



# Are we underestimating the economic costs of wildfire smoke? An investigation using the life satisfaction approach



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## ARTICLE INFO

### Article history:

Received 6 January 2017

Accepted 27 March 2017

### JEL classification:

Q51

Q53

I31

C21

### Keywords:

Wildfire smoke

Life satisfaction

Direct costs

Willingness to pay

Health

## ABSTRACT

Understanding the economic costs imposed by wildfire smoke is important to evaluating competing fire management approaches and setting appropriate mitigation budgets. The nascent literature on wildfire smoke costs has largely examined the indirect health costs associated with individuals' exposure to smoke. However, this ignores the direct costs of wildfire smoke, that is, the costs that smoke creates by directly affecting an individual's utility. Direct costs may arise from smoke-induced changes in visibility of scenic amenities or disruptions to ecosystem services that individuals see value in preserving. For the first time, the life satisfaction approach is applied to estimate wildfire smoke economic costs faced by individuals from direct and indirect sources. Using nationally-representative data from the US Behavioral Risk Factor Surveillance System over 2006–2010, results suggest that US adults are willing to pay \$373 [95% CI: \$86.8, \$659.2] to avoid one day of wildfire smoke over their county of residence within a six month period. Residents of rural areas are willing to pay \$130 more to avoid one smoke day than urban residents. These results are higher than extant willingness to pay estimates of indirect smoke-induced health impacts, suggestive that the true costs of wildfire smoke are larger than previously estimated.

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## Introduction

“Understanding the economic and ecological costs and impacts of fire management and bushfires is a key research frontier, given the increasing occurrence of highly destructive wildfires and ballooning fire-fighting budgets.”

As the frequency and severity of wildfires grows in the US due to climate change, expansion of the wildland–urban interface, and continued fuels build-up, there has been a subsequent growth in research on the social impacts of wildfires on well-being. Smoke from wildfires, in particular, is an on-going concern. Recent projections are that the Western US will experience a 57% increase in the frequency and a 31% increase in the intensity of wildfire smoke under future climate change between now and the middle of the 21st century (Liu et al., 2016).

Wildfire smoke contributes approximately 18% of the total fine particulate matter (PM<sub>2.5</sub>) emissions in the US (Phuleria et al., 2005) and can create hostile conditions that make it difficult or impossible

to be outside (Thapa et al., 2004). On days when wildfire smoke is present, individuals suffer from many minor and major health impacts such as coughing, watery eyes, hospital admissions, and even death (Reid et al., 2016). Unrelated to health, individual well-being may also be negatively affected by smoke-induced changes in environmental amenities and scenic attributes, such as disutility from being unable to walk in a nearby park.

Economists have recently been called upon to contribute comprehensive estimates of wildfire smoke exposure costs (Bowman and Johnston, 2014), though few estimates presently exist (e.g., Jones et al., 2016; Richardson et al., 2012). Better understanding of wildfire smoke costs can be useful in their own right (e.g., improving the accuracy of damage assessments), but they also have the potential to influence wildfire management policy and mitigation financing by expanding the scope of affected parties beyond considerations of forest products (IAWF, 2015). Damage assessments and benefit-cost analyses of wildfires will be biased without an accounting of wildfire smoke costs, potentially leading to misinformed wildfire management policy.

The only two studies to provide estimates of the economic costs of wildfire smoke have both focused on health or symptom-related costs (Jones et al., 2016; Richardson et al., 2012). While these works break new ground in this literature, they are limited by the fact that the costs of smoke exposure are likely to extend beyond med-

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ical expenditures, spending on defensive activities, and disutility associated with illness. Hence, results from existing research will provide an incomplete picture of the true costs of wildfire smoke in cases where individuals additionally (or alternatively) experience disutility from smoke directly, such as due to changes in environmental aesthetics and scenic amenities. As described in Freeman (2003), if smoke pollution causes disutility directly, for example, by impairing the view from one's house, then economic cost analyses based only on observations of changes in health (e.g., the defensive behavior method) are "not sufficient" to measure the full cost of wildfire smoke. This is because the true cost of wildfire smoke is equal to the direct (non-health) plus indirect (through health) income adjustments that leaves individuals as well off as before experiencing smoke. Despite evidence suggesting that smoke can and does directly affect well-being (e.g., Jones et al., 2016; Stavros et al., 2014; Venn and Calkin, 2011), no utility-theoretic cost estimates exist that include direct effects.

To address this gap in the literature, this study takes a different course from past research and seeks to provide a comprehensive estimate of wildfire smoke costs by employing the life satisfaction approach, which combines survey data with smoke plume data to model self-reported levels of "happiness" or "subjective well-being" as a function of observable characteristics and income, while controlling for unobservable time and location-specific heterogeneity through the use of fixed effects. Using this estimated function, marginal willingness to pay for reductions in wildfire smoke frequency can be calculated.

There are several advantages of the life satisfaction approach over existing methods of valuing wildfire smoke costs. First, life satisfaction is an empirical approximation of "experienced utility" (Kahneman et al., 1997), meaning that any smoke-induced change to well-being, whether direct or indirect, can be captured through the approach. This is an improvement over past methods that have only estimated the indirect health costs of smoke exposure, which are likely a subset of the total impacts of smoke on well-being. Second, this approach does not rely on asking people directly about smoke exposure and wildfire issues, which means that it is not susceptible to strategic biases and framing problems of topic-specific surveys (Levinson, 2012). Lastly, commonly used revealed preference approaches in the smoke valuation literature such as the defensive behavior method are based on stringent assumptions concerning the rationality of agents and the functioning of markets and can capture only those aspects of smoke exposure that the individual is consciously aware of (Welsch, 2006; Freeman, 2003). By contrast, the life satisfaction approach does not presume rational agents or perfect markets.

This study makes several contributions. First, we apply the life satisfaction approach to wildfire smoke for the first time, providing the first comprehensive measure of smoke costs based on changes in subjective well-being, and provide only the third willingness to pay smoke cost estimates of any kind in the literature. Second, we provide the first nationally-representative estimates of smoke costs in the US, unlike past studies which are based on geographically-limited case studies that may or may not be representative of the country as a whole. Finally, we introduce to the wildfire and forestry literatures the life satisfaction approach to valuing smoke impacts, which can serve as a guide for future research in this area where additional smoke cost estimates are urgently needed.

The main finding of this work is that presence of wildfire smoke has a negative relationship to individual well-being. In particular, we find that US adults are willing to pay \$373 [95% CI: \$86.8, \$659.2] to avoid having one day of wildfire smoke present over their county of residence within a six month period. Residents of rural areas are willing to pay more to reduce wildfire smoke than residents of urban areas (\$472 [95% CI: \$85.9, \$858.1] vs. \$342 [95% CI: \$0.96, \$683.0]). Finally, results suggest a nonlinear relationship between

frequency of smoke events and changes in well-being. In particular, the dollar cost of wildfire smoke is driven largely by those individuals living in areas with frequent smoke events.

### Life satisfaction approach in economics

Known under the synonymous terms "happiness", "well-being", and "life satisfaction" is an expansive economics literature that uses surveys of subjective well-being as empirical approximations for individual utility (Bertrand, 2013; Frijters et al., 2004; Kahneman et al., 1997; Easterlin, 1974) – see Clark et al. (2008) and Kahneman and Krueger (2006) for two reviews of this literature. As it is commonly applied, life satisfaction is used as an outcome measure to study economic relationships of interest. In a seminal piece, Krueger and Schkade (2008) demonstrated the reliability of self-reported life satisfaction data and concluded that the "reliability figures for subjective well-being... are probably sufficiently high to support much of the research that is currently being undertaken..." (Krueger and Schkade, 2008, p. 1833).

The life satisfaction approach to environmental valuation uses measurements of the marginal utility or disutility of some environmental change (e.g., pollution, water quality, climate) and the marginal utility of income to construct a marginal rate of substitution or "willingness to pay" measure (Welsch, 2006).<sup>1</sup> This approach has been previously applied to value air quality (Levinson, 2012; Welsch, 2007), droughts (Carroll et al., 2009), scenic amenities (Kopmann and Rehdanz, 2013; Ambrey and Fleming, 2011), and even wildfires (Kountouris and Remoundou, 2011).

There are several identification considerations that must be taken when using the life satisfaction approach in applied settings. The first is based on the well-known Easterlin Paradox (Easterlin, 1974), which states that happiness does not increase with per capita income across individuals within a country over time, but does increase with income across individuals within a country at any moment in time. The implication of the Easterlin Paradox for this analysis is that identification of a relationship between well-being and wildfire smoke requires us to compare similar individuals living in the same community and during the same time of year. Use of location and time fixed effects in addition to controls for observable individual-level characteristics will allow for the relevant comparison to be made.

Aggregation of environmental quality data is another concern that has been leveled against the life satisfaction approach. As pointed out in Levinson (2012), many analyses of pollution and well-being use national measures of environmental quality, which masks much of the rich heterogeneity from region to region. This could be particularly problematic for wildfire smoke, which tends to vary substantially in frequency and intensity across US regions and even substantially within subsets of particular regions (Liu et al., 2016; Westerling et al., 2006). National or even state-level aggregated analyses of the well-being impacts of wildfire smoke lack the richness required to capture impact heterogeneity. Hence, a key feature of this analysis is that we employ high-resolution and high frequency wildfire smoke data at the county-level by day.

Despite the many advantages of the life satisfaction approach over existing valuation techniques, the approach is not without controversy (Smith, 2008). However, as discussed in Levinson (2012), other methods for valuing changes in environmental quality

<sup>1</sup> Technically, the marginal rate of substitution estimated from such an approach does not represent any one person's stated willingness to pay, but represents an estimate of the trade-offs between income and environmental quality that will leave people, on average, equally happy (Levinson, 2012). The term "willingness to pay" has been traditionally applied for simplicity, which is the convention that we follow in this study.

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