University of Nevada, Reno

Essays on Factors of Innovation, Regional Economic Impacts from Rangeland Fires, and Estimation of Health Impacts from Wildfires

A dissertation submitted in partial fulfillment of the
Requirements for the degree of Degree of Philosophy in
Resource Economics

by

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Abstract

This dissertation addresses issues of regional economics and natural resource economics. The dissertation has three main sections that can be taken as separate essays or chapters:

I: Modeling U.S. Counties' Innovation Capacity with a Focus on Natural Amenities.
II: Modeling Regional Impacts from Rangeland Fires: An Application of a LP-SAM.
III: Effects of Wildfires on Hospital Admissions for Respiratory Disease in Reno-Sparks, Nevada.

Chapter one is a novel empirical analysis of innovation capacity for U.S. counties with a focus on natural amenities. This chapter analyzed the factors of innovation using three innovation measures: high technology employment share, number of patents and number of firms in Not-Elsewhere-Classified (NEC) sectors as dependent variables. The explanatory variables are local economic conditions such as population, wage rate and unemployment rate; urban amenities such as crime rate, universities and museums; natural amenities such as climate, boat units, trailheads, camping ground and sites, and other outdoor activity services. An ordinary least square (OLS) model and negative binomial (NB) models were applied to the econometric analysis. Results showed that lower unemployment rates, more museums, more golf courses, warm winters and cool summers increased the innovation capacity for U.S. counties across three innovation measures. Therefore, the non-market attributes of natural amenities should be recognized in terms of their contribution to innovation capacity. Consequently, the competiveness of a county, in terms of innovation capacity, could be increased by providing more natural

amenities to the public.

Chapter two analyzed the regional economic impacts from rangeland fires in southeast Oregon. If a fire occurs on public grazing land, ranchers in the region are restricted access to public land for two years. This action would have substantial economic impacts in a regional economy because public grazing is a major source of forage for cattle and ranching in the region. This chapter developed procedures to simultaneously analyze the ranch and regional level impacts of rangeland fires on public land. This goal was attained by developing a model that links a linear programming (LP) model and a Social Accounting Matrix (SAM) model. Detailed modeling procedures are provided in this chapter. Results showed that the wildfire damage was far beyond simple wildfire suppression cost and direct impact on ranching business. The Cattle Sector, the Service Sector and the Manufacturing Sector are the most impacted sectors in the study area because southeast Oregon relies upon its ranching business. The distributional effect is the key finding from the LP-SAM model. Results showed that medium income households (ranging from $25,000 to $75,000) are most impacted from rangeland fires. The distributive effects from wildfire for ranching business in Oregon are crucial to the policy makers who are dealing with rangeland fires and public land management.

Chapter three analyzed the effects of wildfires on hospital admissions for respiratory disease in Reno-Sparks, Nevada. Wildfires, a common natural phenomenon in the western United States, produce a large amount of greenhouse gas and pollution particles, which might lead to health problems for nearby residents, and thereby increase local health care costs. This chapter identified 35 large wildfires that occurred near Reno-Sparks from 2005 to 2008 in order to explore the relationship between wildfires and

health costs. The daily data of the major air pollutant $PM_{2.5}$ from wildfires and number of respiratory patients admitted were employed in econometric equations to obtain the causal effect of wildfires on health. Results showed that wildfires that occurred away from Reno-Sparks within different distances increased the level of $PM_{2.5}$ in the Reno-Sparks area. Furthermore, the regression on daily respiratory patients' hospital admissions showed that the level of $PM_{2.5}$ positively affected the number of patients admitted. The causal effect of number of patients admitted from wildfire varied by distances. The average damage of one acre burned by wildfires within a given distance category on hospital admissions in Reno-Sparks is $4.83. Wildfires that could affect the air quality in Reno-Sparks were identified with size over 500 acres. Therefore, if one average-size wildfire occurred near Reno-Sparks, the damage would cost approximately $156,096. This effect could be underestimated because historical data of wildfires showed that more than one wildfire occurred during the summer period, which means the damage could be much larger than estimated. Therefore, policy makers should pay more attention to wildfire management because wildfires do not only directly affecting the air quality.

Overall, this dissertation describes the factors of innovation, regional economic impacts from rangeland fires and estimation of health effects from wildfires and offers suggestions to policy makers.

Acknowledgment

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Table of Contents

List of Tables

List of Figures

Chapter One:

Modeling U.S. Counties’ Innovation Capacity with a Focus on Natural Amenities

1.1 Introduction

Due to economic globalization, regional innovation is becoming a decisive factor for obtaining international competitive advantage. The U.S. is building a knowledge-based economy. Innovation, in terms of intellectual capital or knowledge, plays an important role in driving economic growth. In the past few decades, there have been increasing interests in measuring innovation capacity through different methods, such as R&D expenditure, patent counts, and employment in high-technology sectors. In 2009, the U.S. Economic Development Administration (EDA) created a portfolio innovation index to describe the innovation capacity for each U.S. county. These innovation capacity measures showed that U.S. counties' innovation capacities vary. For instance, some of the counties in the western and the northeastern U.S. have higher innovation capacities than the rest of the U.S. counties. In addition, counties represent diverse levels of innovation capacity in terms of different measurements, such as patents, and employment in high technology sectors. Previous studies tried to explain those differences theoretically (Nelson 1993; Freeman 2002), but less evidence is provided by empirical studies.

With the change in economic structure in the U.S. over the past few decades, traditional goods-producing sectors such as agriculture and manufacturing are giving way to service-producing sectors. There is also increasing concern regarding amenities, geography, infrastructure and quality of life, which play an important role in regional economic growth. For years, economists and policy makers alike have analyzed the relationship between amenities (e.g., outdoor recreational infrastructure, climate and land) and the attraction of people and jobs to certain cities or counties, hoping to unlock the key to urban or rural growth and development. Florida's theory of creative class (2002a, 2002b, 2005, 2007, and 2008) has made a notable impact in both the policy making and scholarly fields. Florida argued that in a globalized economy in which innovation constitutes a competitive advantage. It is possible to identify a component of the labor force that is particularly important for this advantage because the labor force is technically, socially, and artistically dependent on the job. This “creative class” within the labor force has particular preferences for work and private life and prefers to locate in cities with high levels of cultural services, ethnic diversity and active outdoor recreation. Gottlieb (1994) and Deller et al. (2001, 2008) also argued that using amenities as an economic development tool appears to be a powerful one and showed that higher amenities areas experience faster growth.

The association between natural and built-in amenities with the overall quality of life and economic growth patterns has been well established within the development literature (Deller et al., 2001; Deller et al., 2008). However, innovation capacity, as an important representation of competitive advantage and a potential indicator of economic growth, has not been analyzed with a linkage to amenities. The lack of analyses which have been linked to amenities creates several limitations that need to be addressed. First, much of the literature lacks solid evidence associating county level innovation patterns with natural amenities. Second, because of the public goods nature of many natural and built-in amenities, the measurement of those amenities has proven to be a challenge. The intent of this applied empirical study is to address the limitations above, while focusing on the potential value of natural amenities.

Beyond these introductory comments, this study is composed of three parts. First, after an introduction of innovation capacity measurements, this study describes measures of natural amenities and other possible driving factors of innovation capacity. The empirical results are then presented, and the study closes with a summary of findings and discussions.

1.2 Literature Review

The U.S. Department of Commerce defines “Innovation” as “the design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational structures, or business models for the purpose of creating new value for customers and financial returns for the firm” (Department of Commerce [DOC] 2008). Innovation can result in the introduction of new or better goods and services and is manifest in adopting new technologies and processes that increase productivity or lower cost. In an article titled “How to keep Americans competitive”, Gates (Wall Street Journal, 2007) wrote that “For centuries people assumed that economic growth resulted from the interplay between capital and labor. Today, we know that these elements are outweighed by a single critical factor: innovation” (Wall Street Journal, 2007).

With globalization, more researchers have participated in the analyses of innovation and technology development. There has been increased interest in the measurements of innovation capacity at the national or regional level. Nelson (1993) compared the national innovation system (NIS) in twenty countries in the world and found out that the modern national innovation system has a complicated structure. The NIS includes various structural and technological behavior factors, such as universities and research institutes, and government research and development funds. Furman et al. (2002) used seventeen Organizations for Economic Co-operation and Development (OECD) countries’ data from 1973 to 1996 to analyze the major determinants of a country's innovation capacity. Their study results showed that the country's innovation capacity, which is measured as the number of patents obtained, is affected by the R&D investment, the choice of institutional policies, the stock of knowledge, the industrial cluster, and R&D investment in universities. Other studies such as Gans and Stern's (2003) research on 29 OECD countries from 1980 to 2000 yields similar results to Furman et al.'s (2002).

Riddel and Schwer (2003) first applied the theoretical structure of the national innovation system to the regional innovation system (RIS). Their study used 52 states data and estimated a generalized two-stage random effects model of hi-tech employment and patenting activity. The results showed that the stock of knowledge, industry R&D expenditures, and the number of high-tech employees explain the rate of change of innovation among the states during the 1990s. Most innovation literature has focused on countries and states due to the greater availability of data. Fewer studies have focused on smaller, disaggregated geographic units. Efforts to compare innovation at a county-level unit of analysis have occurred only sporadically in recent years (Lee, 2006; Barkley et al. 2006). To date, the most comprehensive county-level innovation analysis is from Lee (2006), who examined select counties in the southern United States in a series of descriptive models. Lee's work presented empirical estimates of the impacts of the local characteristics of RIS on innovative activity in non-metropolitan and rural counties, using utility patents as the measure of innovative activity. Results showed that university spillovers and economy size impacted the likelihood of patenting. In addition, the probability of having a patent in rural or non-metro county areas is positively related to university spillovers and the size of local economy. However, the unlikelihood of patenting was positively related to the metro patent activities, indicating “backwash” effects.

This study will analyze the innovation capacity at the county level with a focus on natural amenities. The following literature describes the measurements of innovation capacity in detail and also discusses the importance of natural amenities.

1.2.1 Innovation Capacity Measurements

With rapid economic development in the new century, innovation becomes a prevalent concept in urban and regional studies. Global shifts toward open market-based economies and recent advances in telecommunication technologies have made innovation the “critical factor” for economic success. Innovation, by definition, is a process that begins with an invention, and results in the introduction of a new product, process or service to the marketplace (Small Business Administration, 2009).

Many studies have generally categorized innovation measurements into two groups: innovation inputs and innovation outputs (Patanawaraha and Polenske, 2007; Acs et al. 2002; Slaper and Thompson 2009; Coombs et al. 1996; Barkley et al. 2006). To be more specific, researchers define innovation inputs mainly as R&D expenditures and employment in creative sectors or high-tech manufacturing sectors; innovation outputs are defined as patent counts. Several studies have illustrated and examined innovation activities by analyzing the factors that contributed to them. Attempts to create an index of innovation, such as the innovation index published by Business Week, which compiles the top 20 innovators in North America, have focused on states or countries. In 2005, Oregon’s Governor and Legislature created the Oregon Innovation Council to develop an innovation-based strategy to grow Oregon's economy. The State New Economy Index (New Economy Index) uses 21 indicators to measure the differences among states in terms of economic structure and operation. The innovation capacity category, which consists of five indicators such as high-tech jobs, scientists and engineers, patents, industry investment in R&D and venture capital, is calculated by an aggregated score and ranked by states.

Most efforts have focused on states or countries due to the greater availability of data, but these can introduce aggregation bias. This particular bias occurs when the units of analysis are not specific enough to reveal the true effects on the underlying structural construct of interest. For example, economic growth has not been distributed evenly through states as the U.S. economy has experienced overall growth. The innovation literature has focused on smaller, disaggregated geographic units only in recent years (Barkely et al. 2006; Lee 2006; Slaper and Thompson 2009). According to the empirical econometric analysis of innovation capacity measurements in the previous literature, the following three indicators are summarized as follows:

(1) Number of patents or innovations

By definition, patents counts are the number of patents either applied for or granted during certain periods (USPTO, 2009). Patent counts are the most popular but are also the most arguable indicator in use. Researchers prefer to use patent data because it is available in most states and counties and also can be used extensively by researchers to conduct time-series or cross-sectional analyses. However, as the sole proxy for innovation, Slaper and Thompson (2009) argued that patents are insufficient for monitoring all innovation activity, such as changes in organizational structures that cannot be patented.

Koo (2005) presents an exploratory analysis of U.S. industry clusters from the prospective of knowledge and its flow using a common data reduction technique and patent data. The study also examines geographical patterns of knowledge-based clusters in the U.S. in terms of employment and patents. Acs et al. (2002) provided an exploratory and a regression-based comparison of the innovation count data and data on patent counts at the lowest possible levels of geographical aggregation. Barkley et al. (2006) used county-level utility patents and university research and development expenditures as measures of local innovation and innovative capacity.

Although there are advantages of patent counts that have guaranteed its attractiveness among analysts, patent counts also have many shortcomings. Original patent data in the United States lists cities of inventors and owners of patents, yet the owners of a patent may differ from the inventors of the same patent (USPTO 2008). Additionally, changes in organizational structures cannot be patented, which makes patent counts insufficient to serve as the sole proxy of innovation activity.

Since patents are only intermediate outputs of the innovation production processes, the final innovative outputs as innovations that are introduced to the economic system. In contrast to patent data, which mark the certification of an invention, innovation citations announce the market introduction of a commercially viable product (Acs et al. 2002). The study by Coombs et al (1996) presents an application of a recently developed method for measuring innovative activity in a national economy based on new product announcements in trade and technical journals.

(2) Share of high-tech employment

Since knowledge fuels new ideas and innovations to boost productivity, Henderson and Abraham (2004) analyze innovation in terms of factors that are essential to rural knowledge-based activity. The dependent variable is derived from high-tech occupations; in other words, share of employment in high-tech sectors.

Barkley et al. (2006) also found a strong correlation between local indicator of RIS and measures of economic growth for metropolitan areas in the south. In this research, cluster analysis was used to divide the 107 metro areas in the South according to 16 indicators of innovative activity (e.g., patents, university R&D expenditures); innovative capacity (e.g., employment in high-technology manufacturing, employment in scientific and technical occupations); and entrepreneurial environment (e.g., venture capital investments, employment in business services).

(3) Number of firms in Not-Elsewhere-Classified (NEC) sectors

Services in the NEC sector include activities which cannot be classified, such as activities in business, professional, labor, political, and similar organizations as well as private households. Because of their implicit characteristics in NEC sectors, firms in those sectors have great possibility to be innovative. Firms in NEC sectors are tend to be small firms and two recent studies (CHI Research, 2003, 2004) by the U.S. Small Business Administration (SBA) provided support for small firms as important sources of innovation. The entrepreneur is naturally associated with the small startup-firm, and these reports found that small firms were more innovative per employee than larger firms.

As stated earlier, measurement of innovation activity is a complicated problem because of its spatial distribution characteristic. There are many problems associated with using only one innovation index to analyze all innovation activities. Previous attempts to index innovation have developed schemes that weigh components based on their theoretical importance (Atkinson and Correa, 2007) or elect to equally weigh items due to lack of consensus on the relative importance (EIS 2006a, 2006b). Measures of innovation also may not apply to both rural and urban economies. The three major categories of measurements of innovation capacity have only demonstrated innovation activities through one aspect at a time and do not consider multiple factors.

Some studies have also tried to construct innovation indices from a comprehensive angle. As early as 1998, the Progressive Policy Institute released the first edition of the New Economy Index, which includes the innovation capacity indicator. This study continued in the last decade and has been updated twice. It is a well-known economic index and has attracted social attention. It examines what is actually new about the so-called "New Economy" and offers policy makers a framework for economic development strategies aimed at promoting fast and widely shared economic growth and prosperity. This index only report at the state level, but might foster interest in exploring innovation indicators at the county level.

The most recent study on innovation index constructions was done by the Economic Development Administration (EDA 2009). In their study, a portfolio innovation index (PII) was calculated based on four sub-indices： human capital, economic dynamics, productivity and employment, and economic well-being. Those four sub-indices were weighed relatively equally, and because the economy well-being index has a less direct relationship to innovation activities, it receives one-third the weight of the other sub-indices. Although this study has constructed a general measure for the innovation index, the equal weight of sub-indices has no theoretical support.

1.2.2 Amenities

Numerous studies have documented that amenities play an increasingly important role in driving regional economic growth (Roback 1982; Blanchflower and Oswarld 1994; Gottlieb 1994; Deller et al. 2001; Deller et al. 2008). Theoretical work by Roback (1982) and Blanchflower and Oswald (1994) suggest that amenities and quality of life factors are capitalized into wages and rents in a manner that could hinder broader economic growth. This means areas with higher levels of amenities might experience lower wages and higher unemployment rate. Deller et al. (2001) applied a structural model of regional economic growth to analyze the role of amenities and quality of life. Five indicators of amenities such as climate, land, water, winter recreation and recreational infrastructure are found with strong evidence to be endowments of higher levels of growth. In addition, Deller et al. (2008) employed a Bayesian Modeling Average (BMA) approach to address the theoretical background of amenities and economic growth. Results were similar to the their previous study and showed that areas with higher amenities experienced faster growth but that some level of value-added development still may be required to realize that growth. After a detailed review of the literature, Gottlieb (1994) suggested that the argument for using amenities as an economic development tool appears to be a powerful one. The author also suggested that jurisdictions should focus on basics like schools, environment and crime and that amenities should be managed in the broader context of trends in urbanization.

1.3 Model and Data

1.3.1 Model

To empirically estimate the existence of local characteristics of innovation capacity in U.S. counties, past research (Acs et al. 1994; Audretsch and Feldman 1996; Lee 2006) used the "knowledge production function" (KPF). Griliches (1979) first used the production function approach to model the production of knowledge outputs as a function of knowledge inputs in an effort to estimate the returns to R&D. His KPF included a measure of external knowledge available to firms in order to explicitly capture the spillover of knowledge between firms and industries. The model of KPF (Griliches, 1979) can be represented as:

$$\mathrm{IA} = \alpha \mathrm{HK}^{\beta} \mathrm{RD}^{\gamma} \varepsilon \tag{1.1}$$

Where IA is the degree of innovative activity; RD is industrial R&D expenditures; HK is human capital inputs; α, β and γ are estimated parameters; and ε is the error term. The units of observation for estimating the model of the KPF can be at county, industry, or firm level.

Following Griliches (1979) and others (Jaffe et al., 1993; Acs et al., 2002, Lee, 2006), the concept of KPF was used to identify the contributing factors to a county's innovative activity. This study modified the traditional approach to estimate the relationship between innovative activity and natural amenities. The general relationship is provided in equation (1.2).

$$\mathrm{IA}_{\mathrm{i}} = \mathrm{LE}_{\mathrm{i}}^{\alpha} \mathrm{UA}_{\mathrm{i}}^{\beta} \mathrm{NA}_{\mathrm{i}}^{\gamma} \varepsilon \tag{1.2}$$

Where IA stands for innovative capacity measurements (number of patents, number of firms in NEC sectors and share of employment in high-tech industries); LE stands for local economic conditions (e.g., population, unemployment rate); UA stands for urban amenities (e.g., crime rate, museums); NA stands for natural amenities (e.g., temperature, humidity, number of trails, wild land acres, and number of state and local parks); i is the index for each county in the U.S.; α and β are parameter coefficients; and ε is the error term.

Decomposing equation (1.2) into specific local economic conditions and natural amenities yields the general-form function represented in the following equation:

$$\mathrm{IA_i} = \mathrm{f(POP, CRM, WAR, UEM, UNI, MUS, GOF, TMA, SUN, TMJ, HMJ, WAT, WLA, BOA, PIN, SWM, TRH, CAM, WIN, PAR)} \quad (1.3)$$

Where $\mathrm{IA_i}$ are the three measures of innovation capacity, all variables in equation (1.3) are defined in the following table 1.1.

Table 1.1 Variable Descriptions and Data Sources

Variable	Description
Patents98 **PAT**	Number of Patents, 1998 (USPTO)
hightechemp98 **EMP**	Share of employment in high-tech industries, 1998 (County Business Patterns, U.S. Census)
NEC98 **FIR**	Number of firms in Not-elsewhere-classified sectors, 1998 (County Business Patterns, U.S. Census)
pop98 **POP**	Population, 1998 (U.S. Census)
Crime **CRM**	Number of crime accidents
wage rate98 **WAR**	Wage distributions, in thousands of dollars, 1998 (Bureau of Economic Analysis)
unemployment98 **UEM**	Unemployment rate, 1998 (Bureau of Labor Statistics)
Universities **UNI**	Number of universities which offer bachelor’s degree or higher
#Museums **MUS**	Number of Museums
#Golf courses **GOF**	Number of public and private golf courses
Temperature Jan **TMA**	Temperature in January, 1998, (National Oceanic and Atmospheric Administration, NOAA)
Sunlight Hours Jan **SUN**	Sunlight Hours in January, 1998 (NOAA)
Temperature Jul **TMJ**	Temperature in July, 1998 (NOAA)
Humidity Jul **HMJ**	Humidity in July, 1998 (NOAA)
Water area acres **WAT**	Water area, 1998 (National Out-door Recreation Supply Information System, NORSIS)
Wild land acres **WLA**	Wild land acres, 1997, (NORSIS)
#Boat Units **BOA**	Number of boating units, 1997, (NORSIS)
#Picnic Units **PIC**	Number of picnic units, 1997, (NORSIS)
#Swim Units **SWM**	Number of swim units, 1997, (NORSIS)
#Trailheads **TRH**	Number of trailheads, 1997, (NORSIS)
# Camping **CAM**	Number of camping units (campgrounds and camping sites added together), 1997, (NORSIS)
#Winter activity **WIN**	Number of winter activity units (ski, snowboard added together), 1997, (NORSIS)
#Fish and Hunting **FHU**	Number of fishing and hunting units, 1997, (NORSIS)
#Ski resorts **SKR**	Number of ski **resorts,** 1997, (NORSIS)
#Parks **PAR**	Number of parks (state, local, county and regional parks added together), 1997, (NORSIS)

1.3.2 The Dependent Variables

Since three general categories of innovation capacities measures have been applied to econometric models, this study will adopt the previous measurements as innovation capacity as well.

(1) Number of patents: this is a count of patents provided by United States Patent and Trademark Office (USPTO) from 1990 to 1999.

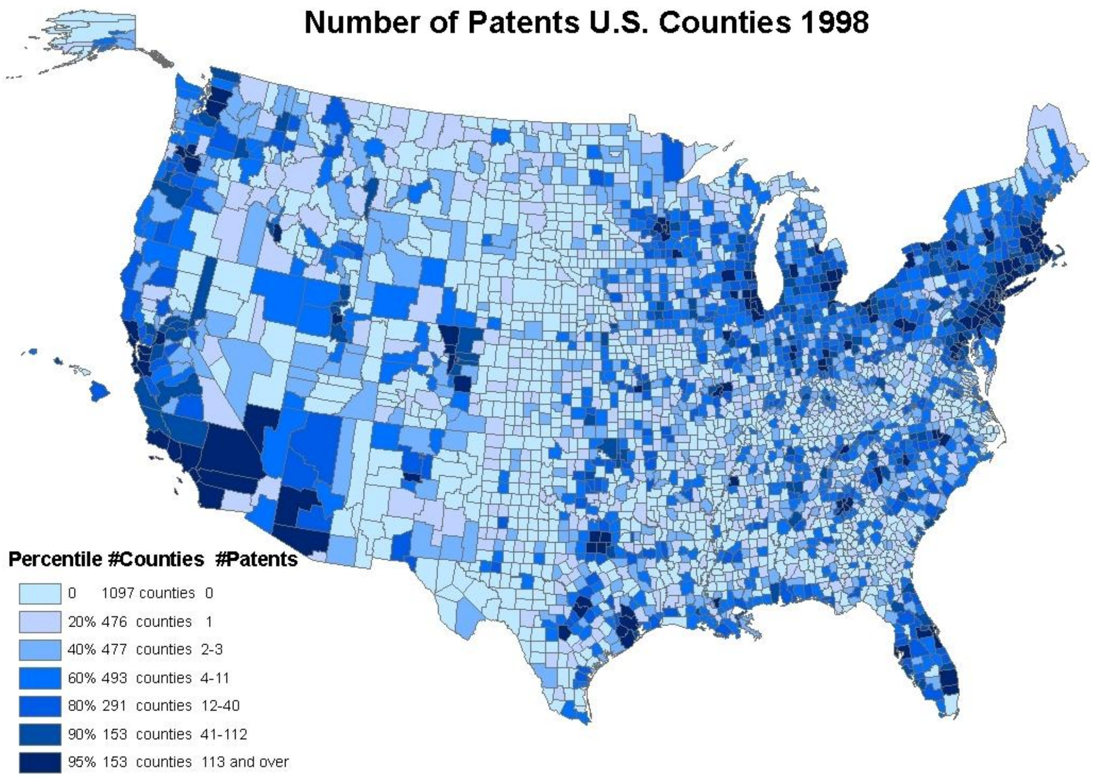

Figure 1.1: Number of Patents, U.S. counties 1998
Source: United States Patents and Trademarks Office

Figure 1.1 shows that counties with high levels of innovation capacity in terms of patents are in California, Illinois, Michigan, Minnesota, New York, Texas, Washington, and some northeastern states.

(2) Number of firms in not-else-where classified (NEC) sectors: this is a count of firms in NEC sectors as defined by the North American Industry Classification System (NAICS), and data is obtained from the County Business Patterns (U.S. Census).

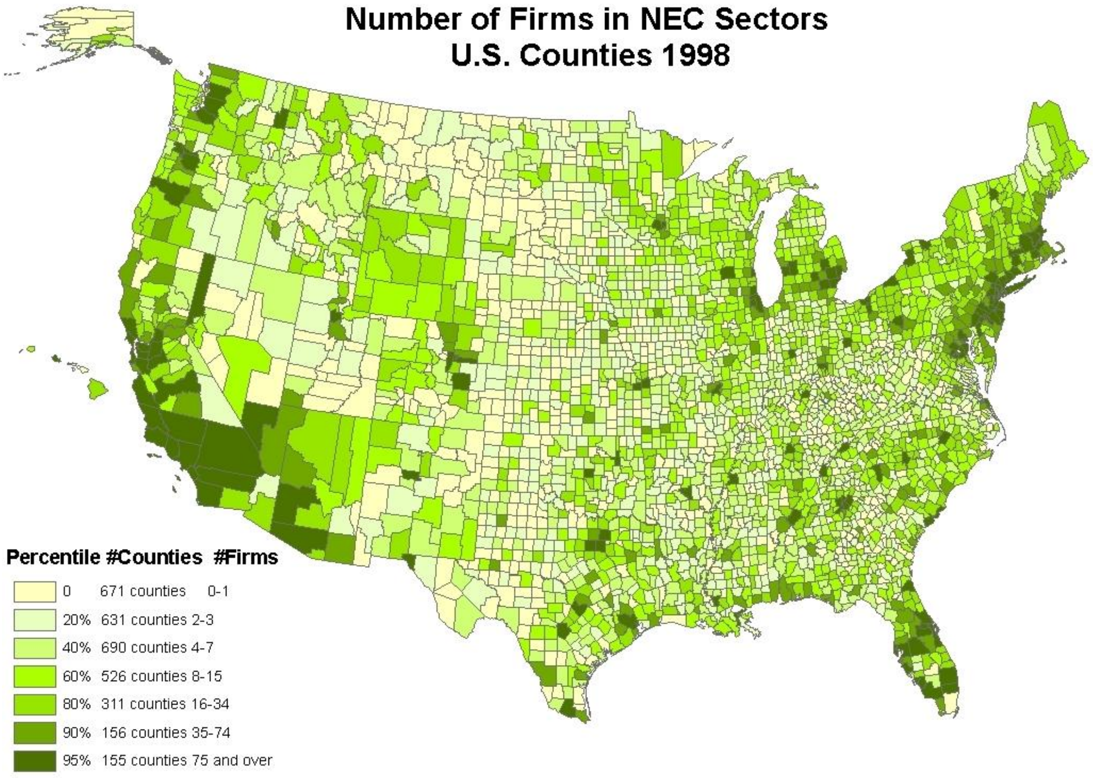

Figure 1.2: Number of Firms in Not-Else-Where classified (NEC) Sectors, U.S. counties 1998
Source: County Business Patterns, U.S. Census; Bureau of Economic Analysis

Figure 1.2 shows that counties with high levels of innovation capacity in terms of firms in NEC sectors are in Arizona, California, Florida, Illinois, Nevada, Washington, and some northeastern states.

(3) High-tech employment share: High-tech sectors are defined by American Electronics Association (AEA) and this selection is also consistent with EDA (2009). Numbers of employees in those sectors are obtained from the County Business Patterns (U.S. Census).

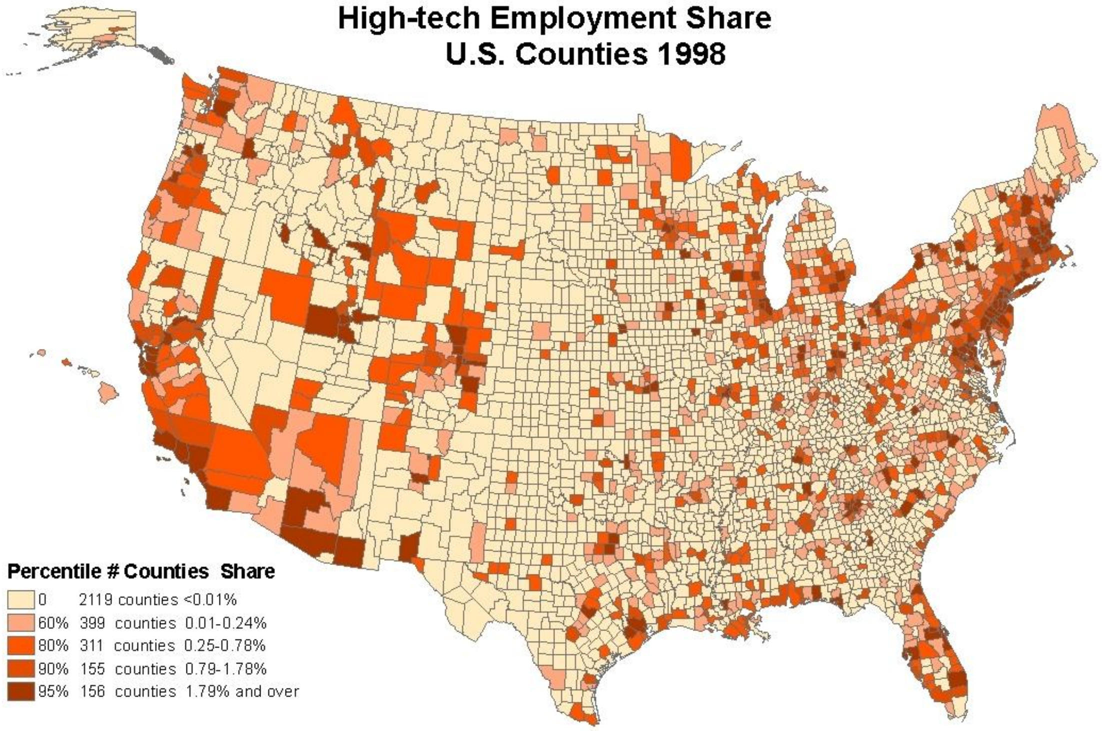

Figure 1.3: High-tech Employment Share, U.S. counties 1998
Source: County Business Patterns, U.S. Census; Bureau of Economic Analysis

Figure 1.3 shows that counties with high levels of innovation capacity in terms of high-tech employment share are in Arizona, California, Colorado, Connecticut, Florida and Massachusetts.

The above three measurements will be dependent variables and the following three groups of measurements will be independent variables.

1.3.3 The Explanatory Variables

The measures of amenities proposed here are built on the work of the Economic Research Service (ERS, 1999), Deller et al. (2001, 2008), among others. The ERS used six measures of natural amenities that include warm winter (average January temperature), winter sun (average January days of sun), summer temperature (average July temperature), summer humidity (July humidity), typographic variation (typography scale) and water area (water area as proportion of total county area). Deller et al. (2001, 2008) used five broad based indices of amenity and quality of life attributes: climate, land, water, winter recreation, and developed recreational infrastructure. The first index captures a region's climatic conditions such as temperature, precipitation, sunny winters, and dry summers. Developed recreational infrastructure represents a region's facilities, such as golf courses, tennis courts, swimming pools, playgrounds and significant historical and cultural dimensions. This study proposes to categorize amenities and other variable that could contribute to innovation capacity as follows:

Group A: Natural Amenities

This group of variables is natural amenities, and includes recreation amenities (ski resorts, national parks, lakes, marinas, golf courses, and water area), and climate (temperature in July and January, precipitation, sunlight).

Group B: Urban Amenities

This group of variables is urban amenities, and includes museums, universities which offer masters degree or higher and crime rate.

Group C: Local Economic Conditions

This group of variables includes wage rate, unemployment rate, and population.

This study uses the National Outdoor Recreation Supply Information System (NORSIS) data set developed and maintained by the USDA Forest Services' (FS) Wilderness Assessment Unit, Southern Research Station, located in Athens, Georgia. The FS maintains an extensive county-level data set documenting facilities and resources that support outdoor recreation activities. In addition to NORSIS, other data that were collected from various sources such as U.S. Census County Business Patterns, Economic Research Service, and Bureau of Economic Analysis are presented below.

Table 1.2: Descriptive Statistics

	Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
Dependent Variables	PAT	#	3097	25.736	139.090	0.000	4931.000
	EMP	%	3111	.335	1.220	0.000	26.207
	FIR	#	3111	19.406	73.721	0.000	2318.000
Local Economic Conditions	POP	100,000	3083	.894	2.920	.001	94.373
	WAR	100,000 $	3086	13.383	59.142	.013	1547.211
	UEM	rate	3110	5.212	2.857	1.000	29.900
Urban Amenities	CRM	1,000 incidents	3111	.414	2.146	0.000	66.351
	UNI	#	3111	0.498	1.928	0.000	43.000
	MUS	#	3111	1.506	4.089	0.000	106.000
Natural Amenities	GOF	#	3111	2.131	4.213	0.000	74.000
	TMA	F^o	3111	32.910	12.027	1.100	67.200
	SUN	hours	3111	151.589	33.138	48.000	266.000
	TMJ	F^o	3111	75.856	5.354	55.500	93.700
	HMJ	10%	3111	5.613	1.462	1.400	8.000
	WAT	100 acres	3111	.459	1.126	0.000	7.500
	WLA	100,000 acres	3081	1.356	5.706	0.000	92.597
	BOA	#	3081	0.871	3.527	0.000	52.000
	PIC	10 #	3081	.085	.402	0.000	7.970
	SWM	#	3081	0.365	1.484	0.000	29.000
	TRH	#	3081	0.940	2.756	0.000	50.000
	CAM	1,000 #	3081	.298	.707	0.000	12.294
	WIN	#	3081	0.074	0.368	0.000	7.000
	FHU	#	3081	0.300	1.057	0.000	22.000
	SKR	#	3081	0.036	0.239	0.000	4.000
	PAR	#	3081	1.739	6.107	0.000	211.000

1.3.4 Ordinary Least Square Models

The innovation capacity consists of three different measurements and there are many factors contributing to the innovation capacities. Thus, a first step in modeling was to treat each variable separately and to perform a test to check multicollinearity. As a result, employment is excluded from the independent variables groups because it is highly correlated with population ($\rho = 0.9957$), crime rate ($\rho = 0.7944$), wage rate ($\rho = 0.9072$), number of universities ($\rho = 0.8087$), number of museums ($\rho = 0.7802$), and number of golf courses ($\rho = 0.7448$). Regular ordinary least squares (OLS) model has been applied to high-tech employment share as the innovation capacity measurement. An F test was performed in order to check whether natural amenities are significant in the models as a group in the last step.

1.3.5 Count Data Models

Count data describe events that take nonnegative integer values for each observation. Count data usually have a non-negligible probability of zero, which makes the use of log-linear relationships problematic. One possibility for dealing with the impossibility of taking a logarithm of zero is to eliminate all groups of data that include observations of zero, but this requires that the number of these groups is small compared to the whole sample. Another possibility is to add a small value to all zero observations, and to add a dummy variable to implicitly allow a value different from one so that the logarithms can be taken.

However, none of these devices is satisfactory because an ordinary least square (OLS) analysis does not constrain the expected number of events to be nonnegative, and thus the analysis will suffer from a sample selection bias (King, 1988). King (1988) reviewed several of the possibilities for dealing with problems where observations were equal to zero, and concluded that OLS estimates of count data were inefficient with inconsistent standard errors, and that logged OLS estimates on event count data had the same problems and were also biased and inconsistent (King, 1988). Various authors have shown that the analysis of count data is improved by the use of discrete distributions, such as the Poisson and the negative binomial distribution (Hausman *et al.*, 1984; Cameron and Trivedi, 1998).

Poisson Regression Models

The Poisson distribution has been widely used to avoid the approximation of count data using a continuous distribution. The primary equation of the model is (Greene, 2003):

$$P(Y_i = y_i|\lambda_i) = \frac{e^{-\lambda_i}.\lambda_i^{y_i}}{y_i!}, \lambda_i > 0 \; and \; y_i = 0,1,2 \ldots \quad (1.4)$$

where *Yi* denotes the number of occurrences of a certain event for an individual *i* within a given interval of time; and any realization y_i is observed only at the end of each interval.

The first two moments of the Poisson distribution are equal, and are given by E[*Yi*] =VAR[*Yi*] = λ_i. If the data are fairly homogenous, this functional form does not cause difficulties, but if some observations are large outliers that cannot be excluded, then λ_i becomes very large and the log likelihood of this observation becomes extremely small. The assumed equality of the conditional mean and variance functions is the major shortcoming of the Poisson Regression Model (PRM). Many alternatives have been suggested (Hausman *et al.*, 1984; Cameron and Trivedi, 1998; and Winkelmann, 2003). The most common is the Negative Binomial Regression Model (NBRM) which arises from a natural formulation of cross-section heterogeneity, and is discussed below.

Negative Binomial Regression Models

Greenwood and Yule (1920) were credited for first deriving and applying the negative binomial distribution in the literature. The suitability of the NBRM is verified by a test to determine whether overdispersion exists. The NBRM addresses the failure of the PRM by adding a parameter, α, that reflects unobserved heterogeneity among observations. Cameron and Trivedi (1998) offered several different tests for overdispersion. A simple regression based procedure was used for testing the hypothesis. The null hypothesis is that $Var(y_i)=E(y_i)$; the alternative hypothesis that $Var(y_i) = E(y_i)+\alpha g(E(y_i))$.

Following Cameron and Trivedi (1998), the negative binomial equation takes the form:

$$\Pr(y|x) = \frac{\Gamma(y+\alpha^{-1})}{y!(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1}+\lambda}\right)^{\alpha^{-1}}\left(\frac{\lambda}{\alpha^{-1}+\lambda}\right)^{y}, y_i = 0,1,2,\ldots, and\ \alpha \geq 0 \qquad (1.5)$$

where Γ() is the gamma function; and $E(y_i|x_i)= \lambda_i = \exp(x_i`\beta)$.

The negative binomial distribution relaxes the Poisson condition that the mean equals the variance so that the variance is given by:

$$v_i = V(y_i|x_i) = v(\lambda_i,\alpha) = \lambda_i + \alpha\lambda_i^2 \qquad (1.6)$$

In the case of overdispersion, as is evident in this analysis, the mean (λ) is less than the variance (v).

The single parameter is equal to the expected value of the Poisson distribution in the Poisson Regression Model (PRM), and the independent variables are introduced into the model by expressing as deterministic function of these variables. In order to guarantee a positive expected value, the functional form estimated by STATA is $\lambda_i = \exp(x_i\beta)$, where β is the parameter vector, and x is the vector of independent variables. Results for PRM are provided in appendix A. Although results from PRM are reasonable, the use of Poisson model is only appropriate if the data have null dispersion, that is, if the mean of the dependent variable is equal to its variance. The likelihood ratio test (LRT) at the bottom of table 1.5 is a test of the overdispersion parameter α. When the overdispersion parameter is zero, the negative binomial distribution is equivalent to a Poisson distribution. In this case, α is significantly different from zero and thus reinforces the assumption that the Poisson distribution is not appropriate. Therefore, a negative binomial model is used for the analysis.

1.4 Results and Discussion

1.4.1 Estimated Results

Table 1.3 shows results using OLS regression for high-tech employment as the dependent variable. The unemployment rate, temperature in July and number of parks show negative effects on the innovation capacity. But crime rate, wage rate, museums golf courses, temperature in January, sunlight hours in January, wild land areas, trailhead and fishing and hunting show positive and significant effects on innovation capacity. In general, warm weather in the winter and outdoor activities increase the innovation capacity for U.S. counties in this model.

Table 1.3: Ordinary Least Square Results for High-tech Employment Share

EMP	Coefficient	Std. Error	t	P	95% Confidence Intervals	
POP98	-0.001814	0.023	-0.08	0.937	-0.047122	0.043494
Crime	-0.030686	0.016	-1.92	0.055	-0.061999	0.000628
Wage rate98	0.008506	0.001	8.48	0.000	0.006541	0.010472
Unemployment98	-0.048966	0.007	-7.12	0.000	-0.062445	-0.035486
#Universities	-0.013739	0.020	-0.69	0.490	-0.052769	0.025291
#Museums	0.022497	0.010	2.24	0.025	0.002825	0.042168
#Golf courses	0.042134	0.007	6.03	0.000	0.028440	0.055827
Temperature Jan	0.011944	0.002	5.05	0.000	0.007308	0.016580
Sunlight Hours Jan	0.001641	0.001	2.44	0.015	0.000323	0.002960
Temperature Jul	-0.035207	0.006	-6.24	0.000	-0.046272	-0.024142
Humidity Jul	-0.004792	0.014	-0.34	0.736	-0.032675	0.023092
Water area acres	-0.004005	0.017	-0.23	0.815	-0.037625	0.029614
Wild land acres	-0.008209	0.004	-2.2	0.028	-0.015512	-0.000906
#Boat Units	-0.004461	0.009	-0.49	0.623	-0.022254	0.013331
#Picnic Units	0.004519	0.069	0.07	0.948	-0.131646	0.140683
#Swim Units	-0.008620	0.019	-0.45	0.651	-0.045924	0.028684
#Trailheads	0.018705	0.008	2.21	0.027	0.002091	0.035320
#Camping	0.004297	0.031	0.14	0.891	-0.057437	0.066031
#Winter activity	0.001251	0.059	0.02	0.983	-0.114278	0.116781
#Fish and Hunting	0.040566	0.021	1.92	0.055	-0.000871	0.082003
#Ski resorts	0.006727	0.080	0.08	0.933	-0.149525	0.162979
#Parks	-0.018388	0.005	-3.91	0.000	-0.027613	-0.009164
_cons	2.447092	0.364	6.73	0.000	1.734182	3.160002

Table 1.4: Joint Test of Amenities Regression Coefficient for Employment Share

Model	Unrestricted Model[1] R^2	Restricted Model[2] R^2	Calculated F-Statistics	Degrees of Freedom
EMP	0.2806	0.2525	7.40*	(16,3031)

*denotes calculated F-statistic is greater than the tabled F-statistics at the one percent significance level.

[1] Unrestricted model denotes the model with all variables included.

[2] Restricted model denotes the model where all the variables which represent natural amenities are excluded.

Table 1.4 shows the F test[1] result that natural amenities as a group was a statistically significant regressor.

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[1] This F test procedure provides a formal method of deciding whether a group of variables should be added to a regression model. It is calculated as the following: $F = \frac{\frac{(R_u^2 - R_r^2)}{\#\, of\ new\ regressors}}{\frac{(1-R_u^2)}{n-k}}$ where R^2 stands for the R-squared and u and r refer to the unrestricted and restricted models; *n-k* is the degrees of freedom of the unrestricted model The null hypothesis is: unrestricted model does not provide a significantly better fit than the restricted model (Gujarati and Porter, 2009 p245).

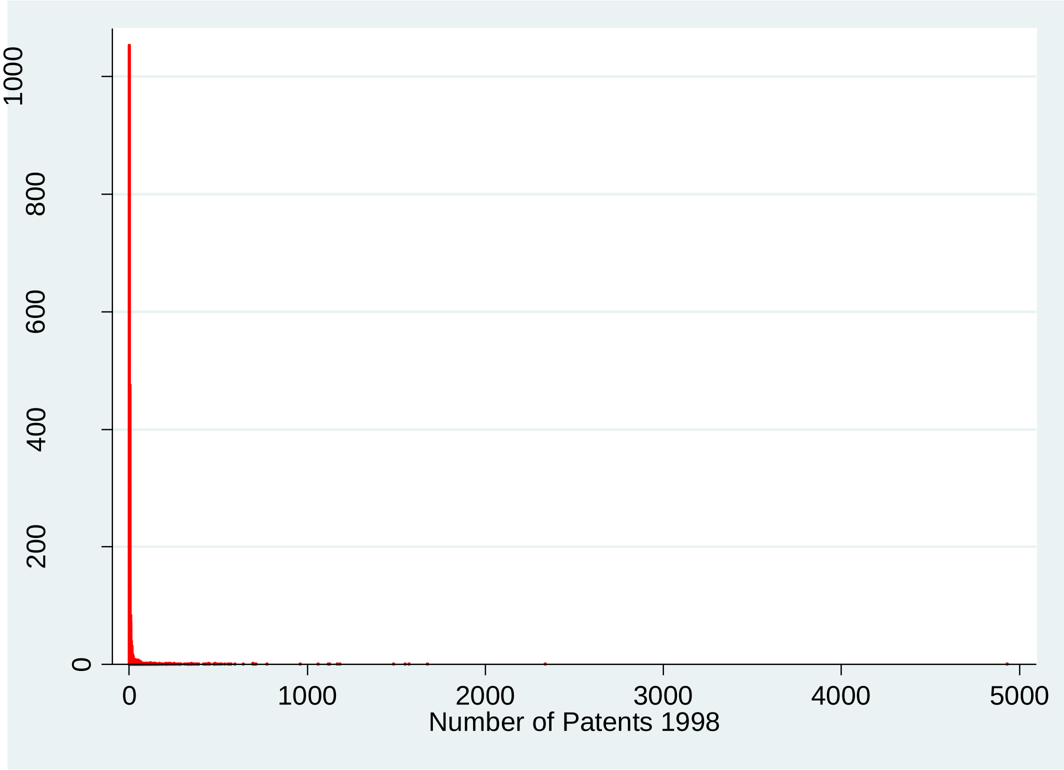

Figure 1.4: Distribution of number of patents in 1998.

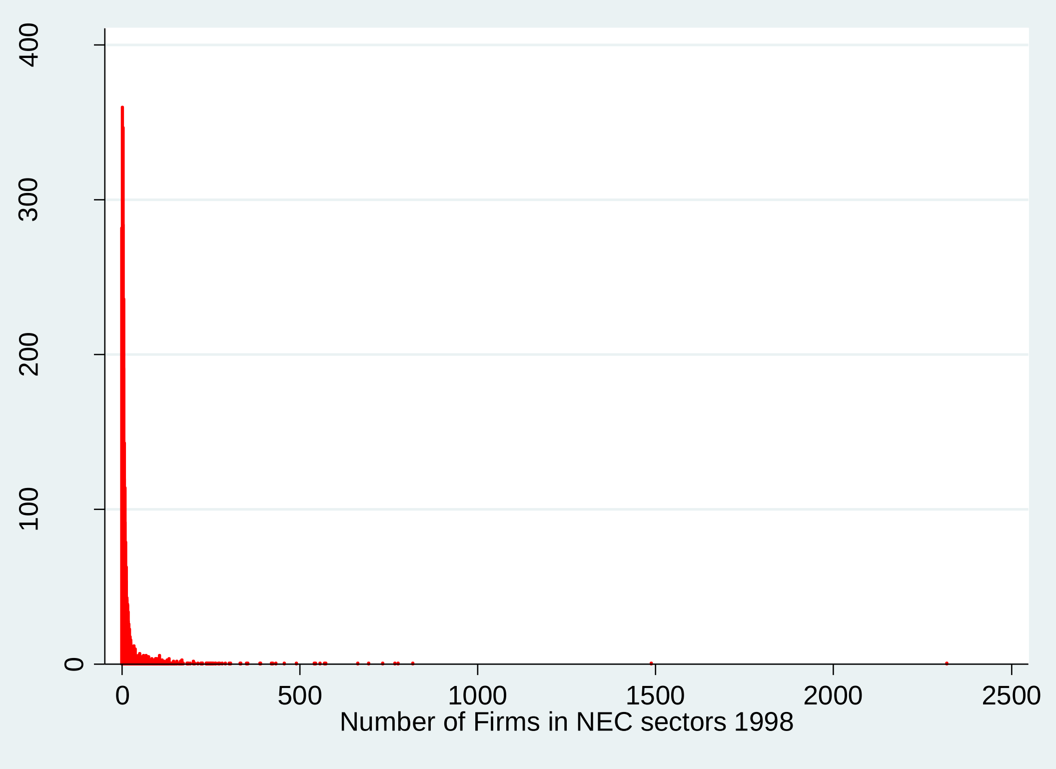

Figure 1.5: Distribution of number of firms in NEC sectors 1998.

Figure 1.4 and Figure 1.5 shows that the distribution of number of patents and the distribution of number of firms in NEC sectors in 1998 for all counties is skewed and not normality distributed. According to the descriptive statistics in Table 1.2, the variances of number of patents and firms in NEC sectors are greater than the means of them. These data suggest that a negative binomial regression may better fit these dependent variables than a Poisson regression model Results for the Negative Binomial regression model are shown in Table 1.5.

Table 1.5: Negative Binomial Regression Model Result for Patents

PAT	Coefficient	Std. Error	t	P	95% Confidence Intervals	
POP98	0.924309	0.057	16.25	0.000	0.812808	1.035810
Crime	-0.324715	0.040	-8.02	0.000	-0.404040	-0.245389
Wage rate98	-0.016967	0.002	-10.16	0.000	-0.020239	-0.013695
Unemployment98	-0.206117	0.012	-17.37	0.000	-0.229375	-0.182858
#Universities	0.182407	0.033	5.51	0.000	0.117551	0.247263
#Museums	0.092248	0.017	5.53	0.000	0.059574	0.124922
#Golf courses	0.120086	0.013	9.2	0.000	0.094514	0.145658
Temperature Jan	0.015089	0.004	4.16	0.000	0.007979	0.022200
Sunlight Hours Jan	-0.001001	0.001	-1.05	0.293	-0.002865	0.000864
Temperature Jul	-0.028914	0.009	-3.26	0.001	-0.046295	-0.011534
Humidity Jul	-0.074096	0.020	-3.7	0.000	-0.113355	-0.034837
Water area acres	0.077860	0.024	3.24	0.001	0.030711	0.125009
Wild land acres	-0.016349	0.006	-2.92	0.003	-0.027319	-0.005380
#Boat Units	-0.025191	0.014	-1.85	0.065	-0.051945	0.001562
#Picnic Units	0.230529	0.113	2.04	0.041	0.009106	0.451952
#Swim Units	-0.009439	0.029	-0.33	0.745	-0.066236	0.047358
#Trailheads	0.018990	0.012	1.53	0.125	-0.005281	0.043261
#Camping	0.212916	0.054	3.95	0.000	0.107387	0.318445
#Winter activity	0.114738	0.090	1.28	0.202	-0.061547	0.291023
#Fish and Hunting	0.027962	0.032	0.87	0.386	-0.035231	0.091155
#Ski resorts	0.041815	0.115	0.36	0.716	-0.183730	0.267361
#Parks	-0.000520	0.011	-0.05	0.962	-0.021923	0.020884
_cons	3.823876	0.579	6.6	0.000	2.688643	4.959110
LR test for $\alpha=0$						
Prob>χ^2	0.000					

Table 1.6: Joint Test of Amenities Regression Coefficient for Patents

Model	Unrestricted Model Log likelihood	Restricted Model Log likelihood	Calculated LR Statistics	Degrees of Freedom
PAT	-8107.1543	-8256.9649	299.261*	16

*denotes calculated LR statistic is greater than the tabled chi-square-statistics at the one percent significance level.

Table 1.5 and table 1.7 show results using negative binomial regression for the count data. The Log Likelihood Ratio test result presented at the bottom of Table 1.5 and table 1.7 indicate that a negative binomial model is a better fit than the Poisson regression model for the data.

Table 1.5 shows regression results for patents as a measure of innovation capacity. Crime rate, unemployment rate and temperature in July, humidity in July and number of boat units are negatively affecting innovation capacity. Meanwhile, population, wage rate, number of universities, number of museums, number of golf courses, temperature in January, water area acres, wild land area acres, number of picnic units, number of camping units are positively affecting innovation capacity. In general, cool and dry summers, warm winters and more outdoor activities such as camping will increase the innovation capacity for U.S. counties in this model.

Table 1.6 shows the log likelihood ratio test (LR test)[2] result that those natural amenities as a group were statistically significant regressors in the negative binomial model.

Table 1.7 shows the regression result for number of firms in NEC sectors. Crime rate, unemployment rate and temperature in July present negative effects to innovation

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[2] The Loglikelihood ratio test is used to compare the fit of two models. The test statistic is calculated as follows: $\lambda = 2(\ln likelihood\ of\ unrestricted\ model - \ln likelihood\ of\ restricted\ model)$. This statistic follows the chi-square (χ^2) distribution with df equal to the number of restrictions imposed by the null hypothesis. The null hypothesis is: unrestricted model does not provide a significantly better fit than the restricted model (Gujarati and Porter, 2009 p274-276).

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capacity. Conversely, population, wage rate, number of universities, number of museums, number of golf courses, temperature in January, sunlight hours in January, water area acres, wild land area acres, number of camping units, number of fishing and hunting units and number of ski resorts present positive effects to innovation capacity. In general, cool summers, warm winters, more outdoor activities such as camping, fishing and skiing and higher urban amenities will increase the innovation capacity for U.S. counties in this model.

Table 1.8 shows the LR test result that those natural amenities as a group were statistically significant regressors in the negative binomial model.

Table 1.7: Negative Binomial Regression Model Result for FIR

FIR	Coefficient	Std. Error	t	P	95% Confidence Intervals	
POP98	0.537488	0.031	17.31	0.000	0.476626	0.598350
Crime	-0.143610	0.023	-6.37	0.000	-0.187808	-0.099413
Wage rate98	-0.009189	0.001	-9.80	0.000	-0.011028	-0.007351
Unemployment98	-0.041104	0.006	-6.57	0.000	-0.053363	-0.028845
#Universities	0.073602	0.019	3.83	0.000	0.035938	0.111266
#Museums	0.075147	0.010	7.60	0.000	0.055779	0.094515
#Golf courses	0.063879	0.007	8.86	0.000	0.049753	0.078005
Temperature Jan	0.014437	0.002	6.57	0.000	0.010131	0.018743
Sunlight Hours Jan	0.002238	0.001	3.73	0.000	0.001062	0.003414
Temperature Jul	-0.037364	0.005	-7.00	0.000	-0.047824	-0.026903
Humidity Jul	0.007518	0.013	0.60	0.551	-0.017177	0.032213
Water area acres	0.029415	0.015	1.96	0.050	0.000023	0.058807
Wild land acres	-0.007786	0.003	-2.26	0.024	-0.014530	-0.001043
#Boat Units	0.000299	0.008	0.04	0.970	-0.015445	0.016042
#Picnic Units	0.075096	0.062	1.21	0.228	-0.047018	0.197209
#Swim Units	-0.018031	0.016	-1.09	0.274	-0.050326	0.014264
#Trailheads	0.003542	0.008	0.45	0.654	-0.011923	0.019007
#Camping	0.215397	0.034	6.43	0.000	0.149702	0.281092
#Winter activity	0.046886	0.052	0.90	0.366	-0.054860	0.148631
#Fish and Hunting	0.060316	0.019	3.21	0.001	0.023488	0.097144
#Ski resorts	0.193649	0.069	2.79	0.005	0.057532	0.329765
#Parks	0.005211	0.006	0.82	0.410	-0.007183	0.017605
_cons	3.823876	0.345	10.33	0.000	2.888012	4.240262
LR test for α=0						
Prob>χ^2	0.000					

Table 1.8: Joint Test of Amenities Regression Coefficient for FIR

Model	Unrestricted Model Log likelihood	Restricted Model Log likelihood	Calculated LR Statistics	Degrees of Freedom
FIR	-9485.7286	-9712.9836	454.51*	16

*denotes calculated LR statistic is greater than the tabled chi-square-statistics at the one percent significance level.

Three models of innovation capacity measurement show relative different results on the contribution of local economic conditions, urban amenities and natural amenities. Across three models, lower unemployment rate, more museums, more golf courses, warm winters and cool summers will increase the innovation capacity for U.S. counties.

1.4.2 Predictive Power of the Preferred Models

The counties with high natural amenities are typically found where the Great Plains meet the Rocky Mountains along the western edge of the region, and in southern states with warmer climates. This study chose Cascade County in Montana, which is supposed to have higher natural amenity due to its location but has an average natural amenity rank (Economic Research Service, 1999) to perform an analysis of the preferred models discussed in section 1.4.1.

The three models were regressed by first leaving out Cascade County, and the dependent variables stands for innovation capacity were predicted for the omitted county. Table1.9 shows the predictive power for the preferred models, taking Cascade County as an example. The OLS model has a difference of 7.18% between observed value and the predicted value. The Negative Binomial model for firms in NEC sectors presents the relative average predictive power by showing the difference between observed value and predicted value for about 41%. The Negative Binomial model for number of patents shows a relative large percentage change between observed value and predictive value.

Table 1.9: Predictive Power for the Preferred Models

Models	OLS	NB	NB
Dependent Variables	EMP	PAT	FIR
Observed (O) Values	0.437545	4	16
Predicted Values (P)	0.468897	7.776356	9.469235
95% CI lower	0.317623	6.031739	8.147290
95% CI upper	0.620171	9.520972	10.791180
Difference (O-P)/OS	-7.18%	-94.84%	40.78%

Table 1.10: Out-of-Sample Predictive Exercise

Models	OLS	NB	NB
Dependent Variables	EMP	PAT	FIR
Out-of-Sample (OS) Values	0.334832	25.73555	19.40566
Predicted Values (P)	0.333926	4.16448	7.520043
95% CI lower	0.295232	3.895645	7.227948
95% CI upper	0.372619	4.433316	7.812138
Difference (OS-P)/OS	0.27%	83.82%	61.25%

An out-of-sample predictive exercise was also performed to fit a hypothetical county where the regressor settings were chosen. The hypothetical county has all the observed value for dependent and independent values as the mean values from the total observed sample. Table 1.10 shows the predicted results for this hypothetical county. Again, the OLS model has a small difference between observed value and the predicted value, which presents a very good predictive power. The observed value for the high technology employment share is within the 95% confidence interval. The negative binomial model for patents and number of firms in NEC sectors showed underestimated values.

1.5 Conclusion and Discussion

This study is a novel empirical analysis of innovation capacity for U.S. counties with a focus on natural amenities. There are four major findings from the results. First, the OLS regression model on high-tech employment share shows that warm weather in the winter and outdoor activities increase the innovation capacity and the joint test procedure also confirms that natural amenities as a group do significantly and positively affect the innovation capacity of U.S. counties. Second, the negative binomial model results showed that climate and natural amenities significantly contribute to the innovation capacity of U.S. counties. To be more specific, temperature in January and July, sunlight hours in January, water area acres, wild land acres, number of museums, number of golf courses, number of camping units, number of ski resorts and number of parks significantly affect the innovation capacity. Third, in general, lower unemployment rate, more museums, more golf courses, warm winters and cool summers will increase the innovation capacity for U.S. counties across three measurements of innovation capacity. Fourth, the predictive powers of the OLS regression on high-tech employment share and the Negative Binomial regression on the number of firms in NEC sectors are relatively strong and natural amenities as a group shows relatively large impact on the innovation capacity from the results of out-of-sample predictions.

As we are in the “knowledge economy” which experiences the technological change, innovation capacity is important for a region to be competitive and leads to the region’s economic development in the long run. This study is the first to associate innovation capacity and natural amenities. Results show that natural amenities do contribute to increasing the innovation capacity. And the results also confirmed Richard Florida’s “creative class” theory that where you are living does matter. Therefore, the non-market attributes of natural amenities should be recognized in terms of their contribution to innovation capacity. Consequently, the competiveness of a county, in terms of innovation capacity, could be increased by providing more natural amenities to the public, and issue regulations to keep the environment clean in order to retain the preferable climate.

There are further analyses could be done in the future. First, an investigation of a double hurdle model could be applied to the number of patents empirical model. It is because there are excess zeros in this innovation measure and a double hurdle model might be a better fit to deal with excess zeros. Second, with different tax policies for each state, state dummy variables could be employed in the empirical models to capture this effect.

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Chapter two:

Modeling Regional Impacts of Rangeland Fires: An Application of a LP/SAM

2.1 Introduction

Wildfires, as a natural component of forest and range ecosystems, substantially affect environment and social activities. Economic losses stemming from wildfires are becoming a growing concern; hence, there is a rapid expansion of literature analyzing wildfire related issues. Most studies focused on fire suppression and pre-suppression costs and fire management, but there is little work focused on the regional economic impacts of wildfires. This is a more challenging task in the western U.S. because more than one million people derive some portion of their income from grazing activities on rangelands, which comprise approximately 80 percent of land in the 17 Western states (James et al. 2003). If a fire occurs on public grazing land, ranchers in the region would be restricted to access to public land for two years. This action would have substantial economic impacts in a regional economy because public grazing is a major source of forage for Cattle and ranching in the region (US Government Accountability Office (GAO), 2005, p61). This chapter will develop procedures to simultaneously analyze the ranch and regional level of rangeland fires on public land. This goal is implemented by developing a model to link ranch level and regional level impacts of public rangeland fire.

Assessment of regional economic impacts will be estimated through an input-output (IO) model or the Social Accounting Matrix (SAM) model. However, these regional models are not very flexible for the rangeland fires study because they do not include the complete set of ranchers’ activities such as, changes in animal production or alternative forage sources. Thus the linkage between the ranch-level economic model and IO or SAM model is required to examine the regional economic impacts from a wildfire. The investigation of the ranch-level linear programming and regional SAM model will be discussed in the following sections.

With rangeland fires becoming a risk to regional production, policy makers might undertake policies to mitigate the risk of rangeland fires on public land. Since the impact of rangeland fires should be considered, a regional study titled “Institutional Design for Resource Allocation and Risk Sharing among Private and Public Sector Agents to Manage Invasive Grasses and Wildfire in the Great Basin” was formed. This study falls under this larger research project and focuses on the regional impact analysis. Therefore, the primary objective of this chapter is to estimate the regional economic impact from the wildfire in the public grazing land. As mentioned the integration of the ranch-level linear programming and regional SAM is the research objective of this paper. The economic model constructed in this chapter provides economic damages from the wildfire which includes the sectoral production change, reductions in earnings, and the distributive economic impacts over income groups. The sub-objectives of this study include: (1) formulating and develop a regional-level economic model with cheatgrass growth and associated wildfire with linkage to a regional SAM model; (2) estimating the regional impact of rangeland fires and their distributional impact; and (3) estimating the impact of alternative rangeland fire policies for the regional economy.

Beyond these introductory comments, this study is composed of three parts. The first section examines the literature on cheatgrass and rangeland fires, and regional impact models. The second section presents methodology and the study will close with a summary of findings and discussions.

2.2 Literature Review

According to the U.S. Geological Survey (USGS), wildfires are a growing natural hazard in most regions of the United States. These wildfires pose a threat to life and property, particularly where native ecosystems meet developed areas. However, because fire is a natural process, fire suppression can lead to more severe fires due to the buildup of vegetation, which becomes more fuel. In addition, the secondary effects of wildfires, including erosion, landslides, introduction of invasive species, and changes in water quality, are often more disastrous than the fire itself. The wildfire problems of the United States continue to plague homeowners, firefighters, and insurers. In fact, the drought of the western U.S is going into its 10th year and its effects are increasingly obvious (Berino et al. 2007).

> As a consequence of decades of fuel accumulation in our nation's forests and rangelands, coupled with persistent drought, state and federal fire managers are faced with larger, more explosive and more costly wildfires than in any period in history. Catastrophic wildfire is growing national issue, demonstrated by the Florida wildfires in 1998 and 1999 and in many Western states over the past five years. Between 2000 and 2004, Arizona, New Mexico, Colorado, Oregon, Montana, Washington, Wyoming, California, South Dakota, Nevada, Utah and Alaska all experienced server fire seasons that set new benchmarks in terms of damages, losses and cost.
>
> ------ National Association of State Forest (NASF) Resolution No. 2005-3

In addition to direct and secondary wildfire effects, regional economic impacts from catastrophic rangeland fires include disruptions in both consumption and production of local goods and services. In the Western states, rangeland fires may bring severe economic loss due to public land restrictions after the fire. This is especially true of the Great Basin area including Oregon, Nevada and Idaho, whose economy largely relies on public land ranching.

2.2.1 Understanding Cheatgrass and Rangeland Fires

Cheatgrass (*Bromus tectorum L.*), an invasive alien annual grass, has become dominant in many areas of the western United States (Yong et al. 1987).Cheatgrass can grow and germinate under harsh conditions allowing it to establish in the interspaces between shrubs on sagebrush shrub lands (Brooks et al. 2004). This increases horizontal fuel continuity that can increase the frequency and extent of fire (Brooks et al. 2004). The length and timing of the fire season in the Great Basin has changed in some areas as the result of cheatgrass invasion. Usually dry by mid-July, cheatgrass has been reported to become flammable four to six weeks earlier and remains susceptible to fire one to two months later than native perennials (Pellant 1996; Swanson et al. 2006). These fires reduce the diversity and cover of native species which aids in the spread of cheatgrass (Link et al. 2006).

Cheatgrass invasion can also influence the size of rangeland fires (Link et al. 2006). A study done by Knapp (1998) examined the occurrence of large grassland fires in the Intermountain West between 1980 and 1995. Landscape structure and human activities together were found to influence spatial patterns of fire, while the timing of fires was successfully linked to climatic conditions that relate to plant growth. The data showed these fires clustered in areas characterized by their abundance of alien annual grasses and suggested that the Snake River Plains Region, along with several other regions in the Intermountain West, have undergone an increase in fire size as a result of alien grass invasion.

Wildfire in the Great Basin is becoming an increasingly important subject due to several catastrophic fire years. Over the last 30 years, cheatgrass rangeland fires have resulted in the loss of rangeland diversity, productivity and private structures (Pellant 1996). Even though cheatgrass can degrade native ecosystems (Pellant 1996), over the last century it has become an important forage resource for both domestic cattle and some wildlife in many areas of the western U.S. (Knapp 1998; Young et al. 1987; Young and Allen 1997). Cheatgrass invasion on federal rangelands entails an increase in the risk of fire, which in turn increases the likelihood that ranchers will be temporarily denied access to public lands. Young and Allen (1997) cited ignitability as the major drawback of cheatgrass as a forage resource. This grass not only ignites easily, but its continuous fuel load enables a fire to spread rapidly and to grow large (Knapp 1998; Link et al. 2006).

The occurrence of fire on public lands is important to ranchers who hold public grazing permits. Post-fire conditions on these public lands preclude domestic livestock grazing for at least two growing seasons (Knapp 1998). Lack of access to public forage forces ranchers to choose substitute sources and / or to limit their herd size during these post-fire years. As cheatgrass continues to invade public lands in the Great Basin region, the risk of rangeland fires will become an increasingly important model of study for public land managers who wish to understand the impact of restoration policies on the ranching community.

2.2.2Regional Impact Models and Wildfire Impact Modeling

2.2.2.1 Regional Impact Models

Different types of models are used in regional economic impact analyses, such as Input-Output (IO) models, Social Accounting Matrix (SAM) models, integrated econometric input-output (EC-IO) models, and Computable General Equilibrium (CGE) models.

IO models have been a fundamental tool for regional economic analysis for the past half century. The SAM model represents a more recent extension of IO analysis arising from dissatisfaction with its limitations in assessing distributional impacts. In both models, the effects of changes in exogenous final demand are calculated using multipliers. The SAM model shares certain limitations with IO. Specifically, in both types of models, prices are assumed to be fixed, and no substitution is allowed between factors in production or commodities in consumption. As a result, in cases where the fixed-price assumption may not be realistic, these models tend to overestimate impacts. Hewings and Jensen (1986) discuss interregional and multiregional IO models. Schaffer (1999) provides a more recent description of basic IO model construction and implementation. Several SAM models have been used for impact analysis or planning purposes in terms of income distribution, employment, and other factors in developing countries such as Egypt, Indonesia, Malaysia, and South Africa (Pyatt and Round 1985).

Regional economists have also used supply-determined IO (SD-IO) and supply-determined SAM (SD-SAM) models in which final demand for some sectors and gross outputs for the remaining sectors are specified exogenously (Miller and Blair 1985). SD-IO models were used in situations where the productive capacity of a sector was exogenously reduced. For example, SD-IO models have been used to examine the impact of a change in industry productive capacity on income distribution. Examples of studies using SD-SAM models include Marcouiller, Schreiner, and Lewis (1995), and Seung, Harris, and MacDiarmid (1997). Although SD-type models can be more useful for analyzing the impact of a reduction in productive capacity than conventional IO or SAM models, SD-IO and SD-SAM models share the same general limitations of IO models discussed above. In addition, the SD models have a theoretical weakness in that the final demand for certain sectors is assumed to be endogenous (Marcouiller et al. 1995; Seung et al. 1997).

One of the attempts to address the weakness of IO-type models is to combine an econometric model with an IO model. The combination is often called an integrated econometric-input-output (EC-IO) model. There are two motivations for developing EC-IO models: theoretical and practical (Rey 2000). One of the most important theoretical motivations is that prices are fixed in IO models, while they can vary in most econometric models. Thus, the weakness of price rigidity in IO models can be somewhat reduced by combining them with econometric models. There are also several practical reasons why the two different approaches are integrated. First, with detailed inter-industry relationships specified in the IO portion of the integrated model, the EC-IO has better forecasting performance compared with traditional structural econometric models. Second, with dynamic features present in econometric models, integrated models have improved impact analysis capabilities and can generate the time paths of the effects of policy impacts. Third, since the econometric portion in the integrated model is usually estimated based on the regional data, the integrated model can be used to reduce the bias of secondary data-type IO models resulting from the regionalization of a national IO model (Rey 2000).

CGE models overcome some of the limitations of fixed-price models. In CGE models, prices are allowed to vary, triggering substitution effects in production and consumption. Therefore, the CGE model enables analysts to easily examine the economic welfare implications of a policy change. Furthermore, the CGE approach is generally more appropriate than other regional economic models for analyzing the impacts of a change in productive capacity of resource-based industries. Details on the structure of CGE models are found in De Melo and Tarr (1992) and Shoven and Whally (1992) for national-level analysis, and Kraybill (1993) for regional-level analysis. CGE models also suffer the weaknesses of relatively high implementation costs and hard estimations of some parameters and elasticities (Partridge and Richman, 2004; Vargas et al. 2003). Although CGE has its own individual strengths due to its ability to incorporate nonlinearities, it is not capable of incorporating some county or regional requirements such as limitations on the level of resources, and the need to find an optimum solution (Seung et al. 1997). However, these elements are addressed well by the Linear Programming (LP) approach. A few LP models have been applied to problems of regional economic development planning (Williams 1981). Moreover, the literature regarding applications of the CGE model and its linkage with SAM to urban and regional analysis is substantial (Adelman and Robinson 1986; Cornelius et al. 2000; Doi 2006; Harris et al. 2002; Partridge and Rickman 2004).

Furthermore, there is some evidence of theoretical or case studies where a regional or national IO model has been used in conjunction with a LP model, such as Everett and

McCarl (1976), Brink and McCarl (1977), Bowker and Richadson (1989). In general, the linkage of the LP model and IO achieves better results concerning regional or national requirements in the real world. Everett and McCarl (1976) provided the modeling technique to consider the direct and indirect effects simultaneously by integrating the linear programming and input-output analysis. In their approach, the original two models have become one large linear programming model where the objective is to maximize the profit from the linear programming problem plus the weighted gross output of the region’s economy. The maximization is subject to the original resource constraints.

Additionally, the second set of constraints requires total output of a given sector minus all intermediate demands on its output to be less than or equal to a predetermined level of final demand. Brink and McCarl (1977) presented a structure to derive the output multiplier as a shadow price in the linear programming formulation. An initial application to link SAM and LP was Sharify and Batey (2006). Their approach shows that by combining an LP model with a SAM, it is possible to determine the activity level of sectors to meet the maximum level of gross regional level product for a region with respect to related goals and constraints. Additionally, their approach is very close to the Brink and McCarl (1977) but using SAM. However, these techniques showed that an integrated LP-SAM model is more appropriate compared to other modeling approaches.

2.2.2.2 Regional Economic Impact from Rangeland Fires

This section reviews the previous works to investigate regional economic impacts from the wildfire. Researchers have tried to analyze the wildfire management policy for the past ninety years. These studies focus on wildfire suppression and pre-suppression (activities that reduce wildfire risk, including vegetation management) costs (Rideout and Omi 1990; Headly 1916; Lovejoy 1916; Davis 1965; Gorte and Gorte 1979; Hesseln and Rideout 1999).

Fewer studies are focused on regional economic impact from wildfire. Maher (2007) analyzed the wildfire impact using a ranch-level linear programming model. Results showed that the impact of a fire go beyond the timeline of the two years of exclusion from BLM allotment use and the model enables the rancher to choose a plan to decrease the herd size prior to a fire year. Riggs et al. (2001) and Harris et al. (2002) both analyzed the economic impact for the wildfire that occurred in northern Nevada in 1999, but used an IO model and a CGE model separately. Riggs et al (2001) tried to quantify the loss from the wildfire using a survey and computed the regional impacts using the multipliers from the IO model. Harris et al. (2002) measured the regional economic impacts using the dynamic CGE which overcomes some drawbacks in the IO model (Harris et al. 2002). The latest attempt to analyze the wildfire impact at a regional level is Alevy and Harris (2008). They used a model called LP/SAM, which captured the regional economic impacts from the reduction in grazing allotment in the ranch sector from the wildfire.

The model used in the study was developed in Alevy and Harris (2008) based on the theoretical supports from Everett and McCarl (1976) and Bowker and Richardson (1989), Alevy and Harris (2008) expanded the LP-IO framework to LP-SAM framework to incorporate the institutional impacts such as impacts to households, employment and regional government to the model, so called LP-SAM. Alevy and Harris (2008) examined the wildfire impacts for Elko County, Nevada using this LP-SAM model. They considered removal of 15% and 50% federal AUMs from the wildfire in public land.

Results showed that sectors that cattle-ranching, trade and service sectors have the significant economic impacts from the wildfire. Under the scenario of intensive fire cycle (10-year fire cycle), cattle-ranching sector lost $25 million, trade sector experienced $10 million loss and service sector experienced about $5 million loss. One drawback in Alevy and Harris (2008) is that the wildfire profile is too simple and unrealistic, which means the results might underestimate the regional economic losses.

Wildfire limits access to public grazing land for ranchers, which has a substantial economic impact on the region because much of the cattle grazing and ranching business in the region is conducted on public land. One of the goals of this paper is to determine the economic impacts from wildfire at a regional level. This study expands on Alevy and Harris (2008) by building a more sophisticated LP/SAM model incorporating a cheatgrass module, a realistic fire module and a land management module.

2.3 Study Area and Rangeland Fires

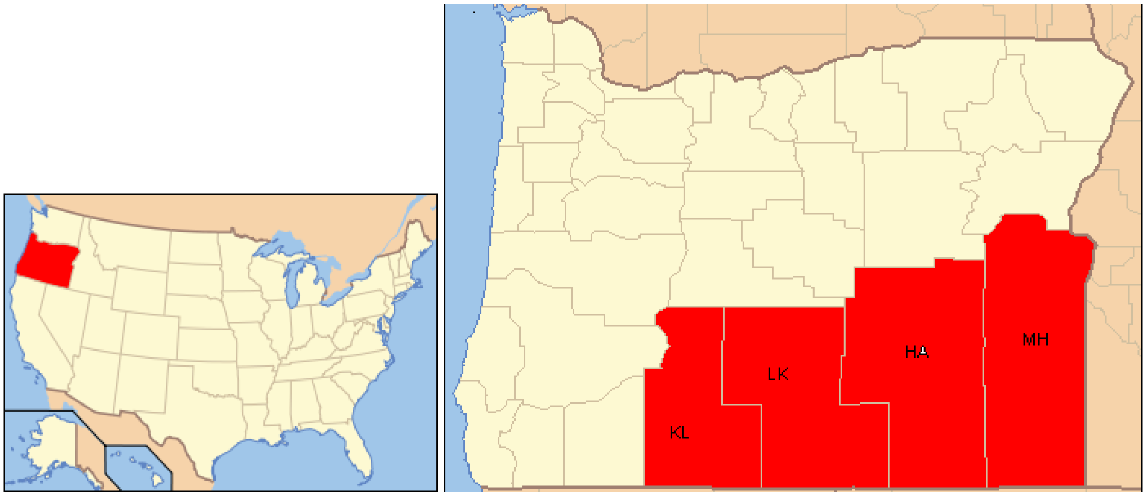

Figure 2.1: Southeast Oregon: Harney, Lake, Klamath and Malheur Counties

Southeast Oregon was selected as the study area. The study area is located on the northern edge of the Great Basin area (Figure 2.1). Because of geological characteristics, this area has a higher temperature than the national average and lower amount of rainfall than the national average (NOAA Satellite and Information Service). As a consequence, this area has frequent wildfire occurrence.

Four counties are specifically included as the study area: Lake, Harney, Klamath and Malheur. The area is approximately 22 million acres which accounts for about 35% of Oregon. These four counties' economies are based on the cattle ranching and farming sectors (Cornelius et al. 2000). In 2006, the cattle ranching and farming sector recorded an output of $258 million which was 4.3% (calculated from IMPLAN database for 2006) of the total value of the regional output, placing this sector fifth among the regions' 191 economic sectors. This area was chosen as the study area because i) range-ranching business in the region is a major business sector, ii) public grazing land is the key source of forage for ranchers, and iii) the frequent rangeland fires limit the access to the public grazing land. In addition, the ranch-level LP model is fully calibrated for a representative ranch in the region in Maher (2007).

Figure 2.2: Number of Rangeland Fires and Size in Southeast Oregon Area
Source: National Fire and Aviation Management http://www.fs.fed.us/fire

Rangeland fire data in the region is gathered from National Fire and Aviation Management website (http://www.fs.fed.us/fire). Figure 2.2 shows, in blue bars, the number of rangeland fires over 10 years. Five rangeland fires occurred each year in the region on average through 1999 to 2008 and the number of rangeland fires peaked in 2002 (25 times), 2005 (22 times), 2006 (38 times) and 2007 (24 times). The number of rangeland fires has a positive trend over time. The average wildfire size[3] is reported as 5,494 acres per year and it fluctuates widely. Figure 2.2 presents the size of the wildfire in red solid line. Likewise the size of the wildfire has a positive trend over time.

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[3] According to the National Interagency Fire Center (2002), Oregon recorded its largest fires in 2002; “Biscuit” in Siskiyou National Forest and “Tool Box Complex” in Fremenont National Forest.

2.4 Methodology

Assessment of the regional economic impact can be done using the Input-Output (IO) analysis or the social accounting matrix (SAM) analysis. As discussed in the above section, they are not very flexible for the wildfire study because they do not include the complete set of ranchers' activities; for example, changes in animal production or alternative forage sources. Thus the linkage between the ranch-level economic model and the IO or SAM model is required to examine the regional economic impact from the wildfire, so called LP-SAM. Basic modeling approach is similar to Alevy and Harris (2008). One of major differences is the wildfire module which generates more realistic wildfire based on historical wildfire data.

2.4.1 A Ranch-level Inter-temporal Linear Programming (LP) Model

The ranchers' behavior can be modeled using the LP model as in Torell et al (2002). The objective of ranch managers is to maximize the sum of discounted profits over a T-year planning horizon subject to resource availabilities, grazing allotment quantities, input and output prices, and resource transfers between periods (especially breeding cows). The LP model considers almost all of the ranchers' decision variables in the typical western US ranches including seasonal forage supply and demand (Torell et al. 2002). This type of model falls on the discrete-time optimal control problem. The general form for this is as follows:

(2.1) Max $$z = \sum_{t=0}^{\infty}(1+r)^{-t}(\mathbf{p'}\,\mathbf{x_t} - \mathbf{m'}\,\mathbf{s_t})$$

Subject to $$\mathbf{s}_t = \mathbf{s}_{t\text{-}1} + \Delta\mathbf{s}_{t-1} - \mathbf{x}_t$$

$$\boldsymbol{s}_t \leq \alpha(1 - F_t)L_t^{pub}$$

$$\mathbf{Dx}_t \leq \mathbf{b}_t$$

$$\mathbf{x}_t \geq 0, t = 1 \ldots . \infty$$

where r = interest rate,

x_t = raising and selling animals,

$\mathbf{s_t}$ = vector of animal inventory (breeding cows),

L_t^{pub}= public land allotment in year t,

F_t = wildfire index (0 or 1)

α = carrying capacity of the grazing land

p = price vector,

m = animal raising and maintaining cost vector,

D = matrix of the technical coefficients (from previous literature),

b_t = resource availability vector which does not including public grazing land,

b = resource availability vector that wildfire affects

The profit equation is the difference between the revenue from ranching operations and the costs of ranching operations. The resource constraint reflects the constraints to ranching production from limited physical and financial resources. The solution of the ranch LP model provides the following information on ranch activities

- Production and sales - cattle sold, alfalfa hay sold
- Resource usage - quantity of each resource used and unused (such as public land grazing permits), and
- Value of financial activities - principal and interest payments and prepay short term loan

The model simulates outputs over a 50 year period (and reports 40 years to avoid biases resulting from the ending conditions such as ending asset values and any transversality conditions). The LP model has the flexibility to alter parameters and provide results on an annual basis, and for inputs for which it is relevant, such as federal AUMs, on a seasonal basis. The LP model is calibrated using the Oregon cow-calf budget data which was calculated by Maher (2007) for the study region.

A baseline “No Fire Model” is run with Ft = 0 which implies the rancher may access to the public grazing land fully. An alternative scenario, “Fire Model” is run with Ft = 1 which means that the rancher may not access to the public grazing land. The rancher may change grazing sources, purchase forage from the outside, or sell more cattle to reduce the cattle size, s_t, in the model. The representative ranch grows 300 cow-calf which is typical in the Oregon area. BLM allotment, 2,310 acres, is available at $8.77/AUM in the model.

The baseline model determined the profit maximizing number of livestock to produce and sell at time T for each class of animal subject to typical operating constraints, including forage supply and costs. It is assumed that the ranch starts within an initial quantity of mature cows (Table 1 in Appendix A), that a minimum herd replacement requirement exists for cows and heifers (Table 1 in Appendix A), and that these replacements come from heifer calves and yearlings saved each year rather than from purchased brood cows. A description of the representative Oregon ranch in terms of key model parameters is presented in Tables 1, 2 and 3 in Appendix A.

Forage demand in each of seven seasons is constrained to be less than or equal to the amount of forage available in the corresponding season. The representative ranch allocates forage (e.g., private lease, deeded range, the BLM allotment, and hay) by season to maintain the cattle herd. The seasons of use for each land type considered in the forage supply equations of the model are listed in Table 4 in Appendix A.

2.4.1.1Central Operating Constraints

This section describes the central equations in the model in equation (2.1). In order to present equations clearly, subscripts of variables should be defined as follows:

$time\ \ t = \{t|year\ 01, year\ 02, \dots year\ 40\}$

$season\ \ ssn = \{ssn|season1, season2, \dots season7\}$

$land\ \ type\ ltp = \{ltp|meadow, alfafa\ hay, state, usfs, blm, lease, private\}$

$Crop\ (land)\ crp = \{crp|\ meadow, alfafa\ hay\}$

$Graze\ (land)\ g = \{grp|state, usfs, blm, lease, private\}$

$livclass\ v = \{v|cow, sellcow, buycow, bull, buybull, steer, heifer\}$

<u>Ranchers Profit Function</u>

$$z = \sum_t^T \frac{Gross_t - ForCost_t - AnimCost_t - LoanCost_t}{(1+r)^t} \tag{2.2}$$

$$Gross_t = \sum_v Live_{v,t}\, P_{v,t} + \sum_c SellCrop_{crp,t}\, P_{crp,t} \tag{2.3}$$

$$AnimCost_t = \sum_v Raise_{v,t} \cdot amcst_v \tag{2.4}$$

$$ForCost_t = \sum_{ssn} \sum_{grz} LandUse_{grz,ssn,t} \cdot forcst_{grz} \tag{2.5}$$

Equation (2.2) presents the rancher's objective of profit maximization. In general, the profit is composed of four parts: gross profit ($Gross_t$), forage cost ($ForCost_t$) animal cost ($AnimCost_t$) and loan cost ($LoanCost_t$). To be more specifically, gross profit is composed of profit from live stock raised and sold (*Live*Price: quantity *price*) and profit from crop sale (*SellCrop*Price=quantity *price*). Animal cost is composed of quantity raised ($Raise_{v,t}$) and the cost of raising each type of animal ($amcst_{v}$), which are presented in Table 1 in Appendix A. Forage cost is also defined as the acres of land used in each season ($LandUse_{grz,\ ssn,\ t}$) multiplied by the forage cost for each type of land ($forcst_{grz}$), which are presented in Table 2 in Appendix B.

Land Availability Constraint

$$\sum_{ssni} LandUse_{grz,ssn,t} \leq forage_{grz} \tag{2.6}$$

Land available for grazing and cropping is restricted by equation (2.6). This equation states that when summed over seasons (ssn), the amount of grazing land (grz) that is either harvested or remains unused must less than or equal to the maximum amount available for that land type, as specified in the table called $forage_{grz}$. Among them, BLM has the wildfire components as in:

$$\sum_{ssn} LandUse_{"BLM",ssn,t} \leq forage_{"BLM",t} \cdot (1 - F_t) \tag{2.7}$$

Equation (2.7) restricts the number of AUMs used in each season ($\mathrm{LandUse}_{"BLM",ssn,t}$) in a given t to be less than or equal the number of AUM available ($\mathrm{forage}_{"BLM",ssn,t}$) that is restricted by the wildfire F_t.

Crop and Forage Transfer Equations

$$\sum_{ssn} FeedCrop_{ccrp,ssn,t,} + SellCrop_{crp,t} \leq \sum_{ssn} LandUse_{crp,ssn,t} * yield_{crp} \quad (2.8)$$

Equation (2.8) transfers feed crop, e.g., alfalfa hay, from the land use activities to feed crop and sell crop activities. Once the wildfire occurs the rancher reduces selling feed crops and uses them as alternative forage sources.

Animal Class Transfers and Production

$$Raise_{\text{"cow"},t} + Raise_{\text{"sellcow"},t} \leq Raise_{\text{"cow"},t-1} * SurvivalRate_{\text{"}cow\text{"}} + Raise_{\text{heifer},t-1} * SurvivalRate_{\text{"}heifer\text{"}} \quad (2.9)$$

$$Raise_{\text{"bull"},t} \leq Raise_{\text{"bull"},t-1} * SurvivalRate_{\text{"}bull\text{"}} + Raise_{\text{"buybull"},t} \quad (2.10)$$

$$Raise_{\text{"heifer"},t} = Raise_{\text{"}cow\text{"},t} * BirthRate_{\text{"}cow\text{"}}/2 \quad (2.11)$$

$$Raise_{\text{"steer"},t} = Raise_{\text{"}cow\text{"},t} * BirthRate_{\text{"}cow\text{"}}/2 \quad (2.12)$$

Equation (2.9) describes that the number of cows in current year is less than or equal to the number of cows in last year multiplied by the survival rate of cows (scalar) plus the heifer raised in last year. Equation (2.10) also states that the number of bulls in current year is based on the number of bulls in last year multiplied by the survival rate of bulls (scalar) plus the number of bulls bought in current year. Equation (2.11) and (2.12) show the cattle production activity by defining the number of heifers ($Raise_{\text{“}heifer\text{”}}$) and the number of steers ($Raise_{\text{“}steer\text{”}}$) is a function of the number of cows multiplied by the birth rate of cows ($BirthRate_{\text{“}cow\text{”}}$).

Livestock Forage Requirements and Forage Transfer

$$\sum_{v} Raise_{v,t} * aue_{v,ssn} \leq \sum_{grz} LandUse_{grz,ssn,t} * avail_{grz,ssn} \quad (2.13)$$

Equation (2.13) transfers forage from forage raising activities and crop feeding activities to meet livestock forage requirements. It states that the number of animal raised multiplied by the animal unit equivalencies (*aue*) is less than or equal to the acres of land used by type (*LandUse*) multiplied the 0 or 1 matrix defined by *avail*. If one (1) is present in the *avail* matrix, it means grazed forages are to be available in the season.

Ranch Borrowing Activity

$$StBorrow_{t-1} \leq RepaySt_t \tag{2.14}$$

Equation (2.14) allows the ranch operator to borrow money from outside to stay in the business. Ranch operate should keep his short term borrowing in last year ($StBorrow_{t-1}$) less than or equal to the amount that he repay for the short term loan in current year ($RepaySt_t$).

2.4.2 Input-Output Analysis and Social Accounting Matrix (SAM)

The IO method is based on the interrelationship between sectors in the economy and how each is affected by a change in the final demand for a sector's output. For a regional economy of n sectors the standard IO model is represented by $\mathbf{X} = \mathbf{Y} + \mathbf{AX}$, where $\mathbf{X}$ is the output vector, $\mathbf{Y}$ is the final demand vector, and $\mathbf{A}$ is the direct requirement matrix, which elements, a_{ij}, are calculated as $a_{ij} = x_{ij}/x_j$, where x_{ij} is the transaction between sector i and j, and x_j is the sectoral output which is $x_j = \Sigma_j x_{ij}$. This relation indicates that the sum of output $\mathbf{X}$ equals to the direct uses in final demand Y and its indirect uses in intermediate production $\mathbf{AX}$.

The solution can be obtained by rewriting it as $\mathbf{X} = (I–A)^{-1}\mathbf{Y}$, where I is the n × n identity matrix. The (I–A) matrix is called the Leontief matrix and $(I–A)^{-1}$ is called Leontief inverse matrix which shows the total-requirements matrix for the economy. This relationship can be interpreted as $\Delta\mathbf{X} = (I–A)^{-1}\Delta\mathbf{Y}$, which means changes in total industry output are predicted using the Leontief inverse matrix. Thus the column sum of $(I–A)^{-1}$ is interpreted as the total changes in output from the changes in final demand, which is called output multiplier, $\alpha= i'/(I–A)^{-1}$, where α is the output multiplier column vector and i is an $n\times1$ column vector of ones. Thus k^{th} element in α implies there is exogenous change in final demand for k^{th} sector total industry output change by α_k. Regional economic impact from the (final demand) changes can be analyzed using the multiplier.

In the IO analysis, only the inter-industry linkages are formally specified. The linkages between household income and spending, government revenues and expenditure, and the linkage between saving and investment are not defined in IO analysis. SAM accounts consider industry-institution linkages. The IMPLAN system provides for the construction of SAM at the regional level (MIG, 2006).

Following Holland and Wyeth (1993), the SAM model can be represented as:

$$(2.15)\quad \begin{bmatrix}\mathbf{X}\\ \mathbf{V}\\ \mathbf{Y}\end{bmatrix} = \begin{bmatrix}\mathbf{ex}\\ \mathbf{ev}\\ \mathbf{ey}\end{bmatrix} + \mathbf{S}\begin{bmatrix}\mathbf{X}\\ \mathbf{V}\\ \mathbf{Y}\end{bmatrix}$$

Where **S** = matrix of SAM direct coefficients likewise A in IO model,

X = a vector of sector supply,

V = a vector of value-added by categories,

Y = a vector of household incomes.

ex= a vector of exogenous commodity demand

ev= a vector of exogenous value added

ey= a vector of exogenous household income

The matrix of direct SAM coefficients, S, is given by

$$\mathbf{S} = \begin{bmatrix} \mathbf{A} & \mathbf{0} & \mathbf{C} \\ \mathbf{V}^* & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{Y}^* & \mathbf{H} \end{bmatrix} \qquad (2.16)$$

Where **A** = a matrix of IO coefficients,

V* = a matrix of value-added coefficients,

Y*= a matrix of value-added distribution coefficients,

C = a matrix of expenditure coefficients, and

H = a matrix of institutional and household distributional coefficients.

Equation (2.15) can be rewritten as

$$\begin{bmatrix} \mathbf{X} \\ \mathbf{V} \\ \mathbf{Y} \end{bmatrix} = (\mathbf{I} - \mathbf{S})^{-1} \begin{bmatrix} \mathbf{ex} \\ \mathbf{ev} \\ \mathbf{ey} \end{bmatrix} \qquad (2.17)$$

Where $(\mathbf{I} - \mathbf{S})^{-1}$ = matrix of SAM inverse coefficients.

Interpretation of $(I - S)^{-1}$ is similar to interpretation of $(I - A)^{-1}$ in the IO model since the households and other institutional linkages are endogenous[4]. Using the SAM model and its multipliers, regional economic impacts from the external shock to the exogenous sectors can be investigated.

2.4.3 Integrated Linear Programming and Social Accounting Matrix Model

To derive distributional impacts of the wildfire on regional economy, the SAM model should be integrated to the LP ranch model. The model will be designated as the LP-SAM

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[4] Actually the case in a Type II IO model (Holland and Wyeth, 1993)

model. Theoretical backgrounds to integrate the LP model and the IO model are explored by Everett and McCarl (1976), and later by Bowker and Richardson (1989) as mentioned earlier. Alevy and Harris (2008) expanded the previous efforts to consider the institutional impacts to incorporate SAM into the LP model.

The LP-SAM model provides the regional direct and indirect effects of changes in sector outputs, that is, changes in output in the cattle sector due to wildfire. In addition, the LP-SAM model can generate changes in employment as well as income distribution in the region through SAM. The basic structure is given by equation (18),

$$(2.18)\text{Max } z = \sum_{t=0}^{\infty}\sum_{i=1}^{I}(1+r)^{-t}(\mathbf{p}'\mathbf{x}_{\mathrm{it}} - \mathbf{m}'\mathbf{s}_{\mathrm{it}}) + 0\times\mathbf{X^1} + 0\times\mathbf{X^{11}}$$

$$\text{Subject to } \mathbf{s}_{it} = \mathbf{s}_{it\text{-}1} + \Delta\mathbf{s}_{it-1} - \mathbf{x}_{it}$$

$$\mathbf{s}_{\mathrm{it}} \leq \alpha(1-F_t)L_{it}^{pub}$$

$$\mathbf{Dx}_{it} \leq \mathbf{b}_{it}$$

$$\sum_{\mathrm{i=1}}^{\mathrm{I}}\mathbf{Vx}_{\mathrm{it}} - \mathbf{X^1} = 0$$

$$(\mathbf{I} - \mathbf{S})\begin{bmatrix}\mathbf{X^1}\\ \mathbf{X^{11}}\end{bmatrix} \leq \mathbf{Y}$$

Where $\mathbf{x}_{\mathrm{it}}$ = vector of ranch level activities (e.g., raising and selling animals)

$\mathbf{s}_{\mathbf{it}}$ = vector of animal inventory (breeding cows),

F_t = wildfire index (0 or 1)

L_{it}^{pub} = public land allotment in year t for ranch i,

α = carrying capacity

$\mathbf{p}$ = price vector,

$\mathbf{m}$ = animal raising and maintaining cost vector,

D = matrix of the technical coefficients (from previous literature),

$\mathbf{b}_{it}$ = resource availability vector which does not include public grazing land,

i = ranch index,

n = economic sectors,

I= identity matrix,

V = vector of change input-output sector commodities to input-output industries,

$\mathbf{X}^{1}$= vector of regional level activities in ranching sectors,

$\mathbf{X}^{11}$= vector of regional level activities excluding ranching sectors,

$\mathbf{S}$ = SAM direct coefficients,

$\mathbf{Y}$= vector of exogenous final demand, value added and household income.

z = the sum of discounted profit.

The restriction in the first equation is the profit equation for ranch i which is the same as in equation (2.1). The restriction is the second equation is the ranch i resource availability as in equation (2.1). The restriction in the third equation is the cattle industry production and hay industry production. The regional production is the sum of all the ranches production. The restriction in the last equation is the SAM relationship as in equation (2.17).

The SAM model in equation (2.16) or (2.17) can be calibrated using the IMPLAN database. Aggregation on four counties data in IMPLAN is based on two digit North American Industry Classification System (NAICS) code. Cattle and Hay sector are aggregated out from Agriculture sector. After the aggregation, a SAM table can be generated from IMPLAN and the structure can also be derived from the SAM table. See

Table 1 in Appendix B for the sector aggregation. Note that we assume the big one ranch in the empirical model to avoid the complicated calibrating procedure with multiple ranchers. The social planner maximizes the regional profit of cattle-ranching industry with constraints in equation (2.18).

2.4.3.2 Stochastic Rangeland Fires

Public grazing allotment for the rancher i, L_{it}^{pub}, would be affected by the wildfire, F_{it}, as in equation (2.13), which puts a constraint to the cattle stock size that $s_{it} \leq \alpha(1-F_{it})L_{it}^{pub}$. F_{it} becomes F_t in the empirical model because we assume the big single ranch and is interpreted as the wildfire size at the regional level. Note that this is different from F_t in the representative ranch level so that F_t is not simply 0 or 1. The LP-SAM model in Alevy and Harris (2008) has a simple wildfire profile, which uses fire/no fire (more specifically, fire, $F_t = 1$; no fire, $F_t=0$. Thus the model results might underestimate the wildfire damage to the regional economy.

This study expands the previous model with a new wildfire scheme using historical wildfire data, which allows for the stochastic wildfire generation. It is noteworthy that the size of wildfire would increase over time presumably because of cheatgrass invasion (Knapp 1998; Link et al 2006). The trend regression is adopted to describe wildfire size over time and generate the stochastic wildfire for the projection period. The trend regression is used because the relationship between cheatgrass and wildfire size at a regional level is not well known. The stochastic wildfire is generated using $\widetilde{F_t} = b_0 +$

$b_1 T + \tilde{\varepsilon}$ where tilde on variables indicate stochastic variables and $\tilde{\varepsilon}$ is the pure stochastic part and assumed to be empirical distribution.

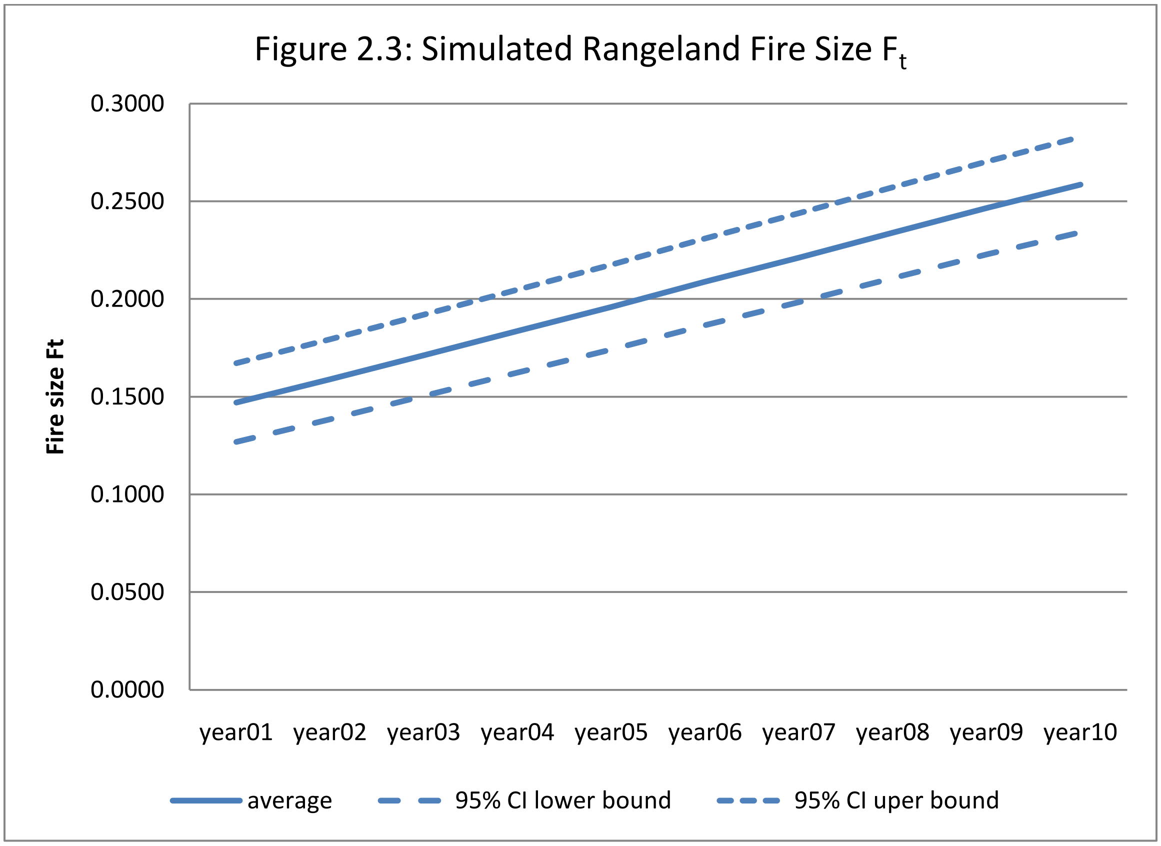


Figure 2.3: Simulated Fire Size from Real Rangeland Fire Data.

Figure 2.3 shows the simulated fire size is increasing over time. From year01 to year20, the average fire size over 200 iterations in the region ranged from 0.1470 to 0.2585. This means the public grazing land in the region is burned 14 percent and 26 percent in year01 and year10, respectively.

After solving the “No Fire” and “Fire” models and calculating the differences between these two models, results and discussion are presented in the following section.

2.5 Results and Discussion

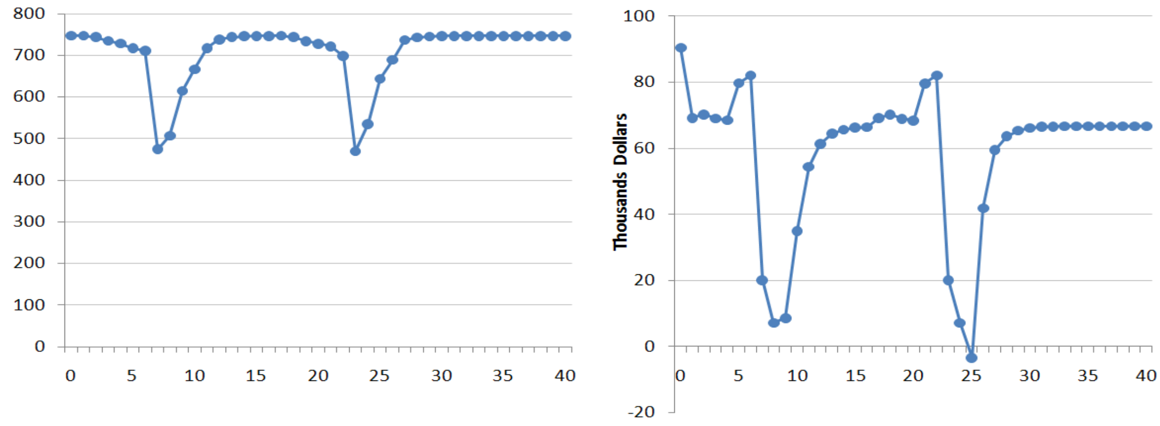
LP-SAM is run over 200 times (Monte Carlo simulation) without stochastic wildfire (baseline) and with stochastic rangeland fires using General Algebraic Modeling System (GAMS) for both the ranch-level and regional level. Multiple iterations allow us to generate proper annual economic impacts distribution (average). Results can be explained from two aspects: ranch-level impact and regional level impact.

2.5.1 Ranch-level Results

Maher (2007) summarized the ranch-level results. Maher (2007) used the LP model which incorporated forage availability constraints imposed on public grazing allotments by cheatgrass rangeland fires in the same region. Results showed that the maximum reduction in herd size is 38% assuming grazing on public land is excluded for two years. Net income (profit, net present value over horizon) would decrease even to negative under high cattle price scenario.

The ranch-level LP model with more a realistic wildfire profile is run assuming that wildfire occurs in year 7 and 23 for illustration purpose. Note that this is one iteration result. The model generates the slightly different results in the herd size (Panel A, Figure 2.4) and in net returns (Panel B, Figure 2.4). Overall, however, changes in herd size and reduction in profit have the similar pattern and magnitude. Assuming grazing on public land is excluded as a forage source for two years, results show that the herd size decreases by 230 animals when the wildfire occurs (33% decreases in total number of animals, Panel A, Figure 2.3). Ranch net returns goes down even below zero when the second fire occurs, which counts 110% decrease of the total profit (Panel B, Figure 2.3).

Wildfire impacts go far beyond the timeline of the two years of exclusion from the BLM allotment as shown in Figure 2.4.



Panel A. Number of Animals Panel B. Profit (TR – TC)

Figure 2.4Ranch-level Impact [1 iteration, fire occurs in year 7 and 23]

Table 2.1 Ranch-level Comparison

	No Fire	Fire
Total Raise (by head)	750 (head)	710(head)
Total Sell (by weight)	396 (pound)	373 (pound)
Ranch Income (dollars)	1774637.817	1612914.426
Net Return (dollars)	34764.55	27618.26
Possibility of Bankruptcy	0%	10%

Table 2.1 shows the ranch-level results which compares the rancher’s activity under fire and no-fire conditions with 200 iterations over 40 years. If there is no wildfire happens, the rancher will raise 75 head of animals and sell 396 pound of animals in every year. The ranch income discounted to the current year is $1.77 million over 50 years. The average discounted net returns for each year is $34,764. Because there is no fire occurs, the rancher will not face the risk of wildfire, the possibility of the ranch going out of business is zero. Under another situation, if the wildfire occurs, the rancher will raise and sell fewer animals in every year than he does in no-fire years. Actually, the rancher will

sell more animals in a fire year as it shows in panel A, figure 2.4. The number “373” presented in table 2.1 is the average pounds of animals sold over 40 years. It has been balanced with the selling in no-fire years. The discounted ranch income in the current year decreased to $1.6 million and counted a 9% decrease. The average discounted net return for each year is $27,618 and counted a 21% decrease. Apparently, the possibility of bankruptcy is 10%, which the rancher has a 10% possibility to quit the business because of rangeland fire occurrences.

2.5.2 Regional-level Results

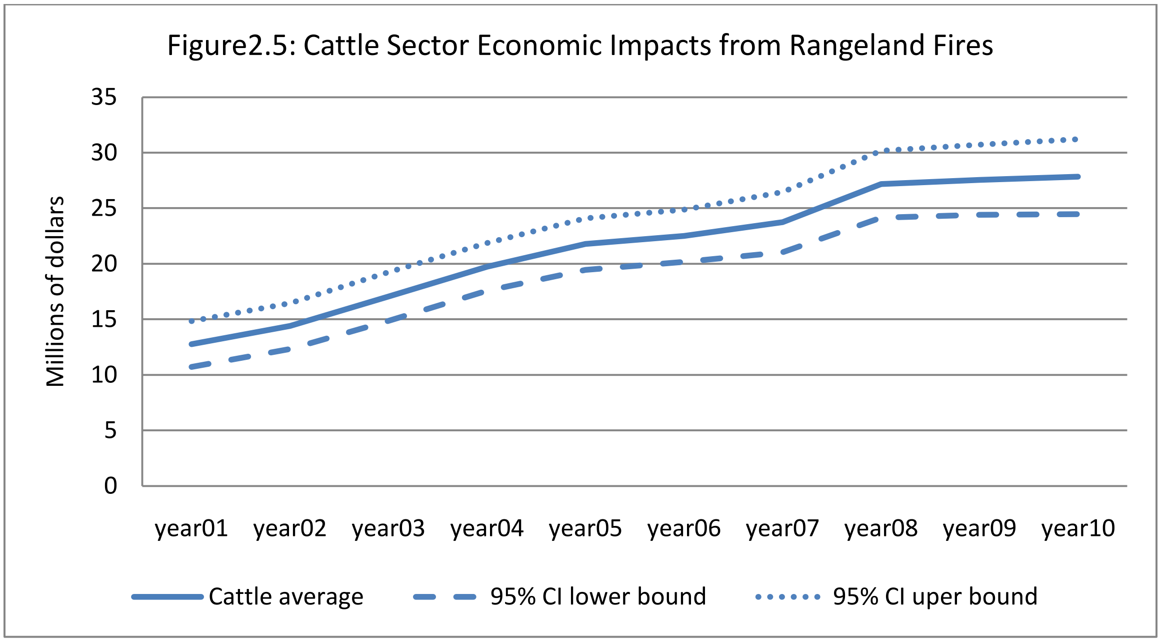


Figure 2.5: Losses from Rangeland Fires: Cattle Sector. (Loss is difference between the value of production under baseline and the value of production under wildfire)

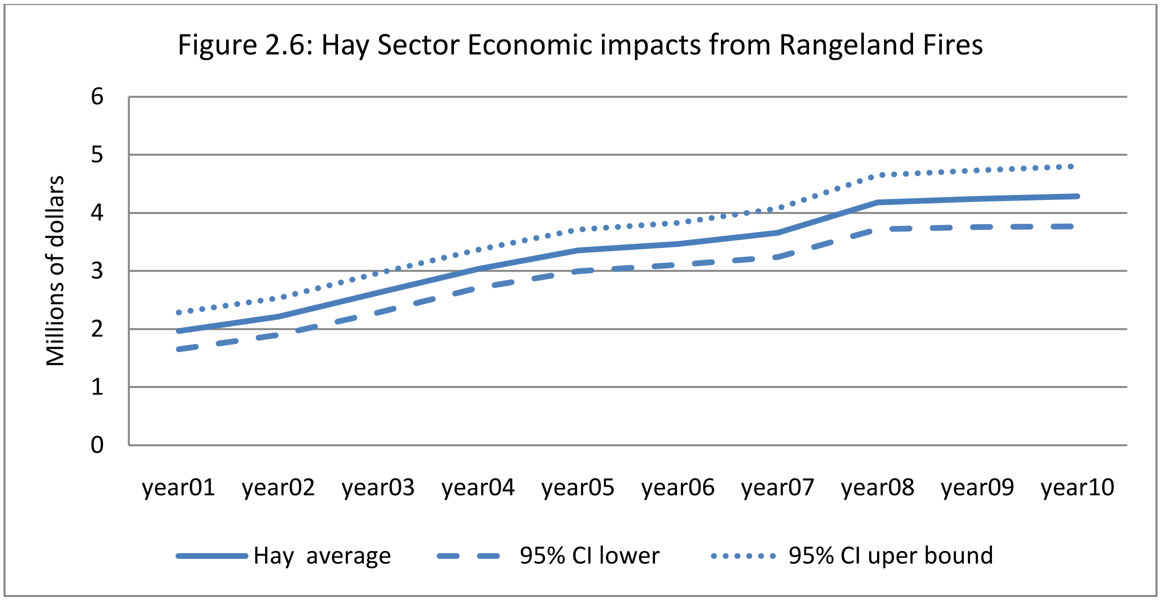


Figure 2.6: Losses from Rangeland Fires: Hay Sector.

Results shown here are based on a ten-year period over 200 iterations. The model includes a Social Accounting Matrix structure, which will change over the period. Figures 2.5 and 2.6 present the two major sectors which have large economic losses from the rangeland fires: Cattle and Hay Sectors. Figure 2.5 shows that the loss from the Cattle Sector varies from $12.77 million to $27.83 million, depending on the wildfire size. The loss from the Hay Sector varies from $1.97 million to $4.28 million. The 95% confidence intervals for both Cattle and Hay Sectors increase with time. Moreover, the economic loss from rangeland fires has a positive slope which means that the size of the rangeland fires keeps increasing over time. It is suspected that the cheatgrass invasion increases the fire size.

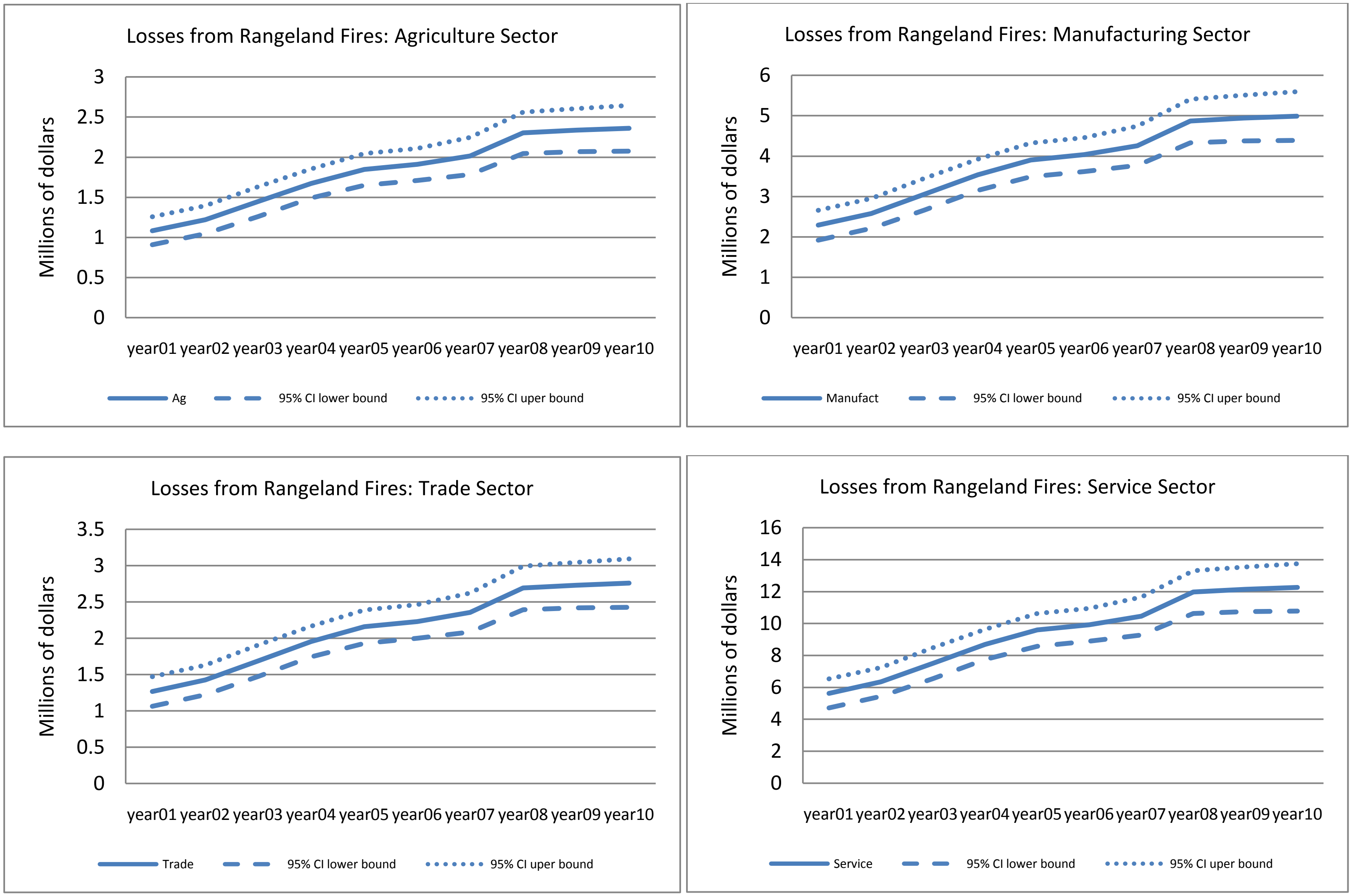


Figure 2.7: Losses from Rangeland Fires Greater Than 1 million for Other Sectors.

Figure 2.7 shows the losses from rangeland fires for other sectors which the losses are greater than one million dollars. Losses from Agriculture Sector vary from $1.1 million to $2.4 million; Manufacturing Sector has the losses from $2.3 to $5.0 million; Trade Sector has the losses from $1.3 to $2.8 million and losses from Service Sector vary from $5.6 to $12.3 million. In general, Service Sector has the largest losses over 10 years among other sectors. It is worth to notice that the 95% confidence intervals for those sectors also increase with time.

Table 2.2: Total Impacts of Rangeland Fire on Income Groups over a Ten-Year Period

Income group	Continuous benchmark No fire ($ millions)	Continuous counterfactual Fire ($millions)	Percentage change (%)
Less than10k	2197.640	2196.195	-0.066
10-15k	1901.820	1899.242	-0.136
15-25k	4005.820	3997.826	-0.200
25-35k	4649.820	4639.842	-0.215
35-50k	6085.570	6070.329	-0.250
50-75k	7241.010	7217.662	-0.322
75-100k	3772.460	3761.485	-0.291
100-150k	2501.730	2494.094	-0.305
More than 150k	1937.860	1931.893	-0.308
Total	34293.730	34208.568	-0.248

Table 2.2 shows the impact of rangeland fires on different income groups. Each of the numbers in column two and column three in the table represents the sum of the stream of output over a ten-year period. Total output for the households with incomes ranging from $50,000 to $75,000 drops by about $23.35 million or about 0.32% as compared to the continuous benchmark. Total output for the households with incomes ranging from $100,000 to $150,000 and more than $150,000 also experienced relatively larger losses than the rest of the income groups'.

Table 2.3 shows the impact of rangeland fires on different income groups in a year-by-year prospect. The total loss of output from rangeland fires for each income group over a ten-year period is about $1.46 million, $2.59 million, $8.04 million, $10.04 million, $15.32 million, $23.47 million, $11.03 million, $7.68 million and $6 million, respectively. It is worth noting that households with incomes ranging from $50,000 to $75,000 have the largest impacts for each year measured. Households with incomes ranging from $35,000 to $50,000 and $75,000 to $100,000 have the second and third highest impacts from rangeland fires for each year among the income groups. In general, households with mid-range incomes are impacted the most from rangeland fires, followed by high-range and low-range income groups.

Table 2.3: Year-by-Year Impacts of Rangeland Fires on Income Groups ($millions)

Income Groups	Year01	Year02	Year03	Year04	Year05	Year06	Year07	Year08	Year09	Year10	Total
Less than10k	0.087	0.098	0.116	0.134	0.148	0.153	0.161	0.184	0.187	0.189	1.457
10-15k	0.154	0.174	0.206	0.239	0.263	0.272	0.287	0.328	0.333	0.337	2.593
15-25k	0.479	0.539	0.639	0.739	0.816	0.844	0.89	1.018	1.033	1.043	8.04
25-35k	0.597	0.673	0.798	0.923	1.019	1.053	1.111	1.27	1.289	1.302	10.035
35-50k	0.912	1.028	1.218	1.408	1.555	1.607	1.696	1.939	1.967	1.987	15.317
50-75k	1.397	1.575	1.866	2.158	2.382	2.463	2.599	2.971	3.015	3.045	23.471
75-100k	0.657	0.74	0.877	1.014	1.12	1.157	1.221	1.396	1.417	1.431	11.03
100-150k	0.457	0.515	0.61	0.706	0.779	0.806	0.85	0.972	0.986	0.996	7.677
More than 150kp	0.357	0.402	0.477	0.551	0.609	0.629	0.664	0.759	0.77	0.778	5.996

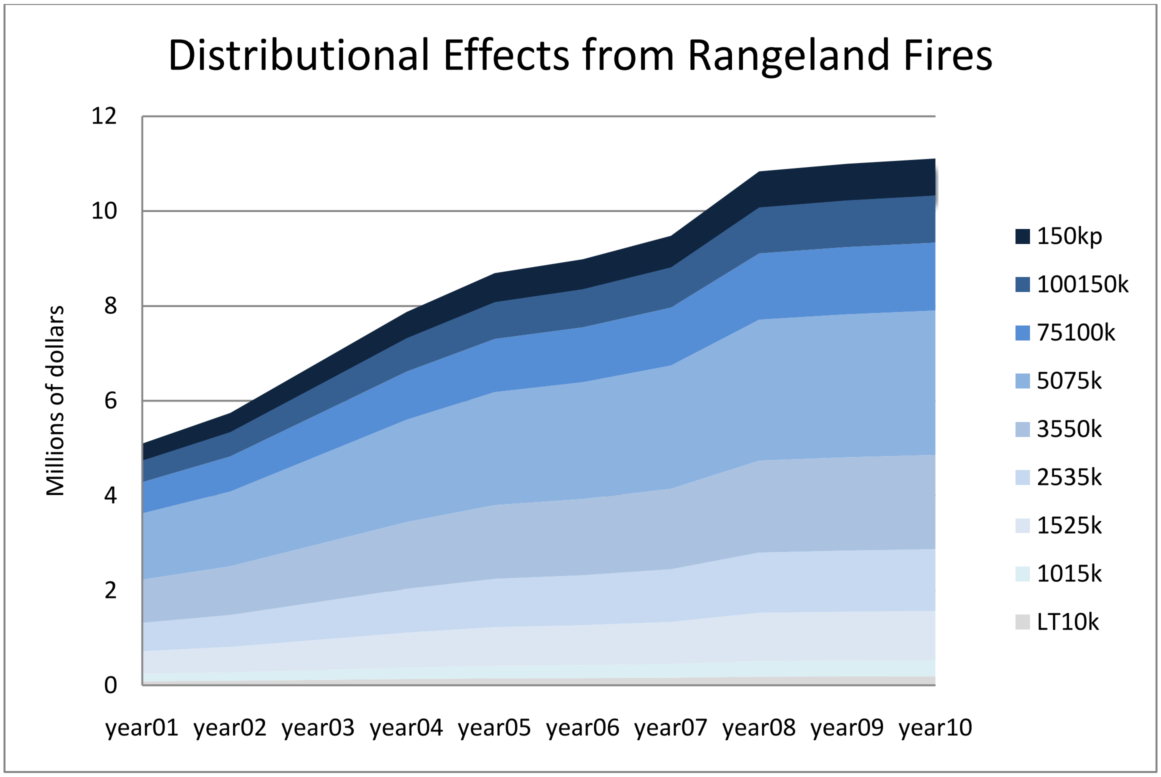


Figure 2.8: Distributional Effects (in millions of dollars) from Rangeland Fires

Figure 2.8 shows the distributional effects from rangeland fires. Apparently, households who have annual income ranging from $50,000 to $75,000 suffered the largest losses from wildfire. The loss varies from $1.39 million to $3.48 million. Households who have annual income ranging from $35,000 to $50,000 realize the second largest impacts from rangeland fires. All losses for households with different income levels show a positive trend, because of the increasing fire size. Generally, households with medium level of annual income (ranging from $25,000 to $75,000) are most affected from rangeland fires.

Table 2.4: Ten Year Average Economic Losses from Rangeland Fires

	10 year average	Direct and Indirect Economic Losses	
	Sector	$ in million	% of value of production
Activities (X)	Ag	1.899	0.63
	Hay	3.447	1.08
	Cattle	22.395	8.68
	Mining	0.006	0.02
	Utilities	0.454	0.50
	Construct	0.166	0.06
	Manufacturing	4.016	0.32
	Trade	2.220	0.38
	Service	9.869	0.34
	Activities total	44.472	0.74
Value Added (V)	EC**	8.074	0.45
	PI	1.010	0.43
	OPI	4.249	0.45
	IBT	1.227	0.62
Households (HH)	Less than 10k	0.152	0.07
	10k to 15k	0.271	0.14
	15k to 25k	0.839	0.21
	25k to 35k	1.047	0.23
	35k to 50k	1.599	0.26
	50k to 75k	2.450	0.34
	75k to 100k	1.151	0.31
	100k to 150k	0.801	0.32
	150k plus	0.626	0.32
	Total Value added & households	23.497	0.36
	Total	67.969	0.54

* *EC =Employee Compensation, PI=Proprietary Income, OPI= Other Property Type Income, IBT= Indirect Business Taxes

Table 2.4 shows the regional economic impact in the region including direct and indirect economic losses from the wildfire. The Cattle Sector has the largest regional impact from the wildfire, which is $22.4 million per year on average (8.68% of the value of the Cattle Sector production). The Hay Sector loses $3.45 million annually on average (1.08% of the value of the hay sector production). The Agricultural Sector loses $1.90 million annually (0.63% of the total value of production). The Service Sector is another sector which has a large impact from the wildfire. The loss is reported as $9.87 million per year (0.34% of total value). The loss comes from the interrelationship between the Cattle Sector and the Service Sector, for example, cattle and meat transportation, restaurants, and grocery stores. The Manufacturing Sector loses $4.02 million annually, probably due to the reduction in the livestock processing production. In total, regional activities' output decreases by $44.47 million annually and it accounts for 0.74% of the value of the regional productions.

This table also contains the institutional impact from the wildfire. Employee compensation reduces by $8.07 million and in turn household income decreases by $8.94 million because of the wildfire. Households which have income ranged from $50,000 to $75,000 dollars per year experienced the largest losses from rangeland fires. Rangeland fires reduce value added and household income by $23.5 million annually which is the 0.36% of the regional total. In summary, Southeast Oregon (four counties) pays $67.97 million as the cost of wildfire which is 0.54% of the regional total (total output plus value added and household income). It should be noted that these values maybe conservative estimations because additional losses are not considered to be associated with wildfire, such as environmental and ecological effects, reductions in recreational access, or direct wildfire suppression costs.

2.5.3 Discussion and Policy Implications

There three major findings in this study. First, the wildfire damage is far beyond simple wildfire suppression cost and direct impact on ranching business. The average of the wildfire economic impact in Southeast Oregon over 10 year period is $68 million dollars. Rangeland managers may need to consider this economic impact as a part of their future plan in order to decide whether cheatgrass invasion should be treated, or at what extent should it be treated. This estimation maybe conservative because non-market values, for example, reduction in recreational access, environmental and ecological effects are not considered.

Second, the Cattle Sector, the Service Sector and the Manufacturing Sector are the most impacted sectors in the study area. The losses come from the interrelationship between cattle sector and service sector and also probably from the reduction in the livestock processing production. Policy makers may consider making compensation for those sectors if the economic loss in a certain year is large.

Third, distributional effects show that medium income households (ranging from $25,000 to $75,000) are most impacted from rangeland fires. Regional economic development which includes components such as income distribution is more complex than models with single value-added components. The distributive effects from wildfire for ranching business in Oregon are crucial to the policy makers who are dealing with rangeland fires and public land management.

Two caveats should be mentioned. First, the model in the study assumes perfect information which means that ranchers know the wildfire incidents in advance and then take actions before or at the wildfire occurrences to reduce the wildfire damage. Even though this is not true in reality, the proposed model in this study describes a full picture of regional economic impacts from rangeland fires. If imperfect information is considered, economic impacts from rangeland fires could be larger. Second, the single rancher assumption may not allow us to investigate substitution effect among ranchers. It is plausible that the larger commercial ranchers are not as vulnerable to rangeland fires as small ranchers. Some of the small ranchers may go bankrupt under the severe wildfire. The model constructed here may not detect this possibility.

Therefore, the future plans for the study could include various types of ranchers and examine the substitution effect among ranchers. It could also construct a model which has multiple objective functions, such as a model which minimizes the cost to mitigate fires.

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Appendix A

Table 1: Livestock characteristics for the Oregon representative ranch

Livestock Class (Model Name)	Sale Weight 100 weight (cwt)	Animal Production Costs ($)	Number or %	Sales Price ($)
Mature cows maintained in the herd (BROODCOW)	0.00	32.00	300	
Cull cows (CULLCOW)	11.00	32.00		50.65
Bulls (BULL)	5.00	0.00		63.96
Steer calves for sale (SCALF)	5.75	0.00		113.41
Heifer calves for sale (HCALF)	5.25	0.00		111.85
Yearling steers for sale (SYEAR)	0 (not raised in ranch)	0.00		
Yearling heifers for sale (HYEAR)	8.00	0.00		87.68
Replacement heifer calves (REPHCALF)	0.00	0.00	60.00	
Replacement heifer yearlings (REPHYEAR)	0.00	32.00	58.00	
Brood cows sold (SELLBCOW)	1.00			
Minimum cow replacement rate (MINREPL)		0.15		
Minimum percentage of heifers for sale (MIN-HYEAR)			0.10	
Maximum percentage of heifer calves produced and saved as replacements (MAXREPL)			0.80	

Table 2: Forage quantity and costs for the Oregon representative ranch according to land type

Land Type (Model Name)	Quantity Available (Acres)	Forage Cost/AUM ($)
BLM Allotment (ACBLM)	2000	8.77
Deeded Range (DEEDRANG)	1700	11.55
Raise Meadow (RMEADOW)	500	130.00
Graze Meadow (GMEDADOW)	500	13.75

Table 3: Ranch fixed income and expenses for the Oregon representative ranch

Income and Savings Rage (SCALER)		Expenses and Borrowing Rate (SCALER)	
Off Ranch (OFFRANCH)	12,168	Fixed ranch expenses (FIXED)	21,229
Family Living Allowance	24,000	Short Term Borrowing Rate (STLOANR)	0.04
Interest Return on Savings account (SAVRATE)	0.03		

Table 4: Seasons of use according to land type

Season	Date Season Starts	Land Type
Season 1	March 15	Deeded Range
Season 2	April 1	Deeded Range, BLM Allotment
Season 3	June 15	Deeded Range, BLM Allotment
Season 4	July 15	Deeded Range, BLM Allotment
Season 5	September a	Deeded Range, BLM Allotment
Season 6	October 1	Deeded Range, Raised Meadow Hay
Season 7	November 1	Hay

Appendix B

Table 1: Aggregation for economic sectors

IMPLAN Number	Sector	
1	Agriculture	Activities (**X**)
10	Hay	
11	Cattle-Ranching	
19	Mining	
30	Utilities	
33	Construction	
46	Manufacture	
390	Trade	
391	Service	
5001	EC*	Value Added (**V**)
6001	PI	
7001	OPI	
8001	IBT	
10001	Households LT10k	Households (**Y**)
10002	HH 10-15k	
10003	HH 15-25k	
10004	HH 25-35k	
10005	HH 35-50k	
10006	HH 50-75k	
10007	HH 75-100k	
10008	HH 100-150k	
10009	HH 150k+	

Chapter Three:

Effects of Wildfire on Hospital Admissions for Respiratory Disease In Reno-Sparks, Nevada

3.1 Introduction

In the last decade, many western states, such as California and Nevada, have experienced some of the largest wildfires in history. As a result of long-term drought and global warming, fire seasons are starting earlier, and fires are more frequent and prolonged (Westerling et al. 2002; Collins et al. 2006). Wildfires can lead to adverse economic impact, such as damaging commercial timber and farmland. Wildfires can also reduce tourism, and cause disruption in other commercial activities. In addition to this economic impact, wildfires also produce a large amount of greenhouse gas and pollution particles, which might lead to health problems for nearby residents, and thereby increase local health care costs.

Wildfires can produce a large amount of smoke that disperses over long distances under certain climatic and terrain conditions. Therefore, smoke may adversely affect communities far away from the locations of wildfires (Viswanathan et al. 2006). Approximately ninety percent of particulate matters (PM) generated in a wild fire incident have diameters of less than 10 μm (PM_{10}) (EPA 1998; Ottma 2001).These harmful fine particles, once inhaled into lungs, can cause respiratory problems (Wilson 1996; Emmanuel 2000).

Recent studies have analyzed the effects of wildfires on human health in the context of air quality changes. Fowler (2003) reviewed how forest fires can affect human health, including health consequences of air pollution, water contamination, psychosocial issues, occupational exposures, visibility impairment and other health care measures. The smoke produced in a forest fire can lead to asthma and other respiratory problems, eye irritation, and, in some cases, even death (Sastry 2002; Viswanathan et al. 2006; Tham et al. 2009).

The relationships between wildfires and air pollution and, between air pollution and human health have been well established in the existing literature. However, wildfire, as a potential direct factor to affect human health in urban areas with dense populations, has not been analyzed. There are some limitations that need to be addressed. First, some studies modeled level of air pollutant emissions from wildfires (Rigg et al. 2000; Dennis et al. 2002). Some of the literature provides theoretical background to explain that how wildfires leads to air pollution, which lacking empirical evidences. Second, while few studies have linked air pollution as a product from wildfire to human health, this linkage has only been made for a specific wildfire period. Third, no studies have shown the direct effects of wildfires on respiratory disease using time series data and how distance impacts the effects of wildfires. Fourth, studies have not estimated the direct health care cost associated with wildfires. Consequently, the major objectives of this study will include the following: (1) To explore the temporal correlation between wildfire and air pollution; (2) To identify the separate effect of wildfires on pollution and morbidity; (3) To analyze whether a significant causal effect can be inferred from wildfire to morbidity and allow effects to vary by fire distance; and, (4) To analyze the implicit/hidden costs of wildfires in terms of respiratory health problems associated with air pollution.

3.2 Literature Review

Wildfire is an uncontrolled fire that occurs in the countryside or in wildness areas. Other names such as bushfire, forest fire, grass fire or wild land fire may be used to describe the same phenomenon, based on the type of vegetation being burned. Controlled fires, on the other hand, are often prescribed to reduce biomass fuels, mitigate wildfire risks, and protect resource values. One of the goals of forestry management is to simultaneously optimize forest health and human health while balancing ecosystem management (Fowler 2003).

3.2.1 Wildfire and Air Pollution

According to the U.S. Environmental Protection Agency (EPA), air pollution refers to the introduction of chemicals, particulate matter (PM), or biological materials that cause harm or discomfort to humans or other living organisms, or damage the natural environment in the atmosphere. Pollutants can be in the form of solid particles, liquid droplets, or toxic gases. Primary pollutants include sulfur oxides (SOx), nitrogen oxides (NOx) , carbon monoxide (CO) , carbon dioxide (CO_2) , particulate matter (PM), volatile organic compounds (VOC), toxic metals and so on. Secondary pollutants include: particulate matter formed from gaseous primary pollutants and compounds in photochemical smog, and ground level ozone (O_3) formed from NOx and VOCs. Wildfire burning emits a substantial amount of gaseous pollutants and PM into the environment and may cause people to suffer from respiratory or cardiovascular illnesses.

Wildfire smoke is comprised of a complex mixture of particles, liquids, and gaseous compounds. These include PM, CO, NOx, and sulfur dioxide (SO_2), oxidants that may include small amounts of O_3, polycyclic organic material, and toxic pollutants (Ward and Smith 2000; Viswanathan et al.2006). These emissions may deteriorate air quality on a local, regional, and global scale. Some events are severe, and the contributions of fires to air pollutant concentrations are readily observable (Dennis et al. 2002). For example, the wildfires in California in 2008 caused massive trans-boundary air pollution, producing large amounts of haze and causing visibility and health problems in California and nearby states.

The most abundant air pollutant from wild land fires is CO (Viswanathan et al. 2006). Fires also emit a large amount of semi-volatile organic compounds (VOCs), which are partitioned between the gaseous and liquid or solid phase at ambient temperatures. Some VOCs are carcinogenic and can condense or be absorbed into the surface of the particulate (Ward and Smith 2000). Furthermore, particulate matter (PM) is also one of the most significant emissions from forest fires. Ninety percent of particulate matter in biomass smoke is PM_{10}, indicating that it is 10 micrometers or smaller in diameter (EPA 1998; Ottma 2001). Seventy to ninety percent of particulate matter in smoke is $PM_{2.5}$, meaning that it is 2.5 microns or smaller in diameter (Fowler 2003).

Evidence has established a clear linkage between wildfire or prescribed fire and air pollution. For instance, early in 1996, the department of ecology issued an emergency ruling that called for a one-third reduction in the number of acres of field and turf grasses that could be burned in Washington State. Holland et al (1996) estimated the costs and benefits from reduction of grass seed field burning and pointed out that the largest potential benefit of the proposed rule was improved air quality from reduced smoke emission. Furthermore, according to Washoe County Health District's reports on air quality, air pollution from wildfires is a concern for Reno-Sparks, Nevada. Specifically, in 2008, the monitored $PM_{2.5}$ exceeded national standards on July 2nd and July 11th. This was influenced by the smoke from numerous wildfires in Northern California. The monitored ozone exceeded national standards on June 13th , June 14th , June 24th , June 25th , June 26th and July 10th, which was influenced by smoke from the Indians Fire in

Monterey County and Northern California (Mendoza 2008).

3.2.2 Air Pollution and Health Problems

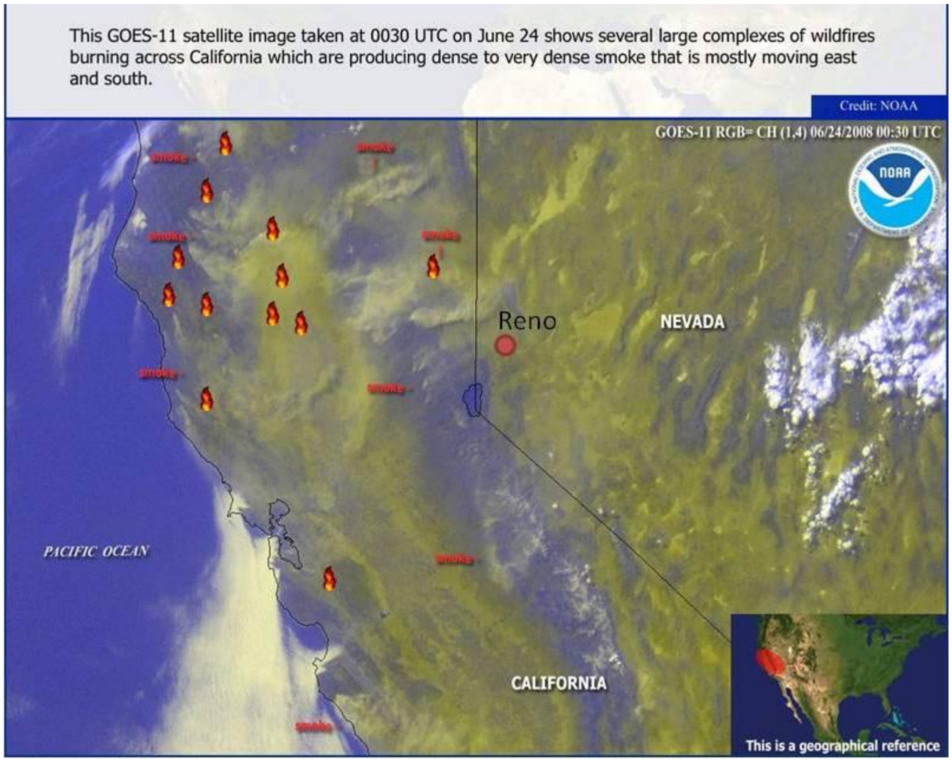
Numerous studies have provided evidence of an association between air pollution and health problems. If the research focus is narrowed to a study of air pollutants from smoke, it will be clear that the causal relationships between particular matters (PM), carbon monoxide (CO), and ozone (O_3), and the respiratory illnesses, morbidity, and mortality are of substantial interest. Recent epidemiological studies have shown that high levels of $PM_{2.5}$ are correlated with substantial adverse health effects, including respiratory disease, heart disease, stroke, and premature mortality (U.S EPA 2004).

Both short-term and long-term health effects of exposure to air pollution are analyzed in existing literature. In the short-term, high levels of air pollutants lead to acute conditions, such as respiratory infections (Schwartz 1994; Chen et al. 2000; Sastry 2002; Tham et al. 2009). Long-term exposure to combustion-related fine particulate and sulfur oxide (SO_x)-related air pollution could also lead to cardiopulmonary and lung cancer mortality (Viswanathan et al. 2006; Yang et al. 1998). Tham (2009) used time-series data to determine whether variation in particulate matter (PM_{10}), visibility-reducing-particles and ozone could explain variation in respiratory related hospital admissions. Only elevated levels of PM_{10} increased the risk for exposed people to attend emergency departments for respiratory conditions. Recent studies have indicated that smaller particles, (defined as no greater than 2.5 μm in diameter), contribute significantly to adverse health effects (Le Tertre et al. 2002). For instance, Viswanathan et al. (2006) used time series data to analyze correlations between pollutant levels and resultant health problems. Their study yielded similar results and showed that increased $PM_{2.5}$ concentration above the federal standard lead to a significant increase in hospital emergency room visits for asthma, respiratory problems, eye irritation, and smoke inhalation. This study will only focus on short-term effects from wildfires. Therefore, $PM_{2.5}$ is the major air pollutant of interest of this study.

3.3 Study Area

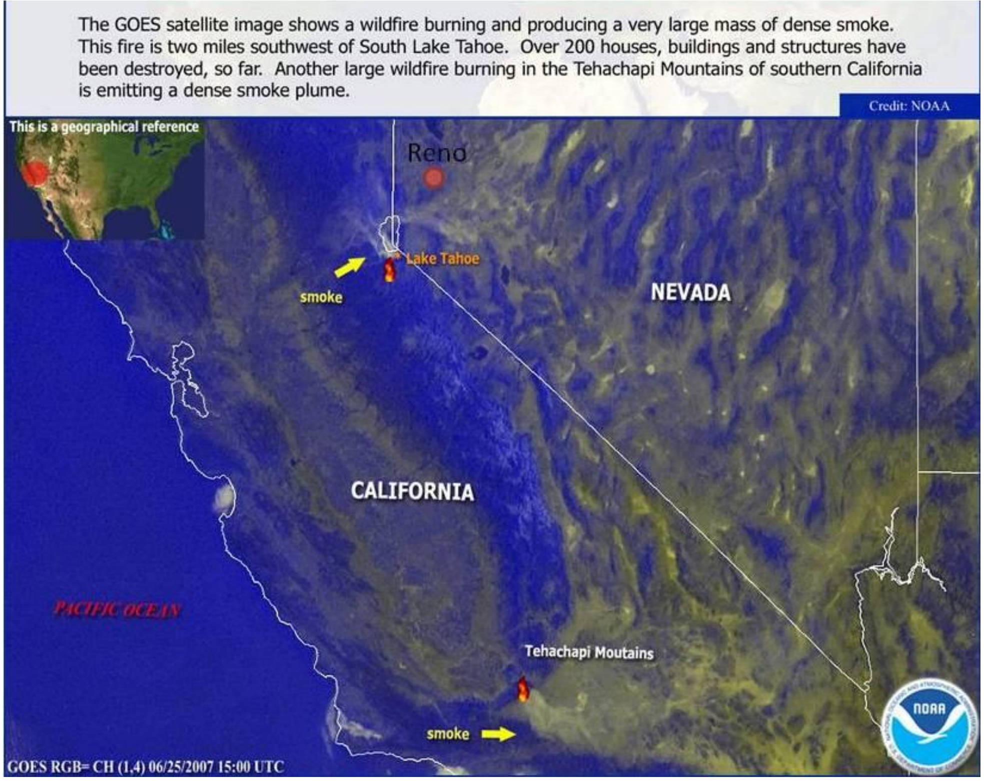
The urban areas of Reno and Sparks, known collectively as the Truckee Meadows, is located in Washoe County in northwestern Nevada at approximately 4400 feet above sea level. Washoe County is bordered by California on the west and Oregon to the north. The county encompasses a land area of 6,551 square miles and, in 2008, had an estimated population of 410,443.

Because of its geological characteristics, the Reno-Sparks area has temperatures above the national average and rainfall below the national average (NOAA Satellite and Information Service). As a consequence, this area has frequent wildfires. In addition to the frequency of wildfires, Reno-Sparks also experiences days of high winds from the west, causing the pollutants produced from large wildfires in California to affect the air quality in the Reno-Sparks area. Data regarding physical phenomena such as the behavior of fire and smoke are obtained from the National Oceanic and Atmospheric Administration (NOAA). Figure 3.1 and 3.2 show the satellite images of wildfire smoke for California and Nevada on two specifics day in 2007 and 2008.



This GOES-11 satellite image taken at 0030 UTC on June 24 shows several large complexes of wildfires burning across California which are producing dense to very dense smoke that is mostly moving east and south.

Figure 3.1: Satellite Image of Wildfires in California, June 24, 2008.
Source: National Oceanic and Atmospheric Administration (NOAA)



The GOES satellite image shows a wildfire burning and producing a very large mass of dense smoke. This fire is two miles southwest of South Lake Tahoe. Over 200 houses, buildings and structures have been destroyed, so far. Another large wildfire burning in the Tehachapi Mountains of southern California is emitting a dense smoke plume.

Figure 3.2: Satellite Image of Wildfire in South Lake Tahoe, June 25, 2007.
Source: National Oceanic and Atmospheric Administration (NOAA)

3.3.1 Identifying Relevant Wildfires Which Affect Reno-Sparks, Nevada in 2005-2008

Since wildfires could produce a large amount of smoke that may be dispersed over long distances, they could affect residents far away from the locations of the wildfires. The Reno-Sparks area experienced wind blowing from the west, northwest and southwest for sixty-seven percent of the days from 2005 to 2008 (calculated from National Weather Service statistics). More specifically, this area experienced wind blowing from the west, northwest, and southwest eighty percent of the days from May to September in 2005 to 2008 (calculated from daily wind direction data from National Weather Service). Therefore, wildfires that occurred in Washoe County, Nevada and nearby counties in California, including Alpine, Amador, Butte, Calaveras, El Dorado, Fresno, Inyo, Lassen, Madera, Mariposa, Modoc, Mono, Nevada, Placer, Plumas, Sierra, Tuolumne, Tulare, and Yuba County are considered. Each wildfire incident that occurred in those counties is identified with a size of over 300 acres (according to Bureau of Land Management, fires over 300 acres are considered large fires) and within 500 (or so) miles from Reno-Sparks (RS) that sent smoke to RS for all or most days of its existence (based on wind direction). Following is a table that lists each large wildfire by name, with begin date, end date, total acres burned, and distance from Reno/Sparks.

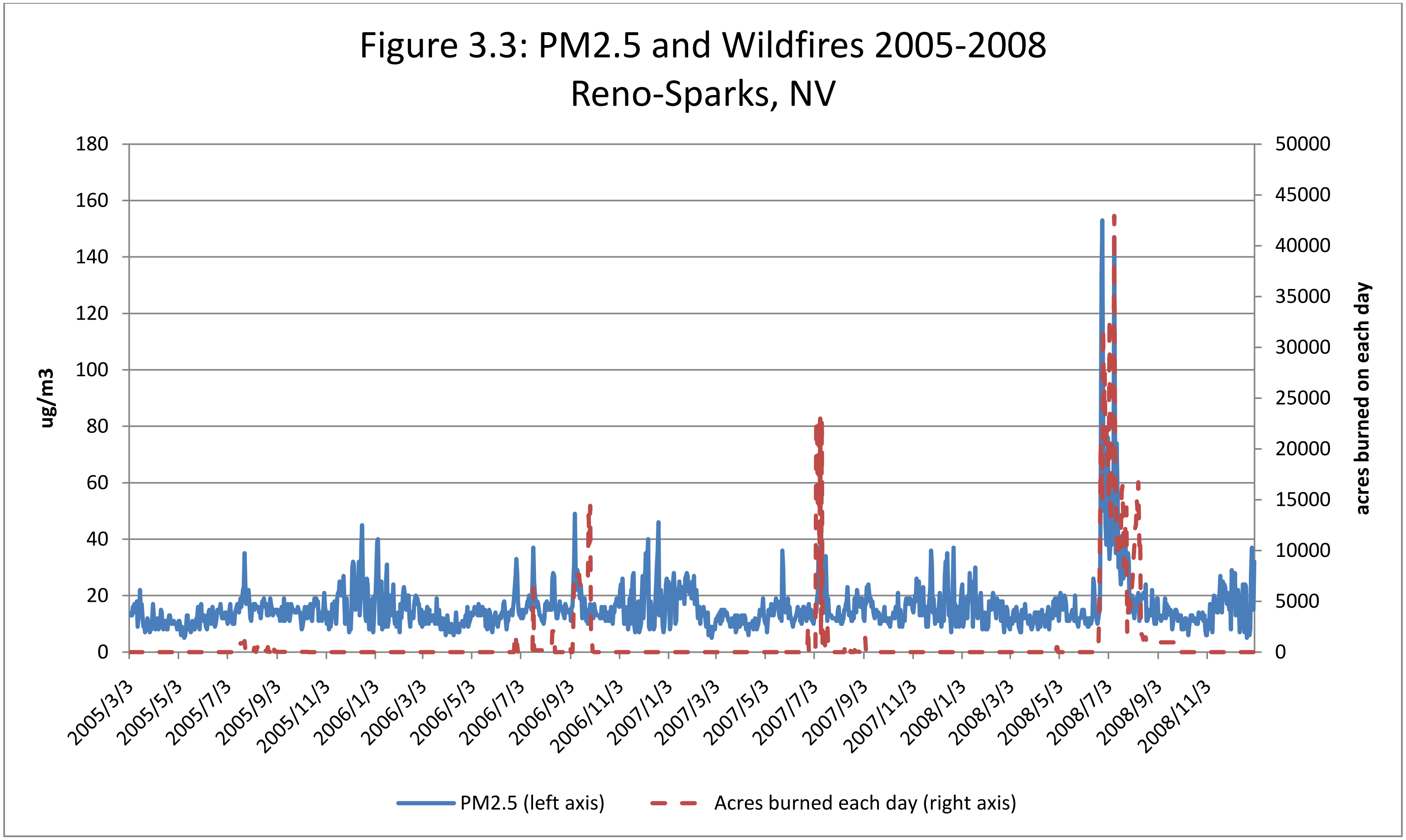
Table 3.1: The 35 Large Wildfires that Affect Reno-Sparks, Nevada, 2005-2008.

Year	Name	Acre	Start date	End date	Distance from RS	State
2005	China Lake	5300	7/19/2005	7/24/2005	123 miles	CA
2005	Comb Complex	8675	7/22/2005	10/15/2005	96 miles	CA
2005	Crag	1200	7/24/2005	7/29/2007	85 miles	CA
2006	Empire	3000	6/25/2006	6/28/2006	95 miles	NV
2006	Squaw	2095	6/25/2006	6/26/2006	100 miles	NV
2006	Bootlegger	6685	7/6/2006	8/13/2006	40 miles	NV
2006	Jackass	6255	7/17/2006	7/21/2006	80 miles	CA
2006	Verdi	5661	8/11/2006	8/13/2006	5 miles	NV
2006	August	461	9/2/2006	9/2/2006	261 miles	NV
2006	Day	162702	9/4/2006	10/2/2006	358 miles	CA
2006	Ralston	8423	9/5/2006	9/17/2006	214 miles	CA
2007	Mustang	572	5/18/2007	5/19/2007	10 miles	CA
2007	Bolli	730	5/22/2007	5/27/2007	292 miles	CA
2007	Honey	688	5/22/2007	5/23/2007	267 miles	NV
2007	Angora	3100	6/24/2007	7/2/2007	60 miles	CA
2007	Antelope Complex	136778	7/5/2007	7/13/2007	101 miles	CA
2007	Balls Canyon	900	7/10/2007	7/13/2007	16 miles	CA
2007	Hawken	2710	7/16/2007	7/23/2007	0 miles	NV
2007	Sand Pass	7000	7/17/2007	7/19/2007	50 miles	NV
2007	Tar	5644	8/10/2007	8/16/2007	33 miles	CA
2007	Vista	420	8/22/2007	8/27/2007	78 miles	CA
2007	North	2200	9/2/2007	9/8/2007	103 miles	CA
2008	East Lake	962	4/29/2008	4/30/2008	15 miles	NV
2008	Lime Complex	116448	6/20/2008	8/15/2008	346 miles	CA
2008	Klamath Theater	192038	6/21/2008	9/30/2008	247 miles	CA
2008	Iron & Alps Complexes	105805	6/21/2008	9/1/2008	196 miles	CA
2008	Yolla Bolly Complex	89389	6/21/2008	8/19/2008	311 miles	CA
2008	Shu Lightening Complex	86500	6/21/2008	7/25/2008	326 miles	CA
2008	BTU Lightning Complex	64995	6/21/2008	7/29/2008	109 miles	CA
2008	Canyon Complex	47680	6/21/2008	8/14/2008	260 miles	CA
2008	American River Complex	20541	6/21/2008	8/1/2008	221 miles	CA
2008	Basin Complex	16281	6/21/2008	7/27/2008	241 miles	CA
2008	Yuba River Complex	3819	6/21/2008	7/15/2008	70 miles	CA
2008	Corral	12434	6/23/2008	7/7/2008	325 miles	CA
2008	Gooseberry	3042	7/29/2008	7/31/2008	49.5 miles	NV

Source: National Fire and Aviation Management SIT report

3.3.2 Wildfires, Air Pollution and Patient Admissions

Although different air pollutants are produced simultaneously by wildfires, this study focuses on $PM_{2.5}$, recognizing that other materials are also generated by fire and may adversely relate to health problems. For the study area of Reno-Sparks, NV, I examine $PM_{2.5}$ as the sole pollutant from wildfires for the following reasons: 1) this fine particle that can be found in smoke and haze and, is directly emitted from sources such as forest fires (U.S. EPA, 2004); 2) For the study period from 2005 to 2008, only short-term effects from wildfire are recognized; and in the short term, $PM_{2.5}$ is the major air pollutant that lead to respiratory disease. The following figures show the relationship between $PM_{2.5}$ and number of wildfires, the relationship between PM2.5 and respiratory patients' admissions in each day from 2005 to 2008.



Source: National Fire and Aviation Management SIT report, Washoe County Health District

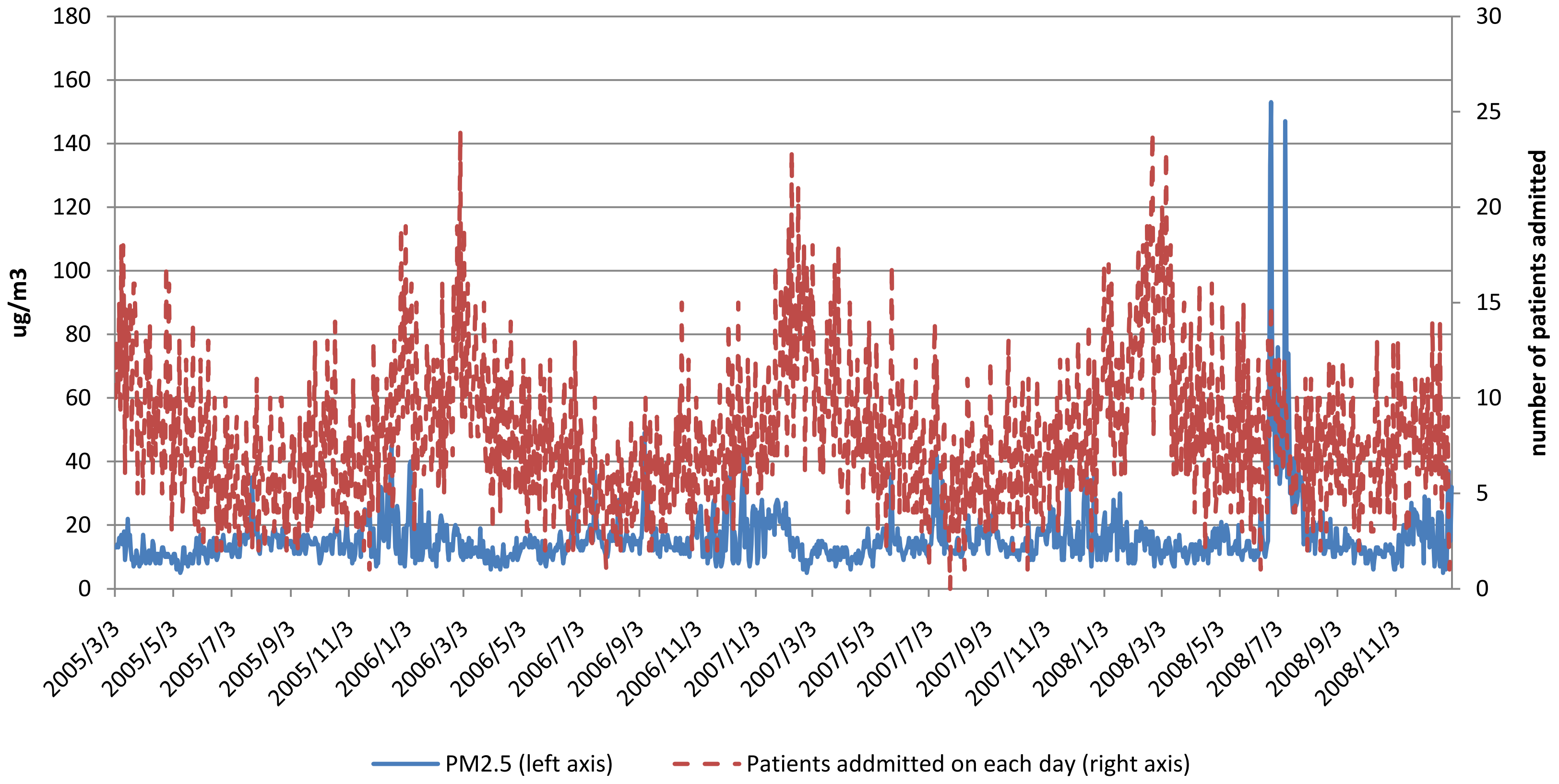


Figure 3.4: PM2.5 and Respiratory Patients Admissions 2005-2008
Reno-Sparks, NV

Source: National Fire and Aviation Management SIT report, University of Nevada Las Vegas and Nevada State Health Division

Figure 3.5: PM2.5 and Patients Admissions 2005

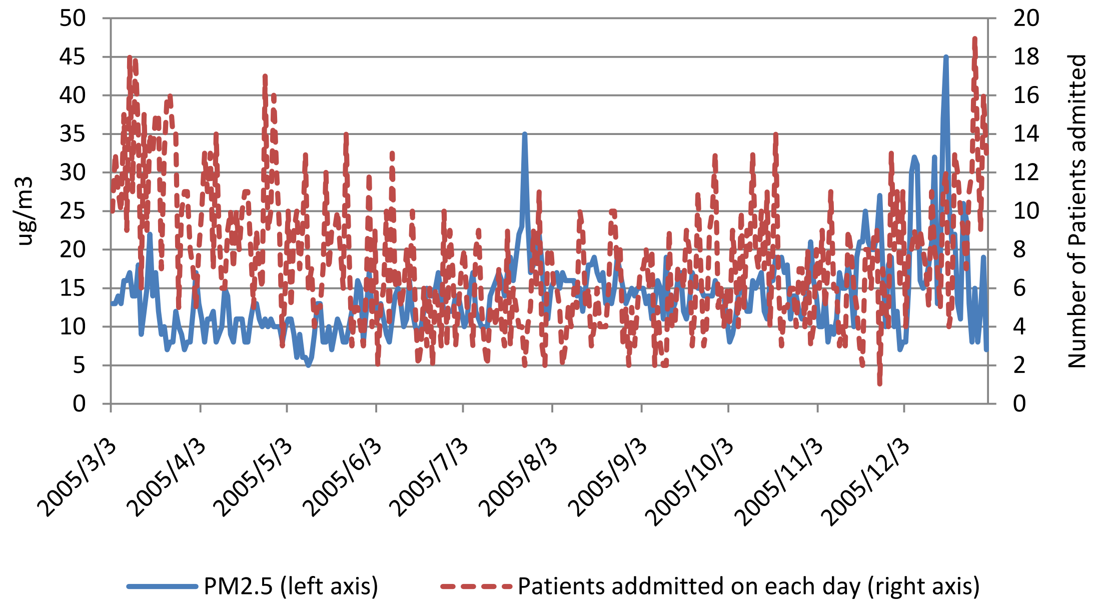
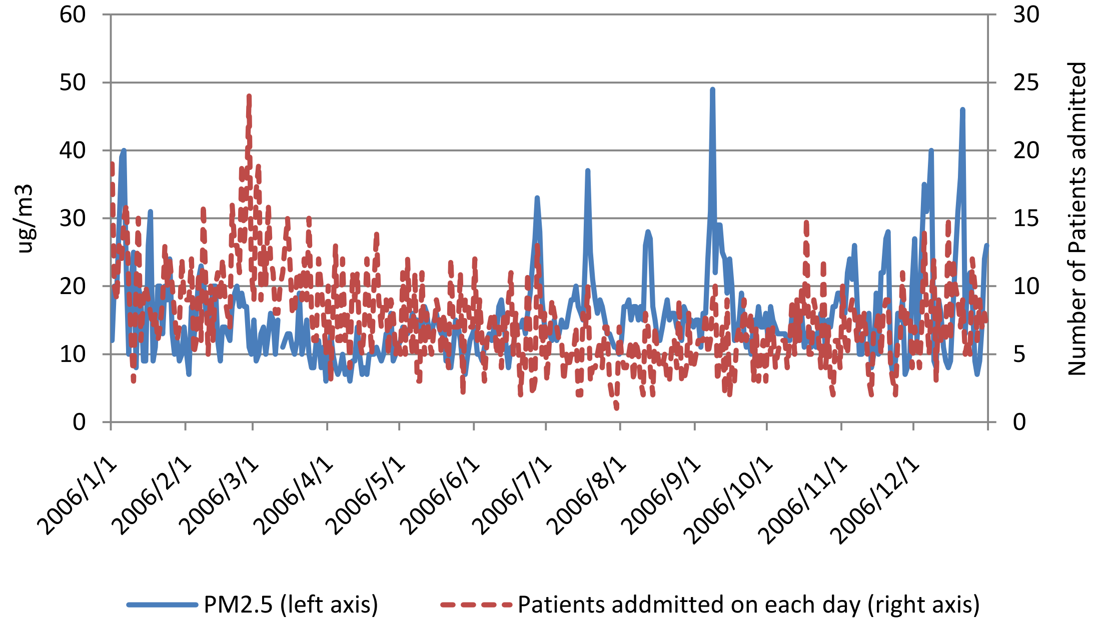


Figure 3.6: PM2.5 and Patients Admissions 2006



Source: National Fire and Aviation Management SIT Report, University of Nevada Las Vegas and Nevada State Health Division

Figure 3.7: PM2.5 and Patients Admissions 2007

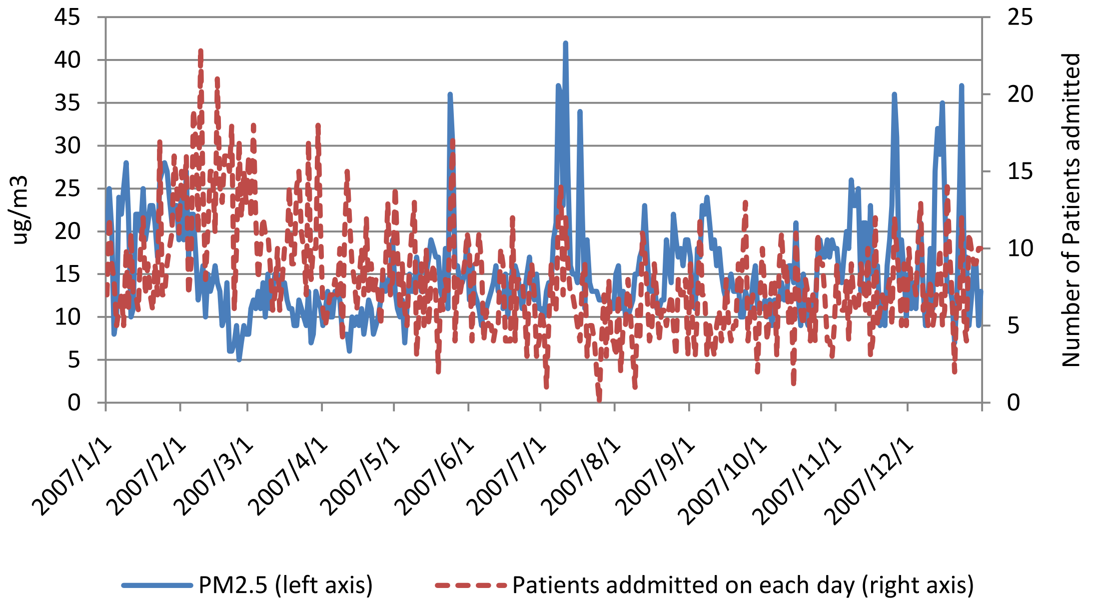
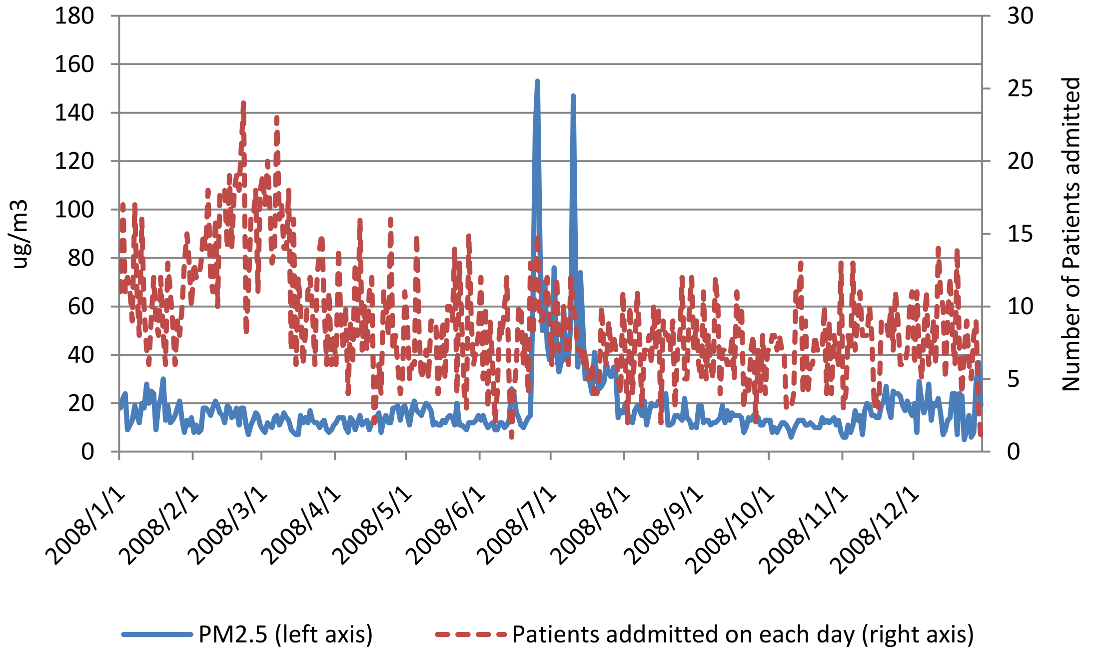


Figure 3.8: PM2.5 and Patients Admissions 2008



Source: National Fire and Aviation Management SIT Report, University of Nevada Las Vegas and Nevada State Health Division

Figure 3.3 shows that the numbers of wildfires in each day are positively related to air pollutant $PM_{2.5}$ in Reno-Sparks from 2005 to 2008. If wildfires occur, the level of $PM_{2.5}$ in the air increases. In Reno-Sparks, Nevada, the average winter (November, December and January) temperature is between 23 ^{o}F and 49 ^{o}F (calculation from NOAA, 1971-2000), which is below the national average winter temperature. Residential wood combustion (RWC) is a significant source of air pollution in Washoe County and RWC emissions have been directly linked to monitored violations of particulate matters less than 10 microns in size (PM_{10}) and carbon monoxide (CO) of the national ambient air quality standards (Medoza 2008). Hence, the peak levels of $PM_{2.5}$ that are not consistent with the occurrence of wildfires could be explained by wood burning in the winter in Reno-Sparks, Nevada.

Figure 3.4 shows that the total number of respiratory patients admitted on each day varies with time but not closely related to the level of $PM_{2.5}$. This is due to other facts that might affect the respiratory patients admitted but hard to measure, such as allergy, patients' health condition. But there are clear winter peaks which show the number of patients admitted and the level of $PM_{2.5}$ are moving to the same direction, such as January 2006 and 2007. The closer look for this relationship is provided in figure 3.5 to figure 3.8 for each year on a daily basis.

3.4 Methodology

3.4.1 Data

This study uses data from Reno-Sparks hospital admissions and emergency department attendances for selected respiratory/ cardiovascular conditions, and from air quality and meteorological measurements recorded during the period 2005-2008.

Hospital Admissions Data

Daily data on hospital admissions for respiratory disease were obtained from all three hospitals in the Reno-Sparks area (St. Mary's Regional Medical Center, Washoe Medical Center, and Northern Nevada Medical Center). Data files were created directly from computerized admissions database obtained from the Nevada State Health Division.

Air Quality and Weather Data

Daily air quality data were obtained from the Washoe County District Health Department Air Quality Management Division's air monitoring stations in the Reno-Sparks area. Among seven air-monitoring stations, three stations (Reno, South Reno, and Sparks) recorded the 24 hour average levels of $PM_{2.5}$ using the 6-day Hi-Vol method, which is the standard U.S. EPA reference method. All monitoring sites and instruments used in this study are maintained according to U.S. EPA standard methods.

Daily data on weather were collected from National Weather Service Forecast Office in Reno, Nevada. Data include daily average temperature, humidity/precipitation, sunlight, wind speed, and wind direction.

Wildfire Data

Wildfire data was obtained from National Fire and Aviation Management SIT report and Western Great Basin Coordination Center. Each wildfire incident with a start and end date in 2005-2008 were identified from the two data sources listed above. In this study, a wildfire day was identified by date. As described earlier, those wildfires were identified by location (occurred in Washoe County, Nevada and nearby Counties in California), size (over 500 acres) and wind direction in the study area during the period of wildfires. Burned area on each day for every wildfire identified was obtained from a GIS specialist from US Forest Service in Pacific Southwest Research Station. For primary analysis, index days are defined as the days that have wildfires occurrence, comparison days are defined as the days that no wildfire occurred on that day. In total, 315 index days were identified in the period of 2005-2008 in Reno-Sparks, Nevada, as showed in table 3.2.

Table 3.2: Wildfire Days Which Affect Reno-Sparks, Nevada, 2005-2008

Year	Date
2005	19 July-October 15
2006	25 June-27 June, 6 July-13 August, 2 September-3 October
2007	18-19 May, 22-27 May, 5-13 July, 16-23 July, 10-16 August, 2-8 September
2008	29-30 April, 21 June-30 September
Total	305 wildfires days in 2005-2008 (index days)

Source: Source: National Fire and Aviation Management SIT report

3.4.2 Model Set Up

The modeling procedure includes two steps. The first step is to analyze the relationship between the major air pollutant, $PM_{2.5,}$ and the wildfires. If wildfire occurs nearby, the wind speed and direction of the wildfire origin will bring $PM_{2.5}$ to Reno-Sparks. The distance of fire is important as well. The further away the fire, the less likely that pollution will reach Reno-Sparks. Monthly dummy variable is employed in order to control the wood burning effect in the winter in Reno-Sparks. The fresh acres burned for every day of every fire was recorded and estimated (if not through direct daily record) by the GIS specialist who works for the National Forest Service. Therefore, the total fresh acres burned on a given day by all fires within a given distance can be calculated as follows.

Let $a_{f,t}$ the fresh acres burned by fire *f* on day *t*, where *f* =1…*F* and *t* =1…*T*. *F* is the total number of individual fires identified, and *T* is the total number of days from 2005 to 2008. There are four categories of distance indicators for each fire indentified. Let $d_{f,50} = 1$ for fires within 0-50 miles, $d_{f,100} = 1$ for fires within 51-100 miles, $d_{f,250} = 1$ for fires within 101-250 miles, and $d_{f>250} = 1$ for fires further away than 250 miles. Then the total fresh acres burned on day t from all fires within distance category c are:

$$a_{c,t} = \sum_{f=1}^{F} a_{f,t} \times d_{f,c} \tag{3.1}$$

The fire distance is important because of dilution effects-smoke from a further-away fire is likely more diluted (less concentrated) by the time it reaches Reno-Sparks (RS) than smoke from a nearby fire. With the distance information, it is clear that even under low to moderate average wind speed (i.e., 20-30 mph) between fire origin and RS the smoke from a given relevant fire, even a far away one, should reach RS within 24 hours. At the same time, smoke produced on a given day will not linger in RS for very long under wind conditions (it will be replaced with smoke from the next day and so on). Therefore, only the acres burned on the current day and the previous day should contribute to the $PM_{2.5}$ production function. Let $\boldsymbol{a}_t = \left[a_{50,t,\dots}a_{>250,t}\right]$ and $\boldsymbol{a}_{t-1} = \left[a_{50,t-1,\dots}a_{>250,t-1}\right]$. The corresponding coefficient vectors as, respectively, $\boldsymbol{\beta}_2 = \left[\beta_{2,50,\dots}\beta_{2,>250}\right]$ and $\boldsymbol{\beta}_3 = \left[\beta_{3,50,\dots}\beta_{3,>250}\right]$. Then, the pollution production function could be modeled as a simple ordinary least square (OLS) regression:

$$p_t = \beta_0 + \mathbf{m}'\boldsymbol{\beta_1} + \mathbf{a}_t'\boldsymbol{\beta_2} + \boldsymbol{a}_{t-1}'\boldsymbol{\beta_3} + \beta_4 w_t + \varepsilon_t \tag{3.2}$$

Where p_t is the $PM_{2.5}$ level on day *t*, $\mathbf{m}$ is a vector of month dummies (this study use the full set of monthly dummies, left March as the reference month) and w_t is the local wind speed at RS on day *t*. The error has the usual OLS properties. The intercept and the month dummies capture local $PM_{2.5}$ production other than from wildfire.

The second step is to analyze the relationship between number of respiratory patients and air quality. In this study, air quality, in terms of $PM_{2.5}$, clearly affects the number of patients over time. Let the effect of $PM_{2.5}$ on daily admissions for respiratory patients presented as a morbidity function as follows:

$$y_t = \gamma_0 + \gamma_1 d + \sum_{\mathrm{j=0}}^{\mathrm{J}} \gamma_{2,j} \times p_{t-j} + \mathbf{m}'\boldsymbol{\gamma_3} + \eta_t \tag{3.3}$$

Where y_t are admissions for day *t*, (total, or by demographic sub-group), d is the days of week factor that affect the patient to go to hospital (i.e., people are not likely to go hospital on Sunday, Sunday dummy (SUN) is used in this study), p_{t-j} is the lagged $PM_{2.5}$ level, *J* is the highest numbered lag that still matters for daily admissions, and $\mathbf{m}$ is a vector of month dummies (this study use the full set of monthly dummies, left March as the reference month). Other variable such as temperature and allergy are also considered but not included in the regression equation because monthly dummies could capture those effects. Previous studies showed that there is a 1- 1.5-day lag between the periods of exposure to the level of $PM_{2.5}$ and the actual time of hospital admission (Viswanathan et al. 2006).

After running regressions in equation (2) and (3), the casual effect of an acre burned within a given distance category c on hospital admissions in RS can be expressed as:

$$e_c = (\widehat{\beta_{2,c}} + \widehat{\beta_{3,c}}) \times \sum_{\mathrm{j}=0}^{\mathrm{J}} \widehat{\gamma_{2,J}} \tag{3.4}$$

The standard errors and confidence intervals for this effect can be derived through simulation.

The cost of each admitted respiratory patient is calculated from "State Hospital Patient Discharge Analysis" (Carns et al., 2005). Respiratory disease leads to in infections, inflammations, major chest procedures, simple pneumonia and pleurisy, bronchitis and asthma (this information is obtained from Dr. Yang from the Division of Health Sciences at UNR). By taking the average cost of those treatments (each case times each bill charge and divided by the total number of cases), the average of treatment cost for one respiratory patient admitted is $23,753. Once the sampling distribution for e_c is obtained, the economic damage distribution of D_c is calculated by multiplying each draw of e_c by the average hospitalization cost for one admission.

3.5 Results and Discussion

In the primary analysis, air pollution on the index days was compared with air pollution on the comparison days. Comparison days are days without fire and are selected from April 1st to October 31st in each year. Since wood burning is the major source of air pollution during winter in Reno-Sparks, this method could exclude the noise from winter air pollution. Other air pollutants could be considered, such as power plant emissions, automobile emissions or summer barbecue events. However, there is no measurement for those variables, and those air pollutants do not vary much during the year compared to wildfires.

Table 3.3: Mean Levels of Environmental Variables on Wildfire Days (index days) and Comparison Days in Reno-Sparks, 2005-2008[5]

Variable	Index days (n=315)	Comparison days (n=541)	P -value (from t-test)
$PM_{2.5}$ (μg/m^3)	20.686 ±0.932	12.706 ±0.266	0.0000
Ozone(ppm)	0.036 ±0.001	0.033 ±0.001	0.0001
CO (ppb)	0.369 ±0.012	0.354 ±0.009	0.0407

Table 3.3 shows the average values of air pollutant levels in Reno-Sparks for the index and comparison days. The average $PM_{2.5}$ level for the index days was 20.686 μg/m^3, which was 7.98 μg/m^3 significantly higher than the average for the comparison days. The average ozone level for the index days was 0.003 ppm higher than the average for the comparison days. The average CO level for the index days was 0.015 ppb higher than the average for the comparison days. The levels of ozone and CO are not very different on wildfire days and no- fires days.

Table 3.4 shows OLS regression results for $PM_{2.5}$ in equation (3.2). The fresh acres burned on each day with different distance categories are positively and significantly affecting the $PM_{2.5}$ level as expected. The fresh acres burned on *t-1* with different distance categories also positively affecting the $PM_{2.5}$ level on current day but only three distance categories are significant. The dummy variables (except March) employed in order to control other factors that affect the $PM_{2.5}$ level such as the wood burning effect in Reno-Sparks and they showed positive effect to increase the $PM_{2.5}$ level and significant at the 1% level. Wind speed showed a negative effect to the level of $PM_{2.5}$. This is because higher wind speed will blow away the $PM_{2.5}$ concentrated in Reno-Sparks.

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[5] Data presented are in the form of $mean \pm 1.96 * {}^{\sigma}/_{\sqrt{n}}$, in other words, they are in 95% confidence interval format.

Table 3.4: OLS Regression Results for $PM_{2.5}$

$PM_{2.5}$	Coefficient	Std. Error	t	P	95% confidence intervals	
$a_{50,t}$	0.003942	0.001553	2.54	0.011	0.000895	0.006988
$a_{100,t}$	0.005116	0.000995	5.14	0.000	0.003164	0.007069
$a_{250,t}$	0.000266	0.000064	4.14	0.000	0.000140	0.000392
$a_{>250,t}$	0.000848	0.000230	3.68	0.000	0.000396	0.001299
$a_{50,t-1}$	-0.000065	0.001552	-0.04	0.967	-0.003109	0.002980
$a_{100,t-1}$	0.004769	0.000995	4.79	0.000	0.002816	0.006721
a_{250_t-1}	0.000168	0.000064	2.61	0.009	0.000042	0.000293
$a_{>250,t-1}$	0.001875	0.000232	8.08	0.000	0.001420	0.002330
Wind speed	-0.162794	0.021433	-7.6	0.000	-0.204841	-0.120747
JAN	6.243876	1.067192	5.85	0.000	4.150291	8.337460
FEB	2.183471	1.088718	2.01	0.045	0.047658	4.319285
APR	-0.114704	1.075552	-0.11	0.915	-2.224689	1.995282
MAY	1.579063	0.992470	1.59	0.112	-0.367935	3.526061
JUN	3.353461	1.014289	3.31	0.001	1.363661	5.343262
JUL	3.583925	1.051678	3.41	0.001	1.520774	5.647075
AUG	2.142360	1.023014	2.09	0.036	0.135441	4.149278
SEP	-0.526648	1.013152	-0.52	0.603	-2.514220	1.460923
OCT	0.819789	0.998377	0.82	0.412	-1.138796	2.778374
NOV	4.085918	1.005931	4.06	0.000	2.112512	6.059324
DEC	6.222418	0.997864	6.24	0.000	4.264839	8.179997
Constant	16.085280	0.956128	16.82	0.000	14.209580	17.960990

Table 3.5 shows that the level of $PM_{2.5}$ is positively and significantly affecting the number of respiratory patients admitted but days of the week and most of the monthly dummies presented negative and significant effects. The $PM_{2.5,t-1}$ is included in this model based on previous literature, hence *J=1* in equation (3.3). which The marginal effect of $PM_{2.5}$ for the current and lagged is approximately 0.048, which means when the level of $PM_{2.5}$ increase by 0.048 ug/m^3, there are will be one more respiratory patient admitted into hospital, keep all other variables constant. The monthly dummy variables (reference month: March) showed negative and significant effects. It seems like March has more respiratory patients admitted than other months except February. This might due

to the fact that people who have respiratory problems are more sensitive to allergy in the spring time.

Table 3.5: OLS Results for Daily Respiratory Patients' Admissions

Respiratory Patients	Coefficient	Std. Error	t	P	95% confidence intervals	
$PM_{2.5}$	0.040381	0.012197	3.31	0.001	0.016454	0.064307
$PM_{2.5,t-1}$	0.007631	0.012219	0.62	0.532	-0.01634	0.031601
SUN	-0.73376	0.229174	-3.2	0.001	-1.18333	-0.2842
JAN	-2.14484	0.419435	-5.11	0.000	-2.96764	-1.32204
FEB	1.765147	0.425636	4.15	0.000	0.930184	2.600111
APR	-2.97176	0.387	-7.68	0.000	-3.73093	-2.21258
MAY	-3.99355	0.384008	-10.4	0.000	-4.74686	-3.24025
JUN	-5.1084	0.393111	-12.99	0.000	-5.87956	-4.33724
JUL	-6.17425	0.398955	-15.48	0.000	-6.95687	-5.39163
AUG	-5.90953	0.38564	-15.32	0.000	-6.66603	-5.15302
SEP	-5.58492	0.388585	-14.37	0.000	-6.3472	-4.82264
OCT	-4.87669	0.384082	-12.7	0.000	-5.63014	-4.12325
NOV	-4.82225	0.389756	-12.37	0.000	-5.58682	-4.05767
DEC	-3.64359	0.389833	-9.35	0.000	-4.40832	-2.87886
Constant	11.08857	0.298636	37.13	0.000	10.50274	11.6744

Table 3.6: Simulated Causal Effect and Damage from Additional Acres Burned from Wildfires

Category	Distances c	Causal effect (e_c) (admission/ acre)	Damage (D_c) (dollars/acre)
1	0-50 miles	0.000186±0.000007	4.429191±0.167212
2	51-100 miles	0.000475±0.000010	11.29273±0.238306
3	101-250 miles	0.000021±0.000000	0.493692±0.011221
4	>250 miles	0.000131±0.000003	3.103461±0.063922

Note: Data presented are in the form of $mean \pm 1.96 * {}^{\sigma}/_{\sqrt{n}}$, in other words, they are in 95% confidence interval format.

Table 3.6 shows the simulated causal effect of an acre burned within a given distance category c on hospital admissions in RS as expressed in equation (3.5). Wildfires occurred 51-100 miles away from Reno-Sparks has the largest causal effect and one additional acre burned from this category of wildfires will increase $11.29 dollars of medical expense in Reno-Sparks area. Wildfires occurred within 50 miles from Reno-

Sparks ranked second. If one acre burned from this category of wildfires, the medical expense will increase $4.43. An acre burned from wildfires occurring over 250 miles away from Reno-Sparks will increase the medical expense by $3.10. The third category of wildfire (101-250 miles) had the least damage.

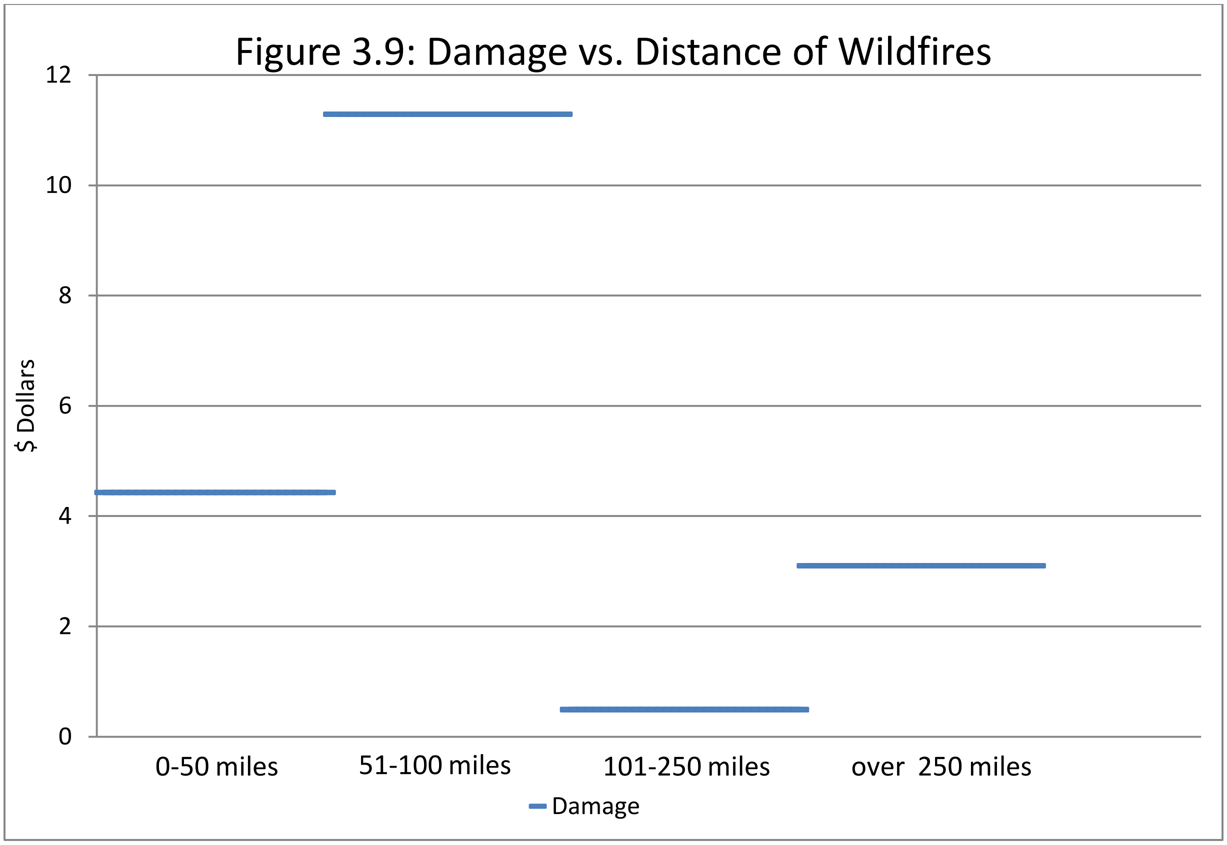

Figure 3.9 shows the economic damage from wildfires with different distance categories. Wildfires occurred 51-100 miles away costs higher than wildfires occurred within 50 miles does. There are nine wildfires occurred and 142 days with fresh acres burned in the first category, but eight wildfires occurred and only 38 days with fresh acres burned in the second category. This implies that the intensity of wildfires in the

second category is larger than the intensity of wildfires in the first category, which explains why the damage is higher in the second category of wildfires. The third and fourth categories of wildfires represent the same relationship. There nine wildfires occurred and 131 days with fresh acres burned in the third category, but nine wildfires occurred and 92 days with fresh acres burned in the fourth category. The rank of damages from wildfires occurred over different distances in a descending order is: category two, category one, category four and category three. With the different intensities among four categories of wildfires, the damage is decrease as the distance from wildfires to Reno-Sparks get further.

Table 3.7: Calculated Effects from Wildfires over Different Distance Categories

Category	Distances *c*	Average size of wildfires	# patients increased	Damage (D_c) (dollars)
1	0-50 miles	3686 acres	0.687365	$16,327
2	51-100 miles	3571 acres	1.697499	$40,321
3	101-250 miles	61373 acres	1.27561	$30,300
4	>250 miles	57448 acres	7.505899	$178,288

Table 3.7 presents the calculated effects from average size for wildfires over different distance categories. For wildfires occurred with 50 miles, the average size is 3,686 acres. If one wildfire occurs within this category, it will increase the medical expense by $16,327. For wildfires occurred with 51 to 100 miles, the average size is 3,571 acres. If one wildfire occurs in this category, it will increase the medical expense by $40,320. For wildfires occurred with 101 to 250 miles, the average size is 61,373acres. If one wildfire occurs in this category, it will increase the medical expense by $30,300. For wildfires occurred over 250 miles away, the average size is 57,488 acres. If one wildfire occurs in this category, it will increase the medical expense by $178,288. In

general, the average size of 35 identified wildfires is 32,318 acres. If one more wildfire occurs, it will increase by medical expense by $156,096.

3.6 Conclusion

This study contributed to the wildfire effect on human health literature in three points. First, it is the first study to identify the separate effect of wildfire on pollution and morbidity, while existing studies have only considered the combined effects of wildfire pollution and non-fire pollution. Second, it is the first study to allow these effects to vary by fire distance. Third, it is the first study to add an economic component to a study of fire impact on health.

There are two major findings from the analysis. First, results showed that wildfires that occurred away from Reno-Sparks within different distances increased the level of $PM_{2.5}$ in the Reno-Sparks area. This effect could lead to the increase in the number of people who are suffering respiratory diseases. Second, the regression on daily respiratory patients' hospital admissions showed that the level of $PM_{2.5}$ is positively affecting the number of patients admitted. The causal effect to number of patients admitted from wildfire varied by distances. Wildfires occurred within 51-100 miles to Reno-Sparks has the largest impact on human health, followed by the impact from wildfires occurred within 0-50 miles, over 250 miles and within 100-250 miles. Damages from wildfires, in terms of treatment cost on admitted respiratory patients, also has the same pattern as the causal effect from wildfires by different distances. The average damage of one acre burned by wildfires within a given distance category on hospital admissions in Reno-Sparks is $4.83. Wildfires that could affect the air quality in Reno-Sparks are identified with size over 300 acres. Therefore, if one average sized wildfire occurred near Reno-Sparks, the damage would cost approximately $156,096. This effect could be underestimated because historical data of wildfires showed that more than one wildfire occurred during the summer period, which means the damage could be much larger than estimated.

This study suggests that policy makers should pay more attention to wildfire management because wildfires are not only directly affecting the air quality. Wildfires also affect human health and increase medical expenses indirectly. Meanwhile, policy makers could form general guidance for residents on how to protect themselves to inhale less $PM_{2.5}$ when wildfires are frequent in summer.

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