to describing their impact on property markets will be discussed next. These include the tension between risks and amenities embodied in a forest resource, the temporal dynamics of disturbance manifestation, and spatial dependence among observed outcomes present challenges to capturing the effects of disturbance shocks. Two case studies will follow, examining the price responses of residential housing to wildfire and an invasive species, the hemlock woolly adelgid. The chapter will conclude with a discussion of management and policy implications of disturbance shocks to property markets.

## 2. HEDONIC PRICE THEORY

The hedonic model simply states that a good's price is a function of the various qualities and characteristics that make up that good. The intuitive nature of the theory underlying the hedonic model, variation in characteristics embodied in a good creates variation in prices (Taylor 2003), is very appealing. In general the hedonic model estimates how the total price of a good changes at the margin—that is, when one of its characteristics changes and all others are held constant. Using the HPM to analyze the residential property purchasing decisions made by households, where houses with differing portfolios of characteristics and prices are bought and sold in a single market, allows the researcher to find the marginal willingness to pay (MWTP) for an additional unit of each characteristic.

Let  $z_1, z_2, \dots, z_m$  be the set of  $m$  characteristics of a property such as lot size, square footage, age, the quality of local schools, distance to a trailhead, etc. We can denote this set as the vector  $\mathbf{Z}$ . The market for property is comprised of buyers on the demand side and sellers on the supply side and is assumed to be in equilibrium. Each buyer's willingness to pay for vector  $\mathbf{Z}$  while one characteristic  $z_i$  is changed and all others are kept constant is described by a bid curve. For each seller, the willingness to accept a price for vector  $\mathbf{Z}$  while one characteristic  $z_i$  varies and others are held constant is represented by an offer curve. The hedonic price function,  $P(\mathbf{Z})$ , an equilibrium relationship between buyers and sellers, is an envelope of tangencies of buyer bid curves and seller offer curves (Taylor 2003 for an extended discussion of bid and offer curves). The first derivative of  $P(\mathbf{Z})$  with respect to characteristic  $i$ ,  $\frac{\partial P}{\partial z_i}$ , yields that characteristic's implicit price, also called the hedonic price. The implicit price is the MWTP for an additional unit of that characteristic.

Using statistical techniques, such as linear regression or maximum likelihood estimation,  $P(\mathbf{Z})$  can be estimated and implicit prices for the various characteristics inferred from the results. A variety of functional forms are available for use

in empirical applications, including linear, log-linear, semi-log, quadratic, and Box-Cox. However little guidance from economic theory is available for the selection of the proper form. It has been demonstrated that the linear and semi-logarithmic forms were among those that performed best when unobserved variables were proxied by others or are not included in the hedonic function at all (Cropper et al. 1993). In some cases the dependent variables or the error terms of different locations may be correlated. Spatial hedonic property models can account for both spatial dependence in the dependent variable and the error structure.

Estimating  $P(\mathbf{Z})$  and the implicit prices for each  $z_i$  is known as first stage analysis. Using first stage results, demands for characteristics of interest can be estimated in the second stage analysis. Because the implicit price represents only one point on the buyer's bid curve, identifying demands can be difficult. Estimating demands requires information beyond that required in the first stage, such as demand shifters and in some cases a second set of implicit prices from another market. Despite the difficulty, second stage analysis is useful because demands can be used to estimate welfare changes that result from changing the quantity of a characteristic. The two applications presented in this chapter will focus only on first stage estimation.

### **3. EMPIRICAL ISSUES IN MODELING DISTURBANCE IMPACTS**

The data used in an empirical application of the HPM must be extensive enough in geographic coverage to capture the disturbance shock, but not so large that the single market requirement of hedonic theory is violated. Defining the extent of the area to be studied is the first step in the broader task of identifying variables of interest for capturing the impact of natural disturbances using the HPM. Natural disturbances possess several unique aspects, including the interaction between risk and amenities, and temporal and spatial dynamics, that have consequences for measuring their influence on the variable of interest. Depending on these unique factors, the price response in property markets to a natural disturbance can be subtle and therefore difficult to detect, or robust and easy to identify. The choice of variables that will relate the disturbance impacts to observable outcomes in the market, as well as the econometric techniques to be employed, requires thoughtful consideration.

#### **3.1 Risk and Amenities**

Many natural areas present some risk of disamenity in addition to the amenities they provide. The same measures that are chosen to capture the positive spillovers from a resource in a HPM may also represent a source of risk to the household. For example, while decreasing the household's distance to a forest boundary may increase scenic woodland views, the risk of property damage due

to a fire may go up as well. There is a danger that the use of a single distance or neighborhood variable to capture the price shock from a disturbance can result in the "netting" of amenity and risk components in the results. For example, Portney (1981) cautions that the estimated value of risk reduction from improvements in air quality can be conflated with the amenity values of cleaner air. In some circumstances it may be possible to include variables which represent both the amenity and risk components of a resource in an attempt to account for this tension. Donovan et al. (2007) consider a novel approach to show that positive amenity values overcome the negative impacts of risk. Modeling the price impacts of risk and amenity attributes requires very careful selection in the variables which will convey the impacts in the model.

Common variable choices for measuring disturbance risk and changes in natural amenities from a disturbance event include the distance to at-risk or impacted areas and the share of land in a neighborhood surrounding the house that is at-risk or impacted. Very precise variables, such as the number of trees within a 100-meter radius that are infected with an invasive species, are also possible but require significant time and effort in data preparation. In choosing to use neighborhood measures, the extent of impact around each data point must be considered. This involves identifying how a disturbance shock to price decays as distance from the impacted area increases. For example, a 50-meter neighborhood around a house would not be sufficient to model the price impacts of a wildfire that damaged a trailhead one mile away. However such a localized neighborhood might suffice for an invasive species study where house values capitalize dead and damaged trees near the property.

The actual, or objective, probability that a household will experience a disturbance may be quite low. Vectors for invasive species may be relatively rare such that the likelihood that a household has one within its parcel boundary or experiences spillovers is small. Likewise, the chance of wildfire burning any one acre and hence affecting a household is very small. Measuring the true, objective probability level for these very infrequent events is difficult both for the household and the modeler. While distance and neighborhood variables can be used to proxy for risk, variables that provide information on the risk-averting behavior of the household can be useful. Homeowners take precautionary steps, such as installing fire-resistant roofs or treating trees to thwart insects and diseases, to protect their property from disturbances. They may also participate in collaborative efforts with other households to reduce risk in their broader neighborhood. These self-protection and community efforts can help to reveal the household's perceived, or subjective, assessment of risk, the value of which can be inferred from the HPM.

### 3.2 Temporal Dynamics

The speed with which a disturbance occurs and spreads across the landscape can vary dramatically. The damage from hurricanes may occur in a matter of hours, whereas wildfire impacts may occur over days to weeks and insect outbreaks

may last for years. The shock to the market also has its own profile across time that may differ from that of the disturbance. Natural disturbances that operate at slow speeds may confound attempts to identify “before” and “after” time periods necessary for choosing the temporal window from which to select data and measure market shocks.

For disturbances that manifest at fast time scales, such as hurricanes or wild-fires, variables that indicate the date of sale can identify the impact of the shock to the overall housing market. Interacting these time variables with variables that identify spatial variation in the shock, such as risk or amenity proxies, produces measures of a disturbance shock at a fine combination of temporal and spatial resolution. To better understand this technique, called “difference-in-differences”, consider two different locations, one exposed to a natural disturbance and one not exposed. Let  $P^{td}$  be the price of a house at time period  $t$  ( $t=1$  during or after the disaster,  $t=0$  before) in location  $d$  ( $d=1$  for the affected location,  $d=0$  for the unaffected) and  $Z$  be a vector of housing characteristics. If  $E[\cdot]$  is the expectations operator, then the conditional difference-in-differences estimator,

$$\{E[P^{11} | Z] - E[P^{10} | Z]\} - \{E[P^{01} | Z] - E[P^{00} | Z]\} \quad (11.1)$$

accounts for the differences in price across locations as well as changes in price due to time that are not attributable to the disturbance. The first term in brackets is the difference in prices between the locations after the disturbance while the second bracketed term is the difference in prices between the locations before the disturbance. By subtracting out the difference in price that prevailed *ex-ante* from the difference *ex-post*, only the effect of the disturbance remains.

The difference-in-differences technique may not be appropriate for modeling impacts from disturbances that do not occur on fast time scales with distinct start and stop dates. The slow, continuous spread of a disturbance at fine spatial scales complicates the identification of time  $t$  when the impact occurs. For instance, the relatively slow spread of an invasive species through small patches in the landscape blurs both the “before” and “after” necessary to identify the time of infection. A further complication arises when insects or diseases take several years to cause mortality in susceptible hosts. In contrast, a natural disturbance that rapidly spreads across a large area is well-suited to this technique since  $t$  can be easily identified.

### 3.3 Spatial Dependence

A final issue that has implications for the empirical estimation of natural disturbance impacts on housing markets is the identification and control of spatial dependence in the data. Spatial dependence is expected when the relative locations of sample observations matters (Bell and Bockstael 2000). Said differently, spatial dependence refers to a spatial association between values observed at different locations. Two potential sources of spatial dependence are of concern:

structural or spatial lag dependencies across observations on the dependent variable and spatial dependence across error terms. In the context of hedonic property value modeling, structural dependence arises, for example, when the sales value of one property is systematically influenced by the sales value of nearby properties. Spatial dependence among the errors is generally due to omitted variables, which are themselves spatially correlated but could also be due to errors in measurement that are systematically related to location. Property characteristics omitted from the hedonic property value model that are spatially correlated would result in spatially autocorrelated or dependent errors.

Spatial dependence has implications for the validity of OLS parameter estimates and variance-covariance estimates and therefore for the validity of hypothesis tests based on such results. If spatial lag dependence is present and ignored in the analysis, OLS will give biased and inconsistent parameter estimates. If spatial error dependence is present and ignored, OLS will produce unbiased parameter estimates but the standard errors associated with these estimates will be biased (inefficient). Spatial lag and error models can be used to correct for spatial dependence problems in the data. Refer to Anselin (1988) for a comprehensive discussion of spatial dependence.

The econometric modeling of spatial effects in housing price studies is at an early stage of development, and little is known about the spatial impact of natural disturbances on housing markets. However, we suspect that spatial econometric methods may be well-suited for identifying the property value impacts of localized disturbances, such as invasive species that operate at small patchy spatial scales and where value spillovers from infected to non-infected properties occur (Holmes et al. 2006). In contrast, spatial econometric methods may prove to be less useful for modeling disturbance impacts which are uniformly distributed across a housing market.

The forgoing discussion emphasizes that the temporal and spatial scope of the data, the list of variables of interest, and the specification of econometric models all need to be evaluated to account for the special nature of disturbances. Two case studies utilizing the HPM will now be presented to illustrate how the specific characteristics of a natural disturbance influence modeling decisions. The first case study analyzes the impact of a large wildfire on housing prices using the difference-in-differences estimator. The second case study investigates how a decline in forest health induced by an exotic forest insect—the hemlock woolly adelgid—is capitalized into housing prices.

#### **4. WILDFIRE IMPACTS ON RESIDENTIAL PROPERTY VALUES**

Wildfire is a common natural hazard in eastern Oregon and Washington. Rapp (2002) explains that frequent, low-intensity fires dominated the historic fire regime of the ponderosa pine forests of this area. Vegetation on the forest floor

and small diameter, less fire-resistant trees burned but larger trees survived. This regime resulted in an open forest with low fuel levels. However, Rapp (2002) further reports that the fire regime has changed to one of more lethal fires that occur more often. As a result of timber harvesting, grazing, the introduction of nonnative plant species, and wildfire management policies that stressed fire suppression and exclusion, these forests have experienced an increase in the probability of severe, stand replacement fires. The result is that many dry, east-side forests have missed between 7 to 10 fire-return intervals.

A set of three wildfires burned over 180,000 acres in the Wenatchee National Forest and Chelan County, on the east side of the Cascades in central Washington, during the late summer of 1994. Suppression expenditures were almost \$70 million, and the economic impacts included losses of personal property, timber, and tourism revenue (Carroll et al. 2000). This empirical application of the HPM will examine the property market impacts from these fires.

#### 4.1 Empirical Model

This model uses the difference in differences technique to capture the impact of the fires on the amenity value of the forest. With a log-linear functional form, the general ordinary least squares (OLS) difference-in-differences hedonic estimating equation is

$$\ln P^{td} = \sum_i \beta_i z_i + \alpha t + \phi d + \delta(t \cdot d) \quad (11.2)$$

where the  $z_i$  are housing characteristics,  $d$  is a measure of forest amenity ( $d = 1$  if high,  $d = 0$  if low), and  $t$  is an indicator of whether the house was sold after a disturbance event ( $t = 1$  if after,  $t = 0$  otherwise). In a very general sense,  $d$  could describe the proximity to a trailhead ( $d = 1$  if close,  $d = 0$  if far) or the quality of a viewshed ( $d = 1$  if good views,  $d = 0$  if poor views). Assuming that  $d$  measures only the amenity role of the forest (and does not include any risk components), it should be the case that  $\phi > 0$  so that price increases with the amenity level. The outcome of interest is the coefficient on the product of the time and location dummies,  $\delta$ , which is the equivalent of the conditional difference-in-differences estimator in equation (11.1):

$$\begin{aligned} & \{E[P^{11} | Z] - E[P^{10} | Z]\} - \{E[P^{01} | Z] - E[P^{00} | Z]\} \\ &= \{\ln P^{11} - \ln P^{10}\} - \{\ln P^{01} - \ln P^{00}\} \\ &= \left\{ \left( \sum_i \beta_i z_i + \alpha + \phi + \delta \right) - \left( \sum_i \beta_i z_i + \alpha \right) \right\} - \left\{ \left( \sum_i \beta_i z_i + \phi \right) - \sum_i \beta_i z_i \right\} \\ &= \delta. \end{aligned} \quad (11.3)$$

If  $\delta < 0$  then it is possible to claim that the disturbance had a negative impact on the market price of a house due to an impaired amenity level. In this application,  $d$  is not binary but semi-continuous to represent how the amenity level varies with distance to the household.

## 4.2 Data

Residential housing transactions for 1992 through 1996 were obtained from the Chelan County Assessor's Office. A review of federal fire records (Coarse Scale Spatial Data 1999) showed that large fires in the study area were unusual. With the exception of the three large fires in 1994, during the period 1992-1996 on the Wenatchee NF in Chelan County, fewer than twelve fires exceeded 100 acres, the largest just under 600 acres. This reveals that the three largest fires in the summer of 1994, when added together, comprised the largest fire event recorded over the period covered by the set of sales transactions.

In addition to sales price, this dataset included a variety of structural variables such as date of sale, living area, date of construction, type of roof, and whether the house included a fireplace, hot tub, garage, carport, patio, or basement. Lot size in acres was also included. The Assessor's office provided a parcel map for the county which was used to spatially reference the sales transactions with ArcView GIS. The centroid of each parcel was used as the location of each property. To account for differences in neighborhood or community characteristics, census tract data for median household income were obtained from the U.S. Census Bureau. Additionally, the kilometers of road in a 0.40-kilometer (0.25 mile) radius around the parcel centroid (from the 2000 TIGER road file for Chelan County) were computed to account for the differing levels of urban development in the data. Lake Chelan is a large lake located in the county which is a popular recreation area. The distance to the lake was included to capture its amenity.

The measures for the amenity role of the forest are the distance in kilometers from the parcel centroid to the closest fire boundary, *fire\_dist*, and the distance in kilometers from the parcel centroid to the national forest boundary, *nat\_for\_dist*. Distance to the national forest embodies characteristics such as access to recreation and viewshed while distance to the burned area controls for the fire-induced change in forest condition.

*NFPA 1144, Standard for Protection of Life and Property from Wildfire* by the National Fire Protection Association, Inc. (NFPA 2002) and the *Urban-Wildland Interface Code 2000* by the International Fire Code Institute (IFCI 2000) include surrounding vegetation and slope in their systems for assigning risk levels to properties in the urban-wildland interface. The National Fire Danger Rating System (NFDRS: Deeming et al. 1977) breaks vegetative fuel into three broad classes (not including slash): shrub (*shrub*), grass (*grass*), and evergreen (*evergreen*). The National Land Cover Data (NLCD) grid provided the link between the NFDRS and the vegetation surrounding each parcel for measuring vegetative risk. Vegetative risk was measured by the percent of land in a 190-meter

neighborhood surrounding a parcel centroid that was in each of the three broad fuel classes of the NFDRS as shown by the NLCD grid. A mosaic of 7.5-minute digital elevation models (DEMs) with 10-meter resolution from the USGS was used to produce a countywide slope grid and measures of slope (*slope*) were developed for the 190-meter neighborhood. Together, the vegetation and slope variables proxied for the level of wildfire risk around each property.

Roofing type, which was included in the data received from the assessor's office, was chosen as the measure of structural fire resistance. Roofing class is measure of fire-resistance, with class-A being the highest level. The *roof* variable (*roof* = 1 for class-A, *roof* = 0 otherwise) will be used to represent the household's self-protecting or averting behavior and infer attitudes on risk.

To account for changes in the general price level in the Chelan residential property market, binary variables for the six month period the sale occurred were included and named *sd921*, *sd922*, *sd931*, etc. where *sd9xy* indicates a sale in year 199x during six month period y (y = 1 for the first six months, y = 2 for the second six months).

The amenity variables *nat\_for\_dist* and *fire\_dist*, the distances from the parcel centroids to the national forest and fire boundaries which proxy for the level of forest amenity, were applied to the difference-in-differences technique. To control for the possibility that the effect of the three fires was transient and would not be detected using a simple before and after measure, the post-fire indicator is decomposed into the five six-month periods during and after the fire. The corresponding five sales date dummy variables were multiplied by *nat\_for\_dist* and *fire\_dist* and are named *nat\_for\_dist942*, *fire\_dist951*, etc. These variables are the equivalent t·d of in equation (11.2). This technique was also applied to the roofing material dummy (*roof*) to examine how the valuation of self-protection evolves after the fires. Table 11.1 contains the summary statistics of the focus amenity and risk variables.

**Table 11.1. Descriptive statistics for risk and amenity focus variables in Chelan County, WA.**

Variable Name	Symbol	Mean	Std. Dev.
Class-A roof (Yes = 1, No = 0)	<i>roof</i>	0.822	0.383
Distance to national forest boundary (km)	<i>nat_for_dist</i>	3.638	2.328
Distance to fire boundary (km)	<i>fire_dist</i>	13.778	8.353
Share in grass (%)	<i>grass</i>	6.861	15.279
Share in shrub (%)	<i>shrub</i>	10.055	16.688
Share in evergreen (%)	<i>egreen</i>	8.505	21.387
Slope	<i>slope</i>	4.619	4.969

### 4.3 Results

Ordinary least squares regression results are presented in table 11.2. Only coefficient estimates for the variables of interest related to the wildfire impacts are presented here. Huggett (2003) includes the complete results with coefficients for the structural variables. All implicit prices are evaluated at the mean price of \$114,315<sup>1</sup>. The general price level falls by \$16,377 from the second half of 1994 to the first half of 1995 as evidenced by the coefficients on *sd942* and *sd951*. Comparing these results with previous work that uses pre- and post-fire indicator

**Table 11.2. OLS results for Chelan County, WA.**  
Dependent variable is the natural log of price.

Variable	Estimate	p > $\chi^2$
<i>sd942</i>	0.268	<0.0001 **
<i>sd951</i>	0.152	0.020 **
<i>sd952</i>	0.272	<0.0001 **
<i>roof</i>	-0.118	<0.0001 **
<i>roof942</i>	0.070	0.070 *
<i>roof951</i>	0.055	0.198
<i>roof952</i>	0.112	0.005 **
<i>roof961</i>	0.175	0.001 **
<i>roof962</i>	0.014	0.673
<i>nat_for_dist</i>	-0.006	0.314
<i>nat_for_dist942</i>	-0.006	0.447
<i>nat_for_dist951</i>	0.005	0.671
<i>nat_for_dist952</i>	-0.001	0.894
<i>nat_for_dist961</i>	0.015	0.082 *
<i>nat_for_dist962</i>	0.007	0.452
<i>fire_dist</i>	-0.006	0.000 **
<i>fire_dist942</i>	-1.93e-4	0.930
<i>fire_dist951</i>	0.006	0.048 **
<i>fire_dist952</i>	-1.04e-4	0.965
<i>fire_dist961</i>	-0.006	0.010 **
<i>fire_dist962</i>	-0.003	0.127
<i>egreen</i>	-0.001	0.008 **
<i>shrub</i>	-7.47e-5	0.866
<i>grass</i>	-3.55e-4	0.487
<i>slope</i>	0.002	0.193
<i>R</i> <sup>2</sup>	0.61	
<i>No. of obs.</i>	4,720	

Note: \*\* denotes significance at 5%, \* at 10%.

<sup>1</sup> With a semi-log functional the implicit price for non-binary variables is  $B \cdot P$  where  $B$  is the coefficient estimate and  $P$  is price. For binary variables, the implicit price is  $\{ \exp[B - .5 \cdot V(B)] - 1 \} \cdot P$  where  $V(B)$  is the variance of  $B$  (Kennedy 1981).

variables, this drop of 13 percent to 14 percent of mean price is between the upper bound of 11 percent in the PricewaterhouseCoopers report (2001) on the Cerro Grande fire and the 15 percent loss that Loomis (2004) found with the Buffalo Creek fire. Absent any other contemporaneous shocks this represents a broad fire-induced response in the Chelan County residential housing market in the first half of 1995. However this shock appears to be short-lived as the price level in the second half of 1995 (*sd952*) increases to the pre-fire level.

The coefficient estimate for *fire\_dist* is negative and highly significant, indicating that prior to the fires households placed a premium on living near the area that would burn. An additional kilometer from the burned area prior to the fire discounts price by \$676. The negative coefficient estimate of *fire\_dist* reveals that the area that burned, in its unburned state before the second half of 1994, possesses some qualities that were unique from the rest of the national forest such as viewshed or opportunities for recreation. The coefficient on *fire\_dist951* is positive and significant. For the first half of 1995 *fire* and *fire\_dist951* combine to add \$48 to price for each additional kilometer from the burned area. None of the distance-to-national-forest variables are significant for the 18 month period during and after the fires. These results indicate that while the fires had no impact on the overall value that households place on living near the national forest, the value for living near the burned area did fall in the first half of 1995 in response to the decreased amenity level. However this response was temporary and disappeared after the first six months of 1995.

For the neighborhood risk proxies, each percent increase in evergreen cover in a 190-meter neighborhood of the house decreases price by \$165. This discount for higher evergreen density corresponds to the findings of Garrod and Willis (1992b) and Wells (2001). The coefficients of *slope*, *shrub*, and *grass* are not significant.

The signs on the coefficient estimates of the roof and sales date interaction variables indicate that having a fire-resistant roof detracted from the price of a house prior to the fire. A class-A roof lowers price by \$12,742 from the beginning of 1992 through the beginning of 1994. The value of a fire-resistant roof increases by \$8,190 in the second half of 1994, \$13,452 in the second half of 1995, and \$21,699 in the first half of 1996 over the pre-fire value. There are several explanations for the increase in the valuation of a fire-resistant roof, including a reassessment of the prevailing risk of wildfire in Chelan County in the presence of increased information (Kask and Maani 1992), increased post-fire demand for fire-resistant roofing, and a supply restriction due to fire-delayed plans to put property with class-A roofs on the market.

This example of the HPM has sought to empirically measure the relationship between the realization of a wildfire event and residential housing prices by accounting for both the spatial variability in fire risk and the change in amenity. The results reveal significant post-fire price impacts on the general price level, the valuation of forest amenity, and the valuation of self-protection.

## 5. EXOTIC FOREST INSECTS AND RESIDENTIAL PROPERTY VALUES

Our second example of the economic impacts of a forest disturbance on private property values considers the case of an invasive forest insect—the hemlock woolly adelgid. The hedonic property value method is used to evaluate both the timing and the magnitude of economic impacts resulting from a gradual decline in forest health.

The HWA was accidentally introduced into Virginian forests from Japan during the 1950's and causes mortality to eastern and Carolina hemlocks. During the past half-century, the HWA has spread to hemlock forests in the Northeast, the Mid-Atlantic region, and the South. Eastern and Carolina hemlocks have shown no resistance to HWA, and once trees are moderately or severely infested, there is little chance for recovery. Dramatic losses of hemlock forests throughout the eastern United States are likely unless successful control measures are found. Hemlocks are also widely used as ornamental trees in residential landscapes. During the early stages of an infestation, individual trees in residential landscapes, or specimens located close to roads, can be successfully treated using insecticidal methods. Severe infestations cause defoliation and a gradual loss of tree vigor, typically resulting in tree death as the extent of defoliation progresses over several years.

Northwestern New Jersey was chosen for the study site as the impact of HWA on hemlock forests in this area is well documented (Royle and Lathrop 1999). The 80 square mile township of West Milford is located in the Highlands region, and had a population of 26,410 according to the 2000 census. The area is characterized by farms, small villages and towns, lakes, forests and wetlands.

### 5.1 Model

This case study employs the hedonic property value model to examine the effects of hemlock decline on residential property values. To understand the model, first recall that a semi-log hedonic price function can be specified as:

$$\ln P = Z\beta + \varepsilon \quad (11.4)$$

where  $\ln P$  is an  $n \times 1$  vector of the natural log of price,  $Z$  is an  $n \times m$  matrix containing explanatory variables, and  $\varepsilon$  is the  $n \times 1$  vector of errors which are distributed normally with zero mean and variance of  $\sigma^2$ . As the impacts of HWA on hemlock health are gradual, with symptoms of decline and finally death extending over several years, a pertinent issue is to identify the point in time at which hemlock decline registers an impact on property prices. We hypothesize that, as hemlock health declines, a threshold is crossed beyond which the presence of hemlocks on the landscape quantitatively shifts the property value function.

The impact of hemlock decline on property value is specified using two related variables. The first variable,  $h\_forest$ , specifies the total area of hemlock trees on parcels sold throughout the period covered by the data record. A second hemlock variable,  $h\_threshold$ , is specified to evaluate the point in time at which hemlock decline shifts the property value function. The model we estimate is specified as:

$$\ln P = \alpha_1 h\_forest + \alpha_2 h\_threshold + Z\beta + \varepsilon \quad (11.5)$$

where

$$h\_threshold = dummy_t \cdot h\_forest \quad (11.6)$$

and  $dummy_t = 1$  for year  $t$  and all subsequent years in the data record;  $dummy_t = 0$  otherwise. The parameter  $\alpha_1$  provides an estimate of the percentage change in property value with respect to a one unit change in the area of hemlock trees on properties that sold prior to the threshold year. The sum of the parameter estimates ( $\alpha_1 + \alpha_2$ ) provides an estimate of the percentage change in property value with respect to a one unit change in the area of hemlock trees on properties that sold after the threshold was crossed. Alternative threshold values are tested in the model specification in order to isolate the value of  $t$  at which a statistically significant impact on the property value function is identified. If more than one value of  $t$  is associated with a statistically significant impact, the year associated with the greatest level of statistical significance is reported.

## 5.2 Data

Housing data for 1992 through 2002 were obtained from the town clerk of West Milford, New Jersey. After cleaning the raw data there were 4,373 usable observations. Available in the data were sales prices and the date each residential property was sold. Structural housing characteristics included square footage of living area, number of bedrooms, number of bathrooms, the year the house was built, and whether the basement and/or attic had been finished. The data also included the size of the parcel in acres.

The average sale price in the sample was \$177,752 (nominal dollars). Dummy variables were included in the model specification for the year of sale. The parameter estimates on these variables control for housing price inflation in this market.

Landsat satellite imagery, at a resolution of 30m<sup>2</sup>, was used to construct land cover and land use variables for each individual parcel. At this degree of spatial resolution, observations on land cover variables represent groups of trees or other cover types and do not represent individual trees. Land cover variables were measured in acres. Variables used in the model specification include highly developed land, medium and low development, deciduous forest cover, hemlock forest cover, other (non-hemlock) coniferous forest cover, mixed (deciduous and other coniferous) forest cover, agricultural land, wetlands, and area covered by streams, ponds, and lakes. Roughly 8 percent of the total land area in West Milford was

covered by hemlocks. Of the total number of observations in the cleaned data set, 329 observations were for parcels with the hemlock cover type present.

Hemlock health data were available for the years 1992-2002 (fig. 11.1). Four hemlock health classes were created from the remote sensing data: (1) a combination of healthy and lightly defoliated hemlocks (less than 25 percent defoliation), (2) moderately defoliated hemlocks (25-50 percent defoliation), (3) severely defoliated hemlocks (50-75 percent defoliation), and (4) dead hemlocks (greater than 75 percent defoliation). Although a mix of healthy and unhealthy (moderately defoliated, severely defoliated, and dead) hemlocks was identified on parcels sold throughout this period, it is apparent that hemlock health declined rapidly on parcels sold in 2000 and subsequent years.

Descriptive statistics for land cover variables at the parcel level are shown in table 11.3. The average parcel sold during the study period was approximately 0.6 acres in size. On average, the most common land cover on parcels sold was low and medium development, followed by deciduous forests. Stands of hemlocks occupied about 7 percent of the land area, on average, on sales parcels. However, parcels with hemlocks were somewhat larger than average (0.8 acres) and hemlock coverage was the dominant land cover on these parcels (0.5 acres).

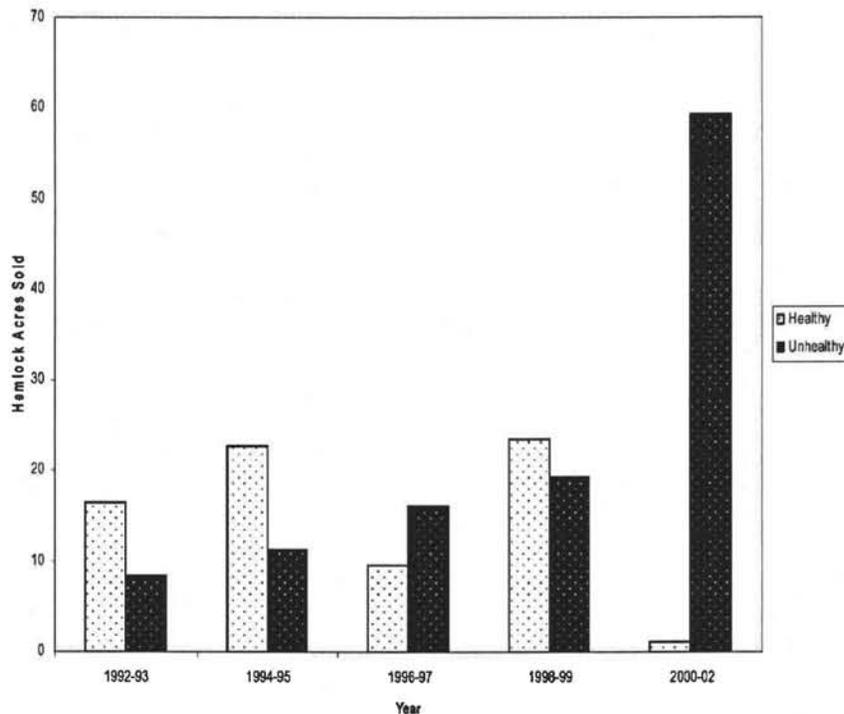


Figure 11.1. Area of healthy and unhealthy (moderately defoliated, severely defoliated, and dead) hemlocks on parcels sold, by time period for West Milford, NJ.

**Table 11.3. Descriptive statistics for land cover variables in West Milford, NJ.**

Variable Name	Symbol	Mean	Std. Dev.
Hemlock forest (ac.)	<i>h_forest</i>	0.039	0.197
Hemlock threshold (ac.)	<i>h_threshold</i>	0.012	0.107
Deciduous forest (ac.)	<i>d_forest</i>	0.159	0.503
Other coniferous forest (ac.)	<i>oc_forest</i>	0.001	0.017
Mixed forest (ac.)	<i>m_forest</i>	0.024	0.124
Wetland (ac.)	<i>wetland</i>	0.017	0.126
Other water (ac.)	<i>o_water</i>	0.003	0.024
Agriculture (ac.)	<i>ag</i>	0.002	0.019
Development: high (ac.)	<i>dev_high</i>	0.006	0.032
Development: low/med (ac.)	<i>dev_lm</i>	0.357	0.296
Grass (ac.)	<i>grass</i>	0.001	0.020

Similar to hemlock forest cover, other coniferous and mixed forest stands were, on average, relatively scarce across the entire sample. Wetlands, lakes/ponds, agricultural land, and grass held minor, but potentially important, positions in the distribution of land cover types represented in the sales records.

### 5.3 Results

Results of the OLS regression model are shown in table 11.4. Although not included in the table, all of the parameters for structural housing characteristics except "finished basement" were significant at the 1 percent level, with the expected signs. Additionally, all of the time dummy variables that were used to control for house price inflation were significant at the 1 percent level.

The model fits the data relatively well, with an  $R^2$  value of 0.58, and the results indicate that several land cover variables are capitalized into property values. Parameter estimates for deciduous forest cover, mixed forest cover, water, agricultural land, grass, high development, and low and medium development were statistically significant at the 10 percent level or higher. The parameter estimate for hemlock forests during the period early on in the HWA outbreak was not significantly different than zero (indicating that hemlock forests during this period did not add to or subtract from property value). However, the parameter estimate on hemlock forests late in the epidemic was negative and significant at the 5 percent level. The best fitting model indicated that the decline in hemlock health crossed a threshold for sales occurring during and subsequent to the year 2000, which is consistent with the distribution of hemlock health classes shown in figure 11.1. In particular, the results indicate that a one acre increase in the area of hemlock decreases property value by 8.3 percent during this period. This loss in value is presumably due to the presence of severely defoliated and dead hemlocks which detract from the aesthetic quality of the landscape.

**Table 11.4. OLS results for West Milford, NJ. Dependent variable is the natural log of price.**

Variable	Estimate	p > $\chi^2$
<i>h_forest</i>	-0.036	0.184
<i>h_threshold</i>	-0.083	0.036 **
<i>d_forest</i>	0.018	0.100 *
<i>oc_forest</i>	-0.127	0.794
<i>m_forest</i>	0.072	0.041 **
<i>wetland</i>	-0.009	0.809
<i>o_water</i>	0.576	0.005 **
<i>ag</i>	0.409	0.013 **
<i>dev_high</i>	0.495	0.013 **
<i>dev_lm</i>	0.155	<0.0001 **
<i>grass</i>	-0.538	0.081 *
<i>R</i> <sup>2</sup>	0.58	
<i>No. of obs.</i>	4,373	

Note: \*\* denotes significance at 5%, \* at 10%.

## 6. MANAGEMENT AND POLICY IMPLICATIONS

The effect of a disturbance on property markets is one component of its overall economic impact. For example, Butry et al. (2001) estimate that the 1998 wildfires in northeastern Florida, which burned approximately 500,000 acres and which were concentrated in the St. John's Water Management District, resulted in \$600 to \$800 million in economic losses. This estimate includes \$10 to \$12 million in insured property losses but no realized losses from the sale of undamaged property. The results presented here from the wildfire and hemlock woolly adelgid case studies reveal statistically significant disturbance-induced impacts to housing prices beyond those related to the structural damage to the house. Although disturbance price impacts may be transient and are unrealized by the household until a sale, any realized losses (or gains) unrelated to insured damages warrant inclusion in economic analyses of disturbance events.

Aggregation of disturbance impacts across a property market must be done with care, as specific assumptions about the stability of the hedonic price schedule must be acknowledged. Bartik (1988) and Freeman (1993) suggest models for calculating the social welfare change from a change in amenity using HPMs. The transient nature of some disturbance impacts implies that there is a transfer of wealth from the seller to the buyer if a sale occurs before price returns to the pre-disturbance level. In the case of the Chelan fires, the 421 residential properties that sold in the first half of 1995 experienced a total decline in sales price of almost \$6.9 million compared to a hypothetical sale date in the second half of 1994 assuming all else equal. This figure does not include impacts from decreased amenity values.

In the case of the HWA outbreak in West Milford, New Jersey, the 104 properties that sold after the threshold year 2000 experienced a total loss of about \$1.2 million relative to sales of parcels with hemlocks before that period. This loss is presumably due to a loss in amenity value as well as pending costs associated with restoring the site to a desirable condition. As such, it is reasonable to propose that property owners with stands of hemlock that did not sell their property during this period likewise experienced a utility loss and other associated damages, although such losses were not capitalized into property values because a sale did not occur.

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