Wildfire in Hedonic Property Value Studies

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Introduction

An expanding wildland-urban interface (WUI)[4] coupled with increased frequency and severity of wildfires has increased the importance of estimating the economic impacts of wildfires. Economic impacts need to be investigated to justify the rapid increase in wildfire suppression costs and inform other wildfire management decisions. Hedonic property modeling is a method that uses changes in property values to estimate the costs (or benefits) associated with wildfire. It is a unique tool that can help inform novel wildfire management and provide insight into ways to balance the social-ecological costs and benefits of wildfire. In this paper, we review hedonic property studies estimating the economic effects of wildfire.

The market costs of wildfire suppression and protection are substantial. Federal fire suppression and protection costs average more than 3 billion dollars per year, consuming almost half of the U.S. Forest Service's annual budget (Gorte 2013). In many western forests, wildfires are an integral ecological driver, resetting forest succession and fostering ecological heterogeneity (Turner 2010). However, western wildfires are becoming more frequent and larger as climate warms. These trends are projected to continue over the 21st century (Westerling et al. 2006, 2011). Wildfires burned approximately 2.75 million ha per year since 2000, more than double the 1990s average (Weeks 2012). Policymakers are therefore under increasing pressure to develop strategies that cost effectively balance protection of WUI property with maintaining the ecological necessity of wildfire (Stephens et al. 2013).

The WUI are areas where at least six homes per square km are interspersed among natural vegetation (Radeloff et al. 2005, Stewart et al. 2007). WUI expansion in the western U.S. often occurs where wildfires burn at high intensity and are difficult to suppress (Theobald and Romme 2007). Developing cost-effective management strategies therefore requires improving understanding of how WUI homeowners perceive and respond to wildfires (Steelman et al. 2004, Sturtevant and Jakes 2008, Hansen and Naughton 2013). Often, policymakers assume humans respond negatively to wildfire. Yet, increasing evidence suggests people evaluate complex tradeoffs between amenities enhanced and degraded by wildfire (Donovan et al. 2007). Geographic variation in fire-regime characteristics also makes developing effective uniform policy problematic because diverse fire-regime characteristics likely influence WUI residents

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[4] WUI is defined as "the area where houses meet or intermingle with undeveloped wildland vegetation" (Radeloff et al. 2005).

differently (Chapin et al. 2008). Finally, actually experiencing wildfire is often still rare, increasing the challenge of fostering public investment (Gill et al. 2013, Hughes et al. 2013).

Wildfire is essential for shaping the structure and function of many ecosystems. It determines vegetation composition, creates wildlife habitat, and alters biogeochemical cycling (Turner et al. 1998, 2003, Turner 2010). Wildfires are often described by their severity (or ecological impact), size, and frequency of occurrence. These characteristics of wildfire can vary greatly by ecosystem (Stephens et al. 2013). For example, wildfires occur as frequently as once every one to five years in grassland ecosystems to once every 300 years, or longer in some coniferous forests (Turner et al. 2003, Schoennagel et al. 2006, Stephens et al. 2013). The characteristics of wildfire determine effects on environmental amenities and dis-amenities provisioned to people, such as carbon storage, timber production, and forest aesthetics (Chapin et al. 2003, Gallant et al. 2003, Hunt and Haider 2004, Balshi et al. 2009). Wildfire also responds strongly to changes in climate. Temperatures are expected to warm substantially over the 21st century, and will likely increase the frequency, size, and severity of wildfire (Westerling et al. 2006, 2011). For example, across the North American boreal forest, annual area burned is expected to increase by 74 to 118% by the end of the 21st century (Flannigan et al. 2005, Balshi et al. 2008). How ecosystems and environmental amenities are affected is therefore likely to vary in complex ways as a function of historical fire characteristics and the magnitude of climate-induced change in fire characteristics (Turner et al. 2013). These changes in wildfire will have important ecological ramifications that will affect people in profound ways.

Despite growing need for high-impact economic research on wildfire-human interactions, the wildfire-economics literature is new and relatively sparse. Primary journals of the American Economics Association[5] have currently published no articles on wildfire. Only six wildfire studies are published in two leading environmental economics journals *The Journal of Environmental Economics and Management* and *Environmental and Resource Economics*.[6] Wildfire economics is better represented in other environmental journals such as *Land Economics*, *Ecological Economics,* and *Journal of Forest Economics*.[7] Of note, high impact journals, such as *Science* magazine have published 26 articles containing both terms “wildfire” and “economics.” The lack of high-impact wildfire-economics publications in leading disciplinary journals, despite clear need, highlights extensive opportunities for research.[8] The outline of this paper is as follows. We briefly introduce the ecological impacts and economics of wildfires. We then discuss current wildfire hedonic property model literature in detail. We conclude by identifying challenges and opportunities in employing the hedonic property method for wildfire valuation in the future.

Wildfire Economics

A comprehensive review of forest-disturbance economics, with a heavy focus on wildfire economics, was compiled by Holmes et al. (2008) in *The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species*. The book advocates for improved connection between

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[5] These are American Economic Journal: Applied Economics, American Economic Journal: Macroeconomics, American Economic Journal: Microeconomics, American Economic Journal: Economic Policy, Journal of Economic Perspectives, Journal of Economic Literature, and American Economic Review.
[6] Journal rankings according to Kodrzycki and Yu (2006).
[7] The full content search for “wildfire” in these journals resulted in 20, 44 and 23 articles, respectively.
[8] This need is also represented in the Joint Fire Science Program’s 2014 Funding Opportunities Notices to advance fire social sciences, see the following link for more information:
http://www.firescience.gov/JFSP_funding_announcements.cfm?pass_fiscal_year=2014

economic and ecological models. Economic valuation of forest disturbance is another major theme emphasized for its role in making management decisions and setting policy priorities. The review finds that too few valuation studies have been completed. Finally, Holmes et al. (2008) suggest improved fire management programs can lower costs and increase benefits to society. Further, management programs need to be evaluated in an integrated system that considers market and non-market values as well as ecological effects of wildfire.

Wildfire effects span relatively easy to measure economic impacts, e.g., suppression expenditures, to more difficult to measure use and non-use values.[9] Use and non-use values include foregone recreation opportunities such as hiking, hunting, and camping, and ecosystem services.[10] To implement efficient wildfire policy, the nonmarket effects of wildfire need to be quantified. Economists appeal to non-market valuation to obtain the total economic effects of wildfire, including use and non-use values. Non-market valuation is based on revealed or stated preferences. Revealed preference models estimate non-market values based on observed data. Stated preference models estimate non-market values using survey instruments.[11] While stated and revealed preference models each have strengths and limitations, a thorough analysis of how these methods apply to the non-market valuation of wildfire is beyond the scope of this paper, and yet another potential area of further research.[12] However, it is well established that a large number of homeowners in the WUI are directly experiencing the impacts of more frequent wildfires in the US. Furthermore, the costs of wildfire suppression are positively related to protecting properties within the WUI (Liang et al. 2008). We therefore focus on wildfire in hedonic property models.

Hedonic Property Models

The hedonic property model estimates the value of different environmental characteristics, such as proximity to wildfire, by examining their impact on nearby housing or land prices. Rosen (1974) formalized the theoretical framework for the hedonic property model. This framework is based on the proposition that identical houses in similar neighborhoods are valued differently if the houses have varying levels of an environmental amenity or dis-amenity. Hedonic property models are considered revealed preference models of non-market valuation because via the house price, the researcher observes the monetary trade-off a consumer is willing to make to obtain certain housing characteristics (Taylor 2003). The hedonic property model formalizes the familiar idea that we expect houses with an environmental amenity, such as an ocean view, to have higher selling prices than houses without an ocean view.

Hedonic property models have been used to value a range of amenities and dis-amenities, including: heterogeneity in public lands (Ham et al. 2012), environmental amenities and agricultural land value (Wasson et al. 2013), open space and water resource ownership (Netusil 2013); water quality (Leggett and Bockstael 2000), and even nuclear waste transport (Gawande and Jenkins-Smith 2001). Forest-related HPMs include estimating the value of forest fuel reduction in Arizona (Kim and Wells 2005), and forest proximity and management practices

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[9] See Barrio and Louriero (2010) for a meta-analysis of contingent valuation forest studies.

[10] See Loomis (2005) for an updated meta-analysis of recreational use values on national forests and public lands.

[11] See Venn and Calkin (2011) for a wider of review research related to non-market effects of wildfires.

(Kim and Johnson 2002). Despite the depth and breadth of hedonic property models in the environmental economics literature, we find little consensus on effects of wildfire from hedonic property studies. While hedonic property studies vary somewhat in method of estimation and specific variables, all follow the general format:

$$P_{it} = f\,(S_{it},\, N_{it},\, E_{it}) \qquad (1)$$

where the value of property i in period t (P_{it}) is estimated as a function of the structural characteristics of the property (S_{it}), neighborhood demographics (N_{it}) and environmental variables (E_{it}). In order to determine the marginal implicit price using a hedonic property model, it is necessary to control for other characteristics that determine house price or property value, including structural characteristics, neighborhood demographics, and housing market trends.[13] The resulting house price differential between houses with varying levels of an environmental amenity or dis-amenity is homebuyers' marginal willingness to pay, or the marginal implicit price.

Specification and method of estimation of hedonic property models is a well-established area of research spanning decades (Cropper et al. 1998). Most hedonic property models estimate equation (1) above, which provides the marginal prices of environmental amenities. If sufficient data are available, these first-stage parameters can be used to estimate a second-stage model of inverse demand function for these amenities (Rosen 1974). Studies that estimate both stages of the hedonic property model include Garrod and Willis (1992), Chattopadhyay (1999), Mahan et al. (2000) and Netusil et al. (2010). None of the wildfire hedonic property models to date estimate the second-stage model. Most hedonic studies, including the wildfire hedonic studies we discuss below, use semi-log specifications with the natural log of P_{it} as the dependent variable. Furthermore, Ordinary Least Squares (OLS) and Maximum Likelihood (ML) are the most popular estimation methods. Of the wildfire hedonic studies discussed next, Loomis (2004) and Mueller et al. (2009) use OLS, and the remaining papers use ML.[14]

Wildfire in Hedonic Property Models

Wildfire in the western U.S. has become increasingly prevalent on landscapes. Hedonic property models have been employed across many ecosystems ranging from southern California to Alaska. Thus far, results of the hedonic property model literature align with Spash and Vatn's (2006) conclusion that non-market values of wildfires cannot be transferred across regions because social and cultural preferences associated with wildfire and characteristics of wildfires are heterogeneous.

In the 1990s, the WUI near Los Angeles, California experienced five wildfires burning a total of around 1,100 ha. Employing property sales data from 1989-2003, Mueller and Loomis (2008), and Mueller et al. (2009) find negative effects of wildfire. Because of repeated fires in a small area, these studies are able to identify a drop in sales prices following the first and another drop following a second fire within 1.75 miles of a property. The consistent negative effects of fire may be explained by the moderate- to high-fire frequency in the region (Keeley 2006). Following a fire in the chaparral dominated landscape of Southern California, there is little decrease in

[13] See Taylor (2003) and Palmquist (1991) for a comprehensive discussion of the theoretical aspects of hedonic property models.

[14] A more detailed discussion of specification and methods of estimation is beyond the scope of this paper.

subsequent fire risk. Thus, from a homebuyers' perspective, the reminder of fire risk outweighs any potential long-term ecological benefits, resulting in a drop in house price.

In Colorado, fire frequency varies with elevation, from lower elevation ponderosa pine forests, that burn relatively frequently, to higher elevation conifer forests that burn less frequently (Veblen et al. 2000, Romme and Knight 1981). In 1996, the Buffalo Creek fire burned almost 5,000 ha, destroying 10 houses two miles from Pine, Colorado. In the first published study estimating the impacts of wildfire on house prices, Loomis (2004) found that property values in the nearby town of Pine decreased by an average of 15%. The author cites an increased perceived fire risk and reduced recreational and aesthetic amenities as potential reasons for negative effects.[15]

In 2002 the Colorado Springs fire department used a website to make public estimated wildfire risk to 35,000 WUI homeowners. Risk was calculated based on environmental and home characteristics. Using home sale prices pre-website (1998-2001) and post-website (2002-2004), Donovan et al. (2007) estimate the economic value associated with property characteristics. Some determinants of wildfire risk, e.g. dangerous topography near homes, changed little post-website. The positive and statistically significant effect of dangerous topography on sales prices endures pre and post-website. This suggests that property owners on ridges with higher wildfire risk and better vistas may have been aware of the wildfire risks associated with living on the ridge, or once they became aware, the vistas still outweighed the risk. Conversely, the value of wood roofs and siding (important contributors to homes' risk of catching fire) became negative post-website. The latter finding highlights potential opportunities for public education related to wildfire risk.

In the northern Rocky Mountains, Stetler et al. (2010) estimate the impacts of 256 wildfires on house prices across 4 million ha of northwestern Montana, between 1996 and 2007. Similar to California and Colorado, the authors find that proximity to wildfire and view of burned area has a "persistent negative effect" on house prices. Interestingly, Stetler et al. (2010, pp. 2241-2242) find evidence of "out of sight, out of mind" mentality with respect to wildfire. Many coefficients estimating economic value associated with higher wildfire risk (e.g. canopy cover) are negative and statistically significant for the subsample of homes *with views of past fire* but become statistically insignificant for the subsample of homes *without views of past fire*. This suggests public education campaigns, similar to those in Colorado Springs, could improve knowledge, fostering private proactive fire-mitigation strategies, particularly for properties *without views of past fire*.

Exploring the effect of 33 large wildfires (>3.3 ha) and 1160 small wildfires (<3.3 ha) that burned on the western Kenai Peninsula, south-central Alaska, between 1990 and 2010, Hansen and Naughton (2013) find wildfires can actually increase property values. Using assessed property-value data for 2001 and 2010 reveals small wildfires decrease property values while large wildfires increase values on Kenai Peninsula. Furthermore, they find the estimated positive effect of large wildfires does not appear until five years after fire. They speculate that, while small wildfires have little impact on forest density, large wildfires could open up aesthetically pleasing views of mountains and Cook Inlet beyond. Further, fire frequency is lower in white spruce of the Kenai compared to ecosystems in California and Colorado (Berg and Anderson 2006). Thus, people on the Kenai may evaluate risk of subsequent fire in different ways, compared to other study sites.

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[15] Of note, the Buffalo Creek fire was followed by a devastating flash flood two months later that destroyed the town's water treatment system and main highway. Thus, it is difficult to separate the effects of flooding versus fire on property values in this study.

Table 1. Summary of reviewed wildfire hedonic property models.

Study	State	Direction of effect on property values	Percentage change in property values (if reported) and distance to wildfire	Historical fire characteristics	Number of Observations
Loomis 2004	CO	Negative	15% for wildfire within 2 miles	Moderate to infrequent wildfire [2.]	504
Mueller et al. 2009	CA	Negative	10% for first, 23% for second wildfire within 1.75 miles	Moderate to high frequency wildfire[1.]	2,520
Stetler et al. 2010	MT	Negative	7.6% for homes within 5k and 13.7% for homes between 5k and 10k	Moderate to infrequent wildfire[3.]	11,817
Donovan et al. 2007*	CO	Conflicting	Percentage not reported, all homes within a 45 mile radius WUI area	Moderate to infrequent wildfire[2.]	9,903
Hansen and Naughton 2013	AK	Conflicting	18.6% increase for large wildfire within 0.1 k, 5.5% decrease for small wildfire within 0.1k, 2.4% increase for small wildfire within 0.1 and 0.5k	Infrequent wildfire[5.]	8,796

*This study explicitly addresses the risk versus amenity tradeoff. [1.] (Keeley 2006) [2.] (Loomis et al. 2000, Romme and Knight 1981) [3.] Stetler et al. 2010, Brown et al. 2004. [4.]Everett et al. 2000. [5.] Berg and Anderson 2006.

Challenges, Opportunities and Conclusion

Our review suggests impacts of wildfire on home values vary by ecosystem and may influence amenity values for homes differently. Many appealing amenities are also associated with higher wildfire risk. We find this in the conflicting estimated implicit prices—after wildfires in certain ecosystems home values increase, in other areas home values decrease. To encourage further research, we conclude with key challenges and future opportunities summarized in Table 2 below.

Table 2. Identified challenges and proposed research opportunities in future wildfire hedonic property models (HPMs).

	Description	Recommendations
Challenges		
Spatial dependence	Not resolved how important spatial dependencies are in wildfire HPM and how they should be statistically analyzed.	Apply current spatial-econometric best practices to wildfire HPMs.
Data availability	Property sales data are not publically disclosed in many states.	Use sales data to evaluate suitability of assessed property values.
Opportunities		
Varying fire characteristics	Frequency, size and severity of wildfire varies profoundly across ecosystems.	Determine how variation in wildfire frequency and severity affects property values differently.
Amenities affected	Studies often quantify the effect of wildfire itself.	Identify amenities affected and incorporate into HPMs.
Amenity versus Risk Tradeoffs	Relative importance of amenities versus risk unclear.	Integrate ecological study, statistical tools, and survey results to explicitly incorporate risk and amenities into HPMs.

Spatial dependence within housing and property data inherently confound hedonic property studies. However, the extent to which spatial dependencies impact estimated values and how they should be modeled is not yet resolved. If the data generating process exhibits spatial dependence, failure to allow for the dependence may cause biased and inefficient coefficient estimation (Brasington and Hite 2005). LeSage and Pace (2009) argue for the spatial Durbin model when estimating equations with potential spatial dependence in the data generating process (Elhorst 2010). Ham et al. (2012) apply a joint spatial lag and error model in a hedonic property model estimating the value of public lands, whereas Wasson et al. (2013) apply a two-step feasible generalized least squares in a hedonic property model estimating the impact of environmental amenities on agricultural land. Other recent developments in spatial econometrics, however, argue for the spatial error model (Glass et al. 2012). In addition, some studies suggest incorporating nonstationarity in spatial processes (Chadourne et al. 2013). For current wildfire hedonic property models, Hansen and Naughton (2013) use the spatial lag model while Mueller and Loomis (2008) present the spatial error model. Mueller and Loomis (2010) consider the spatial Durbin model, however their specification criteria reject the spatial Durbin model in favor of the spatial error model. Since the non-market values of wildfire from hedonic property models are a direct function of the estimated statistical model, reliable and accurate measurements are essential for informing management policies. Current literature shows that explicit spatial modeling is likely necessary to obtain reliable and accurate measurements of the effects of wildfire from hedonic property models, however there is not a consensus on the preferred spatial model.

A second challenge is the confidentiality of property sales price data. Law prevents fourteen states from publically disclosing sales data.[1] For these states the tax-purpose assessed property value data have been used instead. While the mainstream hedonic property models overwhelmingly favor sales data, the superiority of sales data is debatable (e.g. Kim and Goldsmith 2009, Ma and Swinton 2012).

> “The presumed superiority of individual transaction data over non-market estimates […] is based on the [heroic] assumption that the housing market is in an equilibrium in which all opportunities for possible gains from further trade at the revealed set of prices have been exhausted (Freeman 2003, p. 361).”

According to Freeman (2003) and Horowitz (1986) this assumption about sales data does not hold in the real world. It is also not clear whether assessed property values approach an equilibrium price. However, assessed values are a practical alternative that make hedonic property studies possible in non-disclosure states. Assessment processes and models vary by states and assessors offices. Therefore, it is possible that the superiority of assessed property values over sales data in hedonic property studies, found in a number of studies (see Kim and Goldsmith 2009, Ma and Swinton 2012), may not be universally applicable. Further research, comparing sales versus assessed property values is warranted. Regardless, widely accessible and appropriate housing data is central to effectively using hedonic property models to inform wildfire policy.

Despite challenges, we identify several exciting opportunities for wildfire hedonic property studies to pursue, including:

- *Varying fire characteristics:* The lack of consistent results in the literature suggests that future research is needed to distinguish how varying wildfire frequency, size, and severity across ecosystems influence property values differently (Fig. 1). Within ecosystems, researchers must better quantify how wildfire effects vary spatially (distance from fire) and temporally (time since fire).
- *Amenities affected:* The next generation of wildfire hedonic property models must go beyond quantifying effects of the wildfire itself. Researchers need to identify suites of amenities affected by fire, how they change, and whether people value the affected amenities. For example, In Alaska, it is likely that fire led to aesthetically pleasing views increasing property values and outweighing negative effects (Hansen and Naughton 2013). In contrast, in Montana, views of wildfire decreased property values (Stetler et al. 2010).
- *Amenity versus Risk Tradeoffs:* Further, researchers need to evaluate whether tradeoffs exist between amenity and risk. A forested view, highly sloped property, and wooden

[1] The states are Alaska, Idaho, Indiana, Kansas, Louisiana, Maine, Mississippi, Missouri, Montana, New Mexico, North Dakota, Texas, Utah and Wyoming.

roofing can have high amenity value. However, wildfire risk associated with these characteristics is also high, resulting in conflicting amenity versus risk value. The hedonic property model is well established to estimate implicit prices for wildfire. However, it is difficult to measure amenity- and risk-value tradeoffs (Donovan et al. 2007). Rigorously incorporating tradeoffs will likely require interdisciplinary research, integrating ecological study, statistical tools and survey techniques.

Climate-driven changes to wildfire and continued WUI expansion are leading to increasingly intractable conflict. Solutions will require improved information on how people respond to wildfires under different social and geographic contexts. Wildfire hedonic property models could contribute to developing effective strategies that successfully balance human-wildfire interactions. However, continued development of the hedonic approach, including incorporating both ecological and economic elements, is needed for substantial contributions in wildfire management.

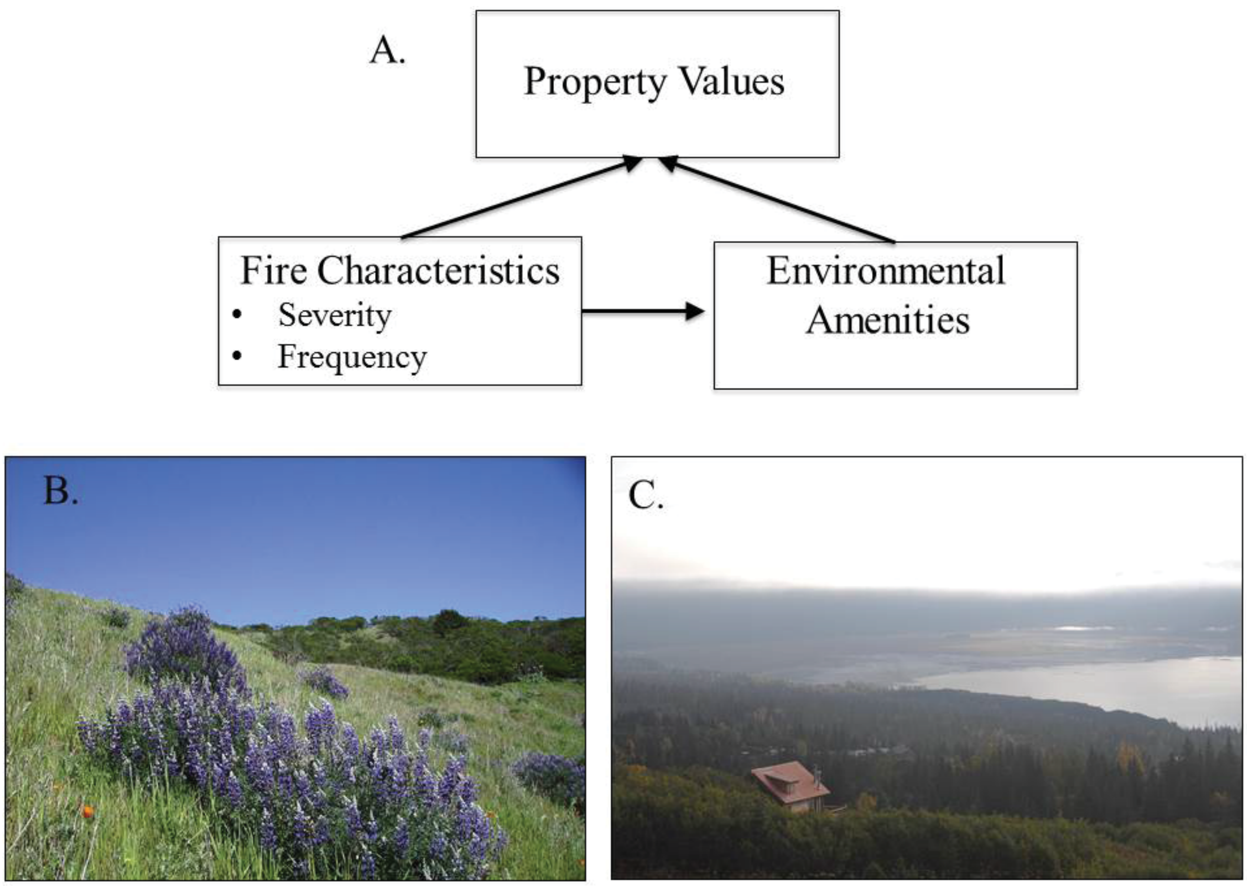

Figure 1. Wildfire effects on property values vary geographically. A. Wildfire effects on property values are a function of fire characteristics such as fire severity and frequency, perceived risk, and amenities. Characteristics of fire contribute to perceived risk and also affect environmental amenities important to people. **B.** In California, grassland-chapparal, fires occur relatively frequently. In this system, the occurrence of fire can serve to remind people of fire risk. However, one wildfire does not preclude the occurrence of subsequent fire. Thus, perceived risk may outweigh any effects on amenities. Photo by B. Harvey. **C.** On the Kenai Peninsula, Alaska, white/Lutz spruce forests also experience wildfire. Historically, however, fires burn much less frequently than the California Chaparral. In this system, the occurrence of fire may lower peoples' perceived risk of subsequent fire. Amenities may dominate effects on property values. Some amenities may be enhanced by fire, others may be degraded. Amenities will be contextually dependent on the system. Photo by W.D. Hansen.

References

Abt, K.L., Huggett, R.J., Holmes, T.P. (2008) Designing Economic Impact Assessments for USFS Wildfire Programs. in Holmes, T.P., Prestemon, J.P., Abt, K.L., eds. (2008) *The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species*. Forestry Sciences series, vol. 79. Springer, New York, NY.

Balshi, M.S., McGuire, A.D., Duffy, P., Flannigan, M., Walsh, J., Melillo, J. (2008) Assesssing the response of area burned to changing climate in western boreal North America using a multivariate adaptive regression splines (MARS) approach. *Global Change Biology* 15:578-600.

Balshi, M., McGuire, A., Duffy, P., Flannigan, M., Kicklighter, D., and Melillo, J. (2009) Vulnerability of carbon storage in North American boreal forests to wildfires during the 21st century. *Global Change Biology* 15:1491-1510.

Barrio, M. Loureiro, M. (2010) A Meta-Analysis of contingent valuation forest studies. *Ecological Economics* 69:1023-1030.

Berg, E.E., Anderson, R.S. (2006) Fire history of white and Lutz spruce forests on the Kenai Peninsula, Alaska, over the last two millennia as determined from soil charcoal. *Forest Ecology and Management* 227:275-283.

Brasington, D.M., Hite, D. (2005) Demand for environmental quality: A spatial hedonic analysis. *Regional Science and Urban Economics* 35:57–82.

Brown, R.T., Agee, J.K., Franklin, J.F. (2004) Forest restoration and fire: Principles in the context of place. *Conservation Biology* 18:903-912.

Chadourne, M., Cho, S.H., Roberts, R.K. (2013) “Identifying priority target areas for the Knoxville-Knox County hillside and ridgetop protection plan: using the value of visual amenity during the real estate boom of 2002-2007 and the recession of 2008. *Annals of Regional Science* 50:911-934.

Chapin III, F.S., Rupp, T.S., Starfield, A.M., DeWilde, L., Zavaleta, E.S., Fresco, N., Henkelman, J., McGuire, A.D. (2003) Planning for resilience: Modeling change in human-fire interactions in the Alaskan boreal forest. *Frontiers in Ecology and the Environment* 1:255-261.

Chapin III, F.S., Trainor, S.F., Huntington, O., Lovecraft, A.L., Zavaleta, E., Natcher, D.C., McGuire, A.D., Nelson, J.L., Ray, L., Calef, M. (2008) Increasing wildfire in Alaska’s boreal forest: pathways to potential solutions of a wicked problem. *BioScience* 58:531–540.

Chattopadhyay, S. 1999. Estimating the Demand for Air Quality: New Evidence Based on the Chicago Housing Market. *Land Economics* 75 (1): 22–38.

Cropper, M.L., Deck, L.B., McConnell, K.E. (1988) On the choice of functional form for hedonic price functions. *The Review of Economics and Statistics* (70)4: 668-675.

Donovan, G.H., Champ, P.A., Butry, D.T. (2007) Wildfire risk and housing prices: A case study from Colorado Springs. *Land Economics* 83:217–233.

Elhorst, P. (2010) Applied spatial econometrics: Raising the bar. *Spatial Economic Analysis* 5:9-28.

Flannigan, M., Logan, K., Amiro, B., Skinner, W., Stocks, B. (2005) Future area burned in Canada. *Climatic Change* 72:1-16.

Freeman, A.M. 2003. *The Measurement of Environmental and Resource Values: Theory and Methods*, second ed., Resources for the future, Washington, D.C.

Gallant, A.L., Hansen, A.J., Councilman, J.S., Monte, D.K., Betz, D.W. (2003) Vegetation dynamics under fire exclusion and logging in a Rocky Mountain watershed, 1856-1996. *Ecological Applications* 13:385-403.

Garrod, G., Willis, K. 1992. The Environmental Economic Impact of Woodland: A Two-Stage Hedonic Price Model of the Amenity Value of Forestry in Britain. *Applied Economics* 24 (7): 715–28.

Gawande, K., Jenkins-Smith, H. (2001) Nuclear Waste Transport and Residential Property Values: Estimating the Effects of Perceived Risks. *Journal of Environmental Economics and Management* 42:207-233.

Gill, A.M., Stephens, S.L., Cary, G.J. (2013) The worldwide "wildfire" problem. *Ecological Applications* 23:438–454.

Glass, A.J., Kenjegalieva, K., Sickles, R. (2012) The economic case for the spatial error model with an application to state vehicle usage in the U.S., Rice University manuscript.

Gorte, R. (2013) *The Rising Cost of Wildfire Protection*. Bozeman, MT.

Ham, C., Champ, P.A., Loomis, J.B., Reich, R.M. (2012) Accounting for heterogeneity of public lands in hedonic property models. *Land Economics* 88(3):444-456.

Hansen, W., Naughton, H. (2013) The effects of a spruce bark beetle outbreak and wildfires on property values in the wildland-urban interface of South-central, Alaska, USA. *Ecological Economics* 96:141-154.

Holmes, T.P., Prestemon, J.P., Abt, K.L., eds. (2008) *The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species*. Forestry Sciences series, vol. 79. Springer, New York, NY.

Horowitz, J. L. (1986) Building models of housing markets. *Journal of Urban Economics* 20: 168-190.

Hughes, T. P., Linares, C., Dakos, V., van de Leemput, I., van Nes, E.H. (2013) Living dangerously on borrowed time during slow, unrecognized regime shifts. *Trends in Ecology & Evolution* 28:149–55.

Hunt, L.M., Haider, W. (2004) Aesthetic impacts of disturbances on selected boreal forested shorelines. *Forest Science* 50:729-738.

Keeley, J. (2006) South Coast Bioregion. Pp. 350-390 in Sugihara, N.G., Van Wagtendonk, J.W., Shaffer, K.E., Fites-Kaufman, J., Thode, A.E., eds., *Fire in California's ecosystems*, University of California Press, Berkley and Los Angeles, CA.

Kim, J., Goldsmith, P. (2009) A spatial hedonic approach to assess the impact of swine production on residential property values. *Environmental Resource Economics* 42:509-534.

Kim, Y.S., Johnson, R.L. (2002) The Impact of Forests and Forest Management on Neighboring Property Values. *Society and Natural Resources* 15: 887-991.

Kim, Y.S., Wells, A. (2005) The impact of forest density on property values. *Journal of Forestry* 103(3):146-151.

Kodrzycki, Y.K., Yu, P. (2006) New approaches to ranking economics journals. *Contributions to Economic Analysis & Policy* 5:Article 24.

Leggett, C., Bockstael, N. (2000) Evidence of the effects of water quality on residential land prices. *Journal of Environmental Economics and Management* 39:121-144.

LeSage, J., Pace, R.K. (2009) *An Introduction to Spatial Econometrics*. CRC Press, Boca Raton, 2009.

Liang, J., Calkin, D.E., Gebert, K.M., Venn, T.J., Silverstein, R.P. (2008) Factors influencing large wildland fire suppression expenditures. *International Journal of Wildland Fire* 17:650-659.

Loomis, J.B. (2004) Do nearby forest fires cause a reduction in residential property values? *Journal of Forest Economics* 10:149-157.

Ma, S., Swinton, S.M. (2012) Hedonic valuation of farmland using sale prices versus appraised values, *Land Economics* 88:11-15.

Mahan, B.L., Polasky, S., Adams, R.M. 2000. Valuing Urban Wetlands: A Property Price Approach. *Land Economics* 76(1): 100–13.

Mueller, J.M., Loomis, J.B. (2008) Spatial dependence in hedonic property models: Do different corrections for spatial dependence result in economically significant differences in estimated implicit prices? *Journal of Agricultural and Resource Economics* 33:212-231.

Mueller, J.M., Loomis, J.B., González-Cabán, A. (2009) Do repeated wildfires change homebuyers' demand for homes in high-risk areas? A hedonic analysis of the short and long-term effects of repeated wildfires on house prices in southern California. *The Journal of Real Estate Finance and Economics* 38:155-172.

Mueller, J.M., Loomis, J.B. (2010) Bayesians in space: Using Bayesian methods to iInform choice of spatial weights matrices in hedonic property analyses. *Review of Regional Studies* 40:245-255.

Netusil, N.R. Chattopadhyay, S., Kovacs, K.F. (2010) Estimating the demand for tree canopy: A second stage hedonic price analysis in Portland, Oregon. *Land Economics* 86 (2): 281-293.

Netusil, N.R. (2013) Urban environmental amenities and property values: Does ownership matter? *Land Use Policy* 31:371-377.

Palmquist, R. (1991) Hedonic Methods. Pp. 77-119 in Braden J., Kolstad, C. eds. *Measuring the Demand for Environmental Quality*. Elsevier Science Publishers, North Holland, Amersterdam.

Radeloff, V.C., Hammer, R.B., Stewart, S.I., Fried, J.S., Holcomb, S.S., McKeefry, J.F. (2005) The wIldland urban interface in the United States. *Ecological Applications* 15:799–805.

Romme, W.H., Knight, D.H. (1981). Fire frequency and subalpine forest succession along a topographic gradient in Wyoming. *Ecology* 62:319-326.

Rosen, S. (1974) Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy* 82:34-55.

Schoennagel, T., Turner, M.G., Kashian, D., Fall, A. (2006) Influence of fire regimes on lodgepole pine stand age and density across the Yellowstone National Park (USA) landscape. *Landscape Ecology* 21: 1281-1296.

Spash, C.L., Vatn, A. (2006). Transferring environmental value estimates: Issues and alternatives. *Ecological Economics* 60:379-388.

Steelman, T.A., Kunkel, G., Bell, D. (2004) Federal and state influence on community responses to wildfire threats: Arizona, Colorado, and New Mexico. *Journal of Forestry* 102:21–27.

Stephens, S.L., Agee, J.K., Fulé, P.Z., North, M.P., Romme, W.H., Swetnam, T.W., Turner, M.G. (2013) Managing forests and fire in changing climates. *Science* 342:41–2.

Stetler, K.M., Venn, T.J., Calkin, D.E. (2010) The effects of wildfire and environmental amenities on property values in northwest Montana, USA. *Ecological Economics* 69:2233-2243.

Stewart, S.I., Radeloff, V.C., Hammer, R.B., Hawbaker, T.J. (2007) Defining the wildland urban interface. *Journal of Forestry* 105:201–207.

Sturtevant, V., Jakes, P. (2008) Collaborative planning to reduce risk. Pp. 44–63 in Martin, W. Raish, C. Kent, B. eds. *Wildfire risk human perceptions and management implications*. Washington, DC: Resources for the Future.

Taylor, L. (2003) The Hedonic Method. Pp. 331-394 in Champ, P., Brown, T., Boyle, K. eds. *A Primer for Non-Market Valuation*, Dordrecht, The Netherlands: Kluwer.

Theobald, D.M., Romme, W.H. (2007) Expansion of the US wildland–urban interface. *Landscape and Urban Planning* 83:340–354.

Turner, M.G., Baker, W.L., Peterson, C.J., Peet, R.K. (1998) Factors influencing succession: Lessons from large, infrequent natural disturbances. *Ecosystems* 1:511-523.

Turner, M.G., Collins, S.L., Lugo, A.L., Magnuson, J.J., Rupp, T.S., Swanson, F.J. (2003) Disturbance dynamics and ecological response: the contribution of long-term ecological research. *Bioscience* 53:46-56.

Turner, M.G. (2010) Disturbance and landscape dynamics in a changing world. *Ecology* 91:2833–2849.

Turner, M., Donato, D., Romme, W. (2013) Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: Priorities for future research. *Landscape Ecology* 28:1081-1097.

Veblen, T.T., Kitzberger, T., Donnegan, J. (2000) Climatic and human influences on fire regimes in ponderosa pine forests in the Colorado Front Range. *Ecological Application* 10:1178-1195.

Venn, T.J., Calkin, D.E. (2011) Accommodating non-market values in evaluation of wildfire management in the United States: Challenges and opportunities. *International Journal of Wildland Fire* 20:327-339.

Wasson, J.R. , McLeod, D.M., Bastian, C.T., Rashford, B.S. (2013) The effects of environmental amenities on agricultural land values. *Land Economics* 89 (3): 466-478.

Weeks, J. (2012) Managing Wildfires. *CQ Researcher* 22:941–964.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., Swetnam, T.W. (2006) Warming and earlier spring increase western US forest wildfire activity. *Science* 313:940–943.

Westerling, A.L., Turner, M.G., Smithwick, E.A.H., Romme, W.H. Ryan, M.G. (2011) Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. *Proceedings of the National Academy of Sciences* 108:13165–13170.