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Valuing hypothetical wildfire impacts with a Kuhn–Tucker model of recreation demand

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Abstract
This study uses a nonmarket valuation method to investigate the recreation values of the San Jacinto Wilderness in southern California. The analysis utilizes survey data from a stated-choice experiment involving backcountry visitors who responded to questions about hypothetical wildfire burn scenarios. Benefits of landscape preservation are derived using a Kuhn-Tucker (KT) demand system. Model results suggest that recreationists are attracted to sites with recent wildfires that can be viewed up-close. For example, recreational welfare estimates increased for sites that were partially affected by different types of wildfires, with the greatest gains being observed for the most recent wildfires. Per person mean seasonal willingness-to-pay varied from a low of $1.23 to a high of $11.05, for total gains ranging from $8,758 to $146,993. However, wildfires that cause trail closures create welfare losses. Seasonal losses per person for complete closure of particular sites range from $3 to $221, for total losses ranging from $29,600 to $2.9 million.

Keywords
Kuhn-Tucker demand system model; Forest recreation value; Hypothetical burn scenarios; Web-based survey; Nonmarket valuation

1. Introduction

Wildland fires affect millions of people worldwide. Globally it is estimated that 350 million hectares of wildland burn annually (González-Cabán, 2008). In the United States, it has become a more serious problem in part due to increasingly dry conditions and forest management practices that have promoted ladder fuel accumulation. From 2000 to 2013, 37.3 million hectares of wildlands burned while the USDA Forest Service (USDAFS) incurred suppression costs of $21.72 billion. This translates to an annual average of 2.66 million ha of wildlands burned at an annual average suppression cost of $1.34 billion (National Interagency Fire Center Wildland Fire Statistics, 2014). Considering that the figures reported in table 1.1 only include the Forest Service, the values would be considerably larger when including other federal and state agencies with wildland fire protection responsibilities.

Fire suppression costs have increased dramatically in the past decade (80% more than the 1994-2003 decade) while congressional funding levels have remained flat (USDA, 2009). Land and forest managers need tools to understand which management strategies are more efficient.

However, current tools used by USDAFS only consider cost of fire prevention or suppression, not the economic benefits a forest provides. Therefore, managers have limited information in their efforts to evaluate investments in and trade-offs associated with fire management strategies.

There are many types of natural and human-made disasters that damage or affect natural resources. Although fire is a natural part of many landscapes, catastrophic fires--often produced by a combination of both natural and human factors--are particularly damaging to forests. The impact of fire on natural resources and the associated economic consequences are difficult to estimate (González-Cabán et al., 2003). The difficulty arises because there is limited information about the effects of fire on nonmarket values provided by forests. Early studies (Flowers et al., 1985; Vaux et al., 1984) found that intense fires are likely to have negative impacts on recreation. Recent studies have explored these negative effects. Loomis et al. (2001) surveyed visitors of National Forests in Colorado to study the effects of fire on hiking and mountain biking visits and benefits. Using the travel cost method (TCM), the authors found that crown fires indirectly affected recreation benefits for mountain bikers, while having no significant effect on hiking trips. The present study follows a similar line of investigation but also utilizes stated preference methods to further investigate impacts on hiking.

Also using TCM, Hesseln et al. (2003) found that both hikers and mountain bikers in New Mexico reacted similarly to recovering prescribed fires and crown fires, with each group decreasing its visitation rate. Hesseln et al. (2004) also found similar results when surveying hikers and mountain bikers in four national forests in western Montana. Differences in results between Loomis et al. (2001) and Hesseln et al. (2003, 2004) suggest that geographic variations may help to determine how recreation users react to fire. Another possible explanation could be socio-economic differences between the two samples.

In studying two hiking trails in the Cascade Mountains affected by a large scale forest fire (40,000 acres), Hilger and Englin (2009) found that, in the short term, the forest ecosystem affected by fire had an increase in visitation, but trip values were largely unaffected. Englin et al. (2001) examined the long term dynamic path of recreation value following a forest fire in three different states: Colorado, Wyoming, and Idaho. Using the TCM the authors found that visitation increased immediately following a fire, then decreased for 17 years, and then rebounded for the remaining 8 years of their observation period. In a similar study by Boxall and Englin (2008) for canoeing in the Canadian Shield boreal forest, damages associated with a fire occurred immediately following a fire, but after 35 years of regrowth, the forest amenity values returned to pre-fire levels. The present study also considers how time since fire impacts visitation and values in a hiking context, while also controlling for other fire characteristics such as intensity and spatial characteristics of the burn.

This study uses the travel cost method to investigate relationships between wildfires and wilderness access value. The San Jacinto Wilderness serves as an excellent case study because it is a popular recreation area, accessible to millions of people throughout southern California, and at the time of the study it had not experienced a fire in several decades[1], even though the area is considered to have a very high fire hazard severity rating (Cal Fire, 2015). The investigation utilizes a web-based survey to collect both revealed and stated choice data from backcountry visitors who responded to questions about past trip-taking behavior and hypothetical wildfire burn scenarios. Benefits/losses are derived from both the revealed and stated choice data using a Kuhn-Tucker (KT) demand system (Phaneuf et al., 2000; von Haefen et al., 2004). The results can help researchers to better understand the economic effects of wildfires, and fire managers to plan more efficient fire management strategies and reduce potential losses from wildfires.

[1] A wildfire occurred recently (July 2013) affecting a part of the area, but not during the study period.

2. Survey Design

This study focuses on backcountry hikers who visit the San Jacinto Wilderness Area, San Bernardino National Forest in southern California (figure 2.1)[2]. The wilderness covers 13,350 hectares and is located within a 2.5 hour drive from the highly urbanized Los Angeles, Orange, Riverside, San Bernardino, and San Diego counties. Elevations range from 1,800 to 3,300 meters and flora varies from desert to alpine species. In 2011, 54,286 visitors obtained backcountry permits to enter the wilderness area (Andrew Smith and Bart Grant, personal communication, USDAFS and Mt. San Jacinto State Park Ranger, October 2013).

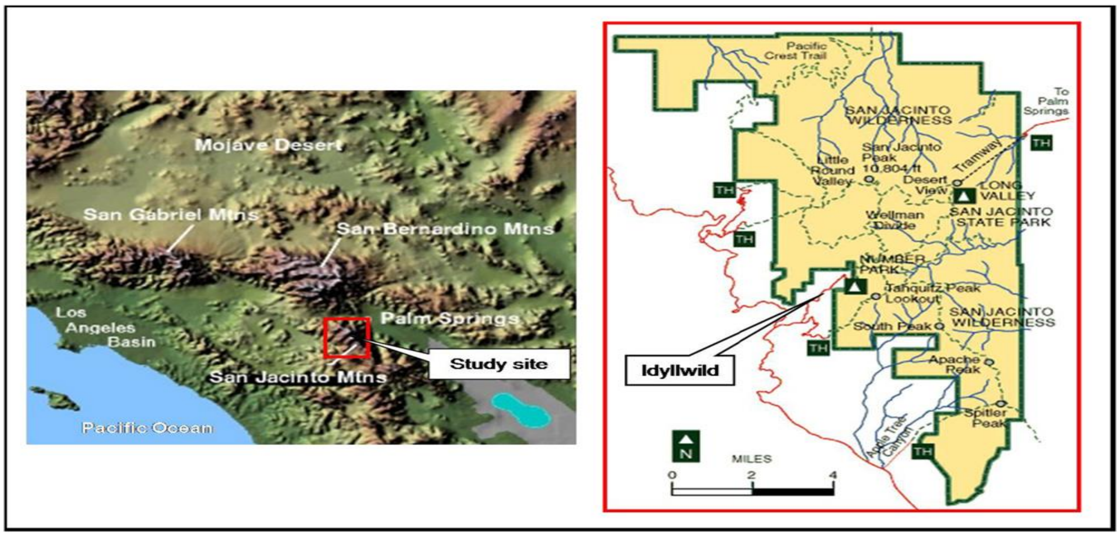

Figure 2.1— Site location-San Jacinto Wilderness area. Map provided by Baerenklau et al. (2010).

The wilderness area is regulated by both USDAFS and the California Department of Parks and Recreation. The most popular activity is day hiking. Recreationists enter the wilderness area via the tramway or by driving to the trailheads located in Long Valley and Idyllwild (figure 2.1). Recreationists entering the wilderness area must acquire a wilderness permit. The permits are free and are obtained at either the Idyllwild or Long Valley Ranger Station. According to Forest Service estimates, the compliance rate is approximately 75%

[2] Description is adapted from Baerenklau et al. (2010).

(Andrew Smith, personal communication, USDAFS, October 2013). Thus barring any selection effects associated with those who submit permits versus who do not, we assume that sampling administered on recreationists who obtain a wilderness permit fairly represents the population of wilderness visitors.

An online survey was developed to collect information on past recreation visits to the wilderness as well as anticipated changes in recreation behavior in response to hypothetical fire conditions. An initial version of the survey was presented to three focus groups (October 2011 to March 2012) to evaluate the study design, clarity of wording, use of graphics, range of values used, and to consider if important issues were omitted or obscured. Revisions of the survey were pre-tested (May and June 2012) to evaluate whether or not respondents were answering questions in a sensible manner, verify that the web-based survey was working properly (i.e., survey link is active, questions are loading correctly), and verify the time required to complete the survey.

Recreationists were recruited into the survey while obtaining their wilderness permits at the USDAFS Ranger Station in Idyllwild and the Mt. San Jacinto State Park Ranger Station in Long Valley during the summer months of June 2012 to September 2012. To decrease self-selection bias and increase response rate, an undergraduate student was stationed at the Idyllwild Ranger Station on the weekends and once during the weekday during regular office hours (8am to 4pm).

The student approached recreationists on their way into the Idyllwild Ranger Station, and provided a brief description of, and incentives for participating in the study[3]. The student collected e-mail addresses of recreationists interested in participating and kept a count of those who declined to participate. E-mail addresses were used to send the survey link and two friendly

[3] Recruitment, e-mail and other scripts are available upon request.

reminders for those who had not completed the survey. A similar protocol was followed at the Long Valley Ranger Station, but a student was there only on the highest visitation days, Friday and Saturday. Across both ranger stations, active recruiting occurred on a total of 37 days during the sampling frame: 25 days at the Idyllwild Ranger Station and for 12 days at the Long Valley Ranger Station. Recruitment flyers also were made available by ranger station staff every day to recreationists at both sites.

Given the advantage of faster delivery, lower cost, and superior graphics (Berrens et al., 2003; Couper, 2000; Fricker and Schonlau, 2002), we elected to use a web-based survey. The survey was implemented using a modified Dillman (2007) approach: first an invitation e-mail, followed by the survey link, and then two friendly e-mail reminders to non-responders. The survey is divided into three sections[4]. The first section elicits the recreation trip behavior, preferred forest characteristics, and cost-related information for the past 12 months. The second section elicits trip taking behavior for hypothetical burn scenarios that contain five attributes of interest: percent of viewshed burned (25%, 50%, and 75%), intensity of fire (low, medium, and high), time since burn (recent: 0-5 years since fire, middle: 6-15 years since fire, and long: more than 15 years since fire), viewing distance (foreground, middle ground, and background), and trail affected by fire. In Idyllwild the four trails selected are: Deer Springs, Devil's Slide, Marion Mountain, and South Ridge; in Long Valley there is one trail: Long Valley. The five trails were selected because they have the highest visitation rates based on 2005 data[5]. The final section of the survey collects demographics and personal information, including gender, ethnicity, age, education level, employment status and income. The income information was used to derive the travel cost variable and test the income effect in the econometric model.

[4] There are nine different survey versions. Surveys are available upon request.
[5] Out of a total of 34,218 permitted visitors to the San Jacinto Wilderness, 33,194 visited the 5 trails (Baerenklau et al. 2010). Similar results were found using 2011 wilderness permit data.

There are a total of 405 (3^4x5) possible treatment combinations for the burn scenarios. A full factorial design was not implemented because higher order interactions are considered negligible and would require either a very large sample size or a large respondent burden to estimate. Instead, a fractional factorial design (Montgomery, 2005) was implemented. Using the SAS macro functions (Kuhfeld et al., 1994; Kuhfeld, 2010) a D-efficient design that is balance and orthogonal containing 45 treatment combinations was selected for the fractional factorial design[6].

Survey participants were shown five different hypothetical burn scenarios (pictures), each containing the five attributes of interest. Each picture depicted a unique hypothetical scenario representing the landscape of the San Jacinto Wilderness if a fire were to occur. For example, one possible hypothetical burn scenario would be represented by a picture of a recent low-intensity burn in the foreground that burned 50% of the viewable area along the Deer Springs trail (figure 2.2)[7].

[6] No prior information on parameters was used to construct the D-efficient design. We considered a separate orthogonal design with 90 treatment combinations, but 45 a design with combinations was selected to achieve a lower respondent burden.
[7] Source of photos: S. Haase, USDA Forest Service, http://www.azfirescape.org/catalina/photo_point_full_index?page=10, http://www.natgeocreative.com/ngs/, https://www.flickr.com/, and http://www.google.com/imghp

12. This picture shows a 0-5 year-old low-intensity burn viewed from up-close. If 50% of the foreground scenery along the Deer Springs trail was similar to this picture, how many recreation trips would you have taken to each trail during the past 12 months?

	Number of recreation trips
Deer Springs Trail	
Devil's Slide Trail (Humber Park)	
Marion Mountain Trail	
South Ridge Trail	
Long Valley (Palm Springs Aerial Tram)	

Figure 2.2— Web-based survey hypothetical burn scenario example

For each picture (burn scenario), participants were asked to report how many trips they would have taken in the past 12 months to each of the 5 trails if the trail conditions changed as described in the picture. The fire conditions and trail affected varied across scenarios, and the question order was assigned randomly in each survey to elimate or reduce order effect (Dillman, 2007). The collection of responses to these scenarios, along with cost information, forms the basis for demand and welfare analysis under different wildfire burn scenarios.

3. Data

A total of 2,201 recreationists were contacted for possible survey participation. Of those contacted, 1,527 agreed to provide e-mail addresses for an initial response rate of 69%. Of those providing email addresses, 768 completed the survey for a response rate of 50%. A total of 70 surveys were deleted for various reasons, including travel times greater than 3 hours or travel costs greater than $1000, for an effective response rate of 46%. Descriptive statistics for respondent characteristics used in the empirical model are shown in table 3.1. All the sites have similar travel costs ($57 to $69 cost per trip) as expected. The travel costs are estimated by the sum of driving cost and time costs. Driving costs are a function of distance (estimated from Google Maps) and the average per-mile cost of operating a typical car ($0.585/mile; AAA, 2012). Time costs are a function of travel time (estimated from Google maps). The opportunity cost of time was included in the travel cost as one-third of the respondent's average hourly income (Hagerty and Moeltner, 2005). Perhaps the most interesting statistics are the income, age and education variables (table 3.1). Visitors to the wilderness are high income earners ($87,235), at 44 years relatively older (median age is 45), mostly white (90%), and well-educated individuals (71% have at least a Bachelor's degree). Furthermore, they take relatively few trips each year. Although descriptive statistics for the population is not available, we can compare our sample against census data for southern California residents living in five nearby counties: Los Angeles, Orange, Riverside, San Bernardino, and San Diego. Residents of these five counties are less affluent, at $61,405 their median annual household income is $25,830 less, younger (median age is only 34), more diverse (37.7% white), and less well-educated (only 28% of the population has at least a bachelor's degree (US Census Bureau, 2014)). Thus there are some noteworthy differences between our sample and the average southern California residents of these five counties.

Table 3.1*—Descriptive statistics of survey responses for variables included in the econometric model specifications*

Variable	Description	Mean (std. dev.)
Trips_Dr	Trips to Deer Springs site	.61 (1.73)
Trips_Dv	Trips to Devil's Slide site	1.22 (3.53)
Trips_MM	Trips to Marion Mtn site	.24 (.62)
Trips_SR	Trips to South Ridge site	.37 (1.49)
Trips_LV	Trips to Long Valley site	2.42 (5.91)
TC_Dr	Per trip travel cost to Deer Springs	$57.28 (26.90)
TC_Dv	Per trip travel cost to Devil's Slide	$59.55 (27.29)
TC_MM	Per trip travel cost to Marion Mtn	$59.90 (26.89)
TC_SR	Per trip travel cost to South Ridge	$59.87 (27.36)
TC_LV	Per trip travel cost to Long Valley	$69.84 (23.76)
Age	Respondent's age	43.82 (12.59)
Degree (dummy variable)	Having at least a Bachelor's degree; if Yes = 1; else = 0	.71 (.45)

Employed *(dummy variable)*	Being employed in the past year; if Yes = 1; else = 0	.65(.48)
EnvGrp *(dummy variable)*	Belonging to an environmental group; if Yes = 1; else = 0	.21 (.41)
Gender *(dummy variable)*	Respondent's gender; Male =1 Female = 0	.58 (.49)
Minority *(dummy variable)*	Being in a minority group if Yes=1; else=0	.10 (.30)
Income	Household annual income	$87,235 (46,930)
n = 698		

4. Econometric Model

The web-based survey produces individual consumption data for multiple trailheads located in the San Jacinto Wilderness under recent (past 12 months) and hypothetical fire conditions. Trail-specific demand often equals zero, a common feature of recreation demand data with multiple sites as many recreationists visit only a subset of sites. A Kuhn-Tucker (KT) model was initially developed by Hanemann (1978) and Wales and Woodland (1983). The KT model has advantages over other recreation demand models in that it provides a theoretically consistent framework for estimating demand functions and welfare effects in a situation like this with multiple goods and corner solutions (i.e., zero consumption or no visits to a particular site). It can model simultaneous decisions on which sites to visit and how many trips to make to each site over the course of a season. The key feature of the KT model is that the consumer's choices regarding which sites to visit and the number of visits made to each site are consistent with utility theory rather than arbitrarily appended to each other as in "linked" models of recreation demand (Herriges et al., 1999). This facilitates smooth integration of the behavioral and econometric models (Phaneuf and Siderelis, 2003).

In a KT demand model, the individual's direct utility function is $u(x, z; q, \varepsilon, \Gamma)$, where x is a vector of trips taken to each trailhead j, z is spending on all other goods with price normalized to one, q is a vector of site characteristics, ε is random error term unknown to the researcher, and Γ represents parameters of the utility function to be estimated. Individuals maximize utility over a season subject to their budget constraint:

$$(4.1) \quad \max_{x,z} u(x, z; q, \varepsilon, \Gamma), \qquad s.t. \;\; y = z + xp, \quad x_j \geq 0, j = 1, \ldots, M,$$

where y is the annual income and p is the price (travel cost) of visiting each trailhead access point. If we assume that for equation 4.1, u is a quasi-concave, increasing, and continuously differentiable function of (x, z), the first-order conditions that implicitly define the solution to the optimal consumption bundle (x^*, z^*) are

$$(4.2) \quad \frac{\frac{\partial U}{\partial x_j}}{\frac{\partial U}{\partial z}} \leq p_j, j = 1, \ldots, M,$$

$$(4.3) \quad x_j \times \left[\frac{\frac{\partial U}{\partial x_j}}{\frac{\partial U}{\partial z}} - p_j\right] = 0, j = 1, \ldots, M.$$

In a model that assumes only interior solutions (i.e., positive trips to a site), equation (4.2) would have the standard equality (i.e., marginal rate of substitution equals the relative price) and equation (4.3) would be satisfied automatically. In the more general KT model, for each visited site, the marginal rate of substitution between trips and the numeraire is equal to the travel cost; while for an unvisited site, the marginal rate of substitution between trips and numeraire is less than the travel cost (i.e. the price is above the consumer's reservation price). Letting $g_j(x, y, p; q, \gamma)$ denote the solution to $\left[\frac{\frac{\partial U}{\partial x_j}}{\frac{\partial U}{\partial z}} - p_j\right] = 0$, equations 4.2 and 4.3 can be rearranged in the following form (Phaneuf et al., 2000):

$$(4.4) \quad \varepsilon_j \leq g_j(x, y, p; q, \gamma),$$

$$x_j \geq 0, \qquad x_j\left[\varepsilon_j - g_j(x, y, p; q, \gamma)\right] = 0$$

4.1 Utility Parameters Estimate

The KT modeling approach relies on the assumption that consumer preferences are additively separable $\left(i.e., U = \sum_j^M u_j\left(x_j\right) + u_z(z)\right)$. Therefore, the specific parameterization of the utility function employed is the following[8]:

$$(4.5) \quad U = \sum_{j=1}^{M} \Psi_j \, ln\left(\phi_j x_j + \theta\right) + \frac{1}{\rho} z^{\rho},$$

$$\Psi_j = exp\left(\delta' s + \varepsilon_j\right) \qquad j = 1, \ldots, M$$

$$\phi_j = exp\left(\gamma' q_j\right)$$

$$\rho = 1 - exp(\rho^*)$$

$$\mu = exp(\mu^*)$$

$$\theta = exp(\theta^*)$$

$$z = y - p'x$$

$$\varepsilon_j \sim EV(\mu)$$

where s is a vector of individual characteristics, z is spending on all other goods (a function of income and travel cost), and $\delta, \gamma, \theta^*, \rho^*, and\ \mu^*$ are structural parameters. The parameter ε_j captures unobserved heterogeneity; ρ embodies income effects; and θ is the "translating parameter", which is needed to ensure that weak complementarity holds. The $\varepsilon_1, \ldots, \varepsilon_M$ represent additional unobserved heterogeneity that varies randomly across individuals and sites; it is assumed that each error term is an independent draw from the normalized type I extreme value distribution.

[8] First suggested by Bockstael et al. (1986) and later modified by von Haefen et al. (2004).

Some features of this utility function merit additional discussion. The additive separability assumption rules out inferior goods and implies that all goods are Hicksian substitutes. For a cross section of outdoor recreationists, additive separability also implies that on average, wealthier recreationists will tend to take more trips to more sites, which seems plausible. However, additive separability also implies weak substitution effects for goods with small income effects. As noted by Kuriyama and Hanemann (2006), this means that KT models may overestimate welfare losses due to individual site closures. This is one of the drawbacks of using the KT model that is otherwise well-suited for modeling recreation site choice data. Finally, the KT specification guarantees that weak complementarity is satisfied for all parameter values (von Haefen et al., 2004). Additional information on weak complementarity can be found in von Haefen (2007).

As shown in Phaneuf et al. (2000), the likelihood function for estimation is constructed from equation 4.4 and the specific joint density function for ε. The likelihood of observing an individual's outcome x conditional on the structural parameters, $(\delta, \gamma, \theta^*, \rho^*, \mu^*)$, is (von Haefen and Phaneuf, 2005):

$$(4.6) \quad L(x|\delta, \gamma, \theta^*, \rho^*, \mu^*) = |\mathbf{J}| \prod_j \left[exp\left(-g_j(\cdot)/\mu\right)/\mu\right]^{1_{x_j>0}} \times \; exp\left[-exp\left(-g_j(\cdot)/\mu\right)\right],$$

where $|\mathbf{J}|$ is the Jacobian transformation and $1_{x_j>0}$ is an indicator function equal to one if x_j is strictly positive and zero otherwise.

In general, the Hicksian compensating surplus (CS^H) for a change in price and quality from baseline conditions p^0 and q^0 to new levels p^1 and q^1 can be defined implicitly using indirect utility functions:

$$(4.7) \quad V(p^0, y; q^0, \gamma, \varepsilon) = V(p^1, y - CS^H; q^1, \gamma, \varepsilon)$$

or explicitly using expenditure functions

(4.8) $CS^H = y - e(p^1, q^1, U^0, \gamma, \varepsilon)$,

where $U^0 = V(p^0, y; q^0, \gamma, \varepsilon)$.

The ε's in CS^H (equation 4.8) are unknown to the researcher, implying CS^H is a random variable. CS^H can be estimated by its expected value $E(CS^H)$, however no close-form solution exists. Therefore, computation of the welfare estimates must be done using Monte Carlo simulation techniques.

Phaneuf et al. (2000) developed the first method to solve for CS^H using simulations for unobserved heterogeneity. This has since been refined by von Haefen et al. (2004) to significantly reduce the computational burden. The iterative algorithm of von Haefen et al. (2004) estimates CS^H using a numerical bisection routine that requires solving only one constrained optimization problem at each iteration of the routine, rather than multiple problems. The Hicksian consumer surplus (CS^H) is constructed by using the bisection routine to find the income compensation that equates utility before and after the price and quality change. Details on the procedure can be found in von Haefen et al. (2004).

5. Model Estimates

Parameter estimates are derived for two separate analyses, each using a different dataset. In the first analysis, the dataset is limited to the revealed preference data (i.e., observations on the number of trips taken in the past 12 months to each of the 5 sites in the survey). In the second analysis, the revealed and stated preference data are combined (i.e., observations on past trip taking behavior as well as responses to questions about hypothetical fire scenarios).

Table 5.1 contains estimates for the parameter model using revealed preference data. In the Ψ matrix (individual characteristics) being male and belonging to an environmental group increases trips to each trailhead; while age tends to decrease the number of trips taken. The remaining estimates, including minority status, having at least a bachelor's degree and being employed full-time, are not statistically significant.

Table 5.1— *Kuhn-Tucker model estimates. The dependent variable is the number of trips taken in the past 12 months to each trailhead (revealed preference data only).*

Parameter	**Model**		
	Estimate	**Std. Err.**	**t-statistics**
Ψ Index parameters			
Constant	-1.2323*	.6574	-1.8745
Gender	0.4180***	.0818	5.1126
Age	-0.0125***	.0035	-3.5565
EnvGrp	0.2387***	.0898	2.6574
Minority	0.0672	.1393	0.4827
Degree	0.0035	.0953	0.0366
Employed	0.0294	.0904	0.3252
Translating parameter			
Θ	0.2727	90.5099	0.0030
Φ *parameters*			
Constant	-0.2727	90.5099	-0.0030
Devil's Slide Dummy	0.3385***	.0765	4.4269
Marion Mtn Dummy	-0.3688***	.0884	-4.1743
S. Ridge Dummy	-0.2801***	.0866	-3.2334
Long Valley Dummy	0.8404***	.0756	11.1093
Rho parameter			
ρ	-0.9044***	.1538	-5.8806
Type I extreme value scale parameter			
μ	-0.0224	.0264	-0.8489
Log-likelihood	-4,524.0583		

Note: * indicates significance difference from zero at the 0.10 level and *** indicates significance difference from zero at the 0.01 level. Robust standard errors reported.

The Φ matrix includes information about site characteristics. For hiking trails, such characteristics might include trail length, steepness, difficulty, scenic quality, etc. Because the revealed preference model includes no such characteristics, we include site-specific (trailhead) dummy variables in the Φ matrix instead of the Ψ matrix where they would normally appear (von Haefen et al., 2004). These dummy variables serve as proxies for fixed (but in this case unobserved) site quality attributes. The associated parameter estimates in table 5.1 demonstrate the popularity of the trails and have magnitudes that are consistent with the visitation data shown in table 5.2.

Table 5.2—*Total San Jacinto Wilderness visitors (2011)*

Trailhead	Visitors
Deer Springs	6,271
Devil's Slide	12,362
Marion Mtn	2,325
South Ridge	2,118
Long Valley	32,163
Total	55,239

Table 5.3 contains estimates for the parameter model using revealed and stated preference data.[9] As shown in the table, the following individual characteristics increase visitation to each site: being male, belonging to an environmental group, being a minority, and being employed. As age increases, the number of visits decreases. The positive and significant minority status variable is surprising. A plausible explanation for this finding is that minority recreationists found the new site conditions resulting from the hypothetical scenarios presented to them interesting causing an increase in visitation. Compared to the previous analysis, the larger number of significant coefficient estimates is likely due to the additional data and the additional variables describing the hypothetical burn scenarios.

The fire characteristics preferred by visitors are recent and foreground fires, while fire intensity and percent of viewshed burn has no statistical influence in preference. When considering the time since fire variable (recent fire: 0-5 years, middle: 6 to 15 years, and long: >15 years), the effect of a burn on visitation remains positive, but decreases through time. Overall this means that a recent foreground fire will have a positive but declining effect on visitation. One possible reason for this is curiosity: the San Jacinto Wilderness has not burned in over 30 years, and recreationists may want to experience the novelty of burned trail conditions immediately after a fire before those conditions begin to diminish as the forest renews itself. These findings are consistent with previous studies that estimate increases in visitation after

[9] A reviewer suggested that it would be appropriate to cluster the standard errors by individual. This is likely true and implies that our reported standard error may be too small. However, extending the Kuhn-Tucker framework to incorporate clustering would not be straightforward and is well beyond the scope of this analysis. We leave this extension for future work.

recent fires (e.g., Englin et al., 2001; Hilger and Englin, 2009) as well as a declining effect on visitation through time (e.g., Englin et al., 2001).

Table 5.3— *Kuhn-Tucker model estimates. The dependent variable is the annual number of trips to each trailhead (revealed and stated preference data).*

Parameter	**Model**		
	Estimate	**Std. Err.**	**t-statistics**
Ψ Index parameters			
Constant	-0.4797**	.2349	-2.0420
Gender	0.4117***	.0306	13.4463
Age	-0.0179***	.0013	-14.0722
EnvGrp	0.0984***	.0359	2.7428
Minority	0.3686***	.0450	8.1879
Degree	-0.0128	.0344	-0.3724
Employed	0.1275***	.0346	3.6846
Devil's Slide Dummy	0.2517***	.0698	3.6035
Marion Mtn Dummy	-0.6004***	.0876	-6.8525
S. Ridge Dummy	-0.4750***	.0844	-5.6260
Long Valley Dummy	1.0307***	.0646	15.9674
Translating parameter			
Θ	-0.0418	.0216	-1.9367
Φ *parameters*			
Time	-0.0095***	.0011	-8.3979
% Burn	-0.0039	.1309	-0.0294
Foreground	0.2028**	.0913	2.2218
Middle ground	0.0267	.0948	0.2822
Background	0.0990	.0944	1.0485
Fire Intensity	-0.0016	.0107	-0.1534
Rho parameter			
ρ	-1.0845***	.0672	-16.1275
Type I extreme value scale parameter			
μ	0.0995***	.0098	10.1166
Log-likelihood	-31,384.32		

Note: * indicates significance difference from zero at the 0.10 level, ** indicates significance difference from zero at the 0.05 level, *** indicates significance difference from zero at the 0.01 level. Robust standard errors reported.

6. Welfare Analysis

Using the numerical bisection method described in von Haefen et al. (2004), we conduct three separate welfare analyses to better understand how the recreation value of the wilderness is linked to both access and wildfire conditions. The welfare estimates represent the compensating surplus: the amount of income that would be required to exactly compensate for the change in site quality. The first analysis uses the parameter estimates from table 5.1 in the numerical bisection algorithm to simulate the welfare loss that would be associated with a high intensity fire that could result in closure of each trailhead or the entire wilderness. Table 6.1 shows that the potential welfare loss is greatest for Long Valley and Devil's Slide; while Marion Mountain is the site with the lowest welfare loss. Under these worst case scenario results, the estimated per trail seasonal losses range from $29,600 to $2.9 million, resulting in a total wilderness loss of $3.7 million.

Table 6.1*—Individual and aggregate seasonal welfare estimates for trailhead using revealed preference data (2012 dollars).*

	Individual		
Scenario	**Mean**	**Std. Err.**	**Aggregate**
Loss of Deer Springs site	-$13.43	0.8602	-$138,065
Loss of Devil's Slide site	-$57.87	2.2807	-$586,384
Loss of Marion Mtn site	-$3.06	0.2438	-$29,644
Loss of South Ridge site	-$8.02	0.5407	-$45,909
Loss of Long Valley site	-$221.49	6.4917	-$2,943,712
Loss of All sites	-$305.22	9.1015	-$3,743,714

Note: Robust standard errors based on 200 Krinsky-Robb simulations.

The second and third welfare analyses (tables 6.2 and 6.3) use the parameter estimates from table 5.3, which are derived using both revealed and stated preference data. Table 6.2 shows the welfare loss from complete site closure, while table 6.3 shows the welfare effects from a specific change in site quality (a hypothetical burn scenario).

Table 6.2 *—Individual and aggregate seasonal welfare estimates using revealed and stated preference data (2012 dollars).*

	Individual		
Scenario	**Mean**	**Std. Err.**	**Aggregate**
Loss of Deer Springs site	-$23.92	0.8493	-$245,905
Loss of Devil's Slide site	-$54.45	1.6095	-$551,730
Loss of Marion Mtn site	-$18.29	0.6920	-$177,184
Loss of South Ridge site	-$19.21	0.6966	-$109,964
Loss of Long Valley site	-$164.05	4.0970	-$2,180,306
Loss of All sites	-$281.23	7.9638	-$2,942,209

Note: Robust standard errors based on 200 Krinsky-Robb simulations.

Table 6.2 exhibits a similar trend as the first welfare analysis: Long Valley and Devil's Slide again have the highest welfare losses due to trail closure; however these estimates are lower than in the first analysis[10], while the other site estimates are higher. The increase in welfare

[10] There is statistically significant difference between the Long Valley welfare estimates, but not for the Devil's Slide estimates.

loss in the other three sites is partly due to individuals demanding more recreational trips to the wilderness for the different site conditions (hypothetical burns).

Lastly, table 6.3 shows the welfare estimates for a change in quality from current trail conditions to a hypothetical burn: specifically, a recent, low intensity fire that burns 25% of a trail's viewshed. The analysis estimates that there would be a welfare gain due to this hypothetical fire[11]. The gain is largest immediately after the fire and decreases as trails return to pre-fire conditions. The most popular trails (Devil's Slide and Long Valley) had the greatest gain, but least popular trails still have significant welfare gains. Part of the welfare gain is due to increased wilderness visitation predicted by the model[12].

Table 6.3— *Individual and aggregate seasonal welfare estimates for hypothetical burn scenario (2012 dollars).*

	Individual		
Scenario	**Mean**	**Std. Err.**	**Aggregate**
Recent, low intensity foreground fire that burns 25% of trail			
Deer Springs	$14.10	3.8443	$144,953
Devil's Slide	$22.73	5.9870	$230,318
Marion Mtn	$10.93	3.0729	$105,884
South Ridge	$10.87	3.0099	$62,223
Long Valley	$47.80	12.8502	$635,286
All Sites	$106.35	28.1308	$1,178,664

Note: Robust standard errors based on 200 Krinsky-Robb simulations.

7. Conclusions

A Kuhn-Tucker demand model was estimated with the web-based survey data to investigate seasonal recreation demand and calculate welfare measures for hiking trails in the San Jacinto Wilderness. An advantage of the KT model over traditional travel cost models is that the KT model can handle corner solutions for recreation data in a theoretically consistent way and can estimate simultaneous decisions on which sites to visit and how many trips to make to each site over the course of a season (von Haefen et al., 2004).

[11] Similar welfare gains, but not as high, were found for all hypothetical burn combinations.
[12] Similar results were found for different burn scenarios.

The estimated model facilitates two important steps toward more efficient management of wildfire prevention and suppression efforts. First, the model allows us to determine the access value of each trailhead. Second, the model allows us to derive, for each trail, the recreation-related welfare effects of wildfire-induced changes in scenic quality associated with mature forests. This includes not only trailhead closures but also the residual impacts of prior burns of varying intensities. For our study area, we estimate potentially significant welfare losses associated with trailhead closures that can be caused by intense wildfires. But we also estimate potential welfare gains associated with changes to the landscape that can be caused by milder wildfires. Both of these results are consistent with previous studies, and demonstrate a more nuanced relationship between the effects of wildfire on a landscape and the effects of the landscape on recreation value. From a forest management perspective, these results imply that the accumulation of ladder fuels due to historical wildfire prevention and suppression policies present a threat to popular backcountry areas and the values they provide to recreationists. Efforts should focus on mitigating these threats in high value areas, where costs can be justified, and returning these landscapes to more natural fire regimes. Once this is achieved, our study suggests that recreationists actually derive greater value from experiencing the periodic effects of smaller wildfires on the landscape than from an artificially maintained “fire-free” landscape. This may be due to curiosity or variety-seeking behavior, but the actual cause is beyond the scope of the current study. In the long-run, these results should be seen as good news for forest managers from a budgetary perspective since it implies that forest recreation resources can provide greater value to visitors when less effort and resources are expended to alter the natural fire regime. Consideration of other non-recreation values that might be derived from a more natural fire regime would further increase the balance of this benefit-cost calculation.

However, these results should be interpreted carefully. The survey did not ask recreationists' perceptions of wildfire and how it affects the ecosystem. Also, these results consider only recreation values, a small subset of possible nonmarket values. Thus, the welfare impact could potentially change when other non-use (i.e., option, bequest, and existence) values are included in the analysis. Further, research should consider the possibility of asking recreationists questions about wildfire's impacts on the ecosystem and include additional non-use values when estimating forest access values.

Based on our results and prior studies cited, it appears that scenic quality may not be completely degraded by certain types of fires. The hypothetical burn scenario analysis suggests that recreationists derive a positive welfare effect from experiencing lightly burned landscapes. Although the welfare impact becomes negative when fires cause complete trail closures, it appears that there is no direct connection between scenic quality degradation and fire.

There are many people who believe that accrued benefits to communities from additional visitation to site caused by human cause disasters (i.e., oil spills) should be deducted from any compensation to the public in the natural resource damage assessment (NRDA) context. However, this topic is still unsettled and if courts rule that in NRDA cases the benefit to communities should be reduced from damages accrued to the community, then the same can probably apply to human cause fires.

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