COMPUTABLE GENERAL EQUILIBRIUM MODELING

OF RANGELAND FIRES IN NORTHERN NEVADA

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Introduction

During the summer of 1999, northern Nevada experienced is worst fire year with over 1.6 million acres of federal, state and private rangeland burned. Lightning from thunderstorms was the primary cause of these late summer rangeland fires. At one point during the summer of 1999, more than 56 percent of the nation's federal fire fighting resources was involved in fighting these rangeland fires in Northern Nevada (U.S. Department of Interior 1999).

Approximately 84 percent of Nevada's land mass is under federal administration. For the five northern Nevada counties (Elko, Eureka, Lander, Humboldt and Pershing Counties) affected by the 1999 rangeland fire, approximately 77.4 percent of their land mass is administered by the federal government. The area damaged by this rangeland fire represents approximately 6 percent of the total land mass in the five county northern Nevada study area. Rangeland in Nevada is the primary source of grazing in the state with approximately 60 percent of the sheep and lambs are located in this five-county northern Nevada study area that was affected by the rangeland fires. (Nevada Agricultural Statistics 1998-99).

In any natural disaster, there is a need for immediate estimation of the monetary impacts. This impact information is used to initiate federal and state emergency programs as well as provide information to private insurance companies. Federal agencies also use impact analysis to prioritize disaster relief funds and determine demands for additional aid. These estimated impacts are also necessary for the formulation and development of mitigation plans which occur following a natural disaster.

Therefore, the primary objective of this paper is to apply dynamic computer general equilibrium modeling procedures to estimate impacts to the five-county northern Nevada study area from a 1.6 million acre rangeland fire. Specific objectives are:

a. To discuss previous economic impact studies of natural disasters;
b. To develop a dynamic CGE model of the five-county northern Nevada study area;
c. To discuss development and data for impact analysis; and

d. To discuss impacts of the 1.6 million acre rangeland fire on the five-county northern Nevada study area by applying a dynamic CGE analysis.

Previous Studies of Natural Disasters

Numerous studies have used interindustry or econometric procedures to estimate impacts of natural disasters. Ellison et al (1984) used an econometric model to estimate impacts of an earthquake. Guimares et al. (1993) also employed an econometric model for analyzing the impacts of natural disasters. Gordon and Richardson (1996) employed a multi-regional input-output model to estimate impacts of an earthquake. Rose et al (1997) derived direct and indirect effects of electricity lifeline disruptions from an earthquake using specially designed input-output and linear programming procedures. Cole (1995) employed a social accounting matrix (SAM) approach to estimate the impacts of an earthquake.

Others have suggested that computable general equilibrium (CGE) models would be advantageous for natural disaster impact analysis (Boisvert, 1992; Brookshire and McGee, 1992.) The advantage of CGE models is that CGE models have the potential to overcome major deficiencies of econometric and input-output models such as linearity, lack of behavioral context, absence of quantity-price interactions, and neglect of resource constraints. Rose and Guha (1999) estimated direct and indirect economic impacts of electric lifeline disruptions caused by earthquakes using a CGE model. However, none of the previous studies of natural disasters have formally investigated impacts of a rangeland fire. Also none have explored using a dynamic CGE model for analyzing impacts of natural disasters through time. For this paper, a dynamic CGE model of a five-county northern Nevada study area will be used to estimate impacts of a 1.6 million acre rangeland fire through time.

Study Area

The five-county northern Nevada study area contains Elko, Eureka, Lander, Humboldt and Pershing Counties. (Figure 1). All five counties make up 27,368,907 acres.

Elko County is one of the fastest growing counties in the state of Nevada. Population in Elko County increased from 33,530 in 1990 to 45,291 in 2000 or a 35.1 percent increase in population over the past ten years (U.S. Department of Commerce 2001a). Most of Elko County's growth can be attributed to expansion in the gold mining and casino/gambling sector.

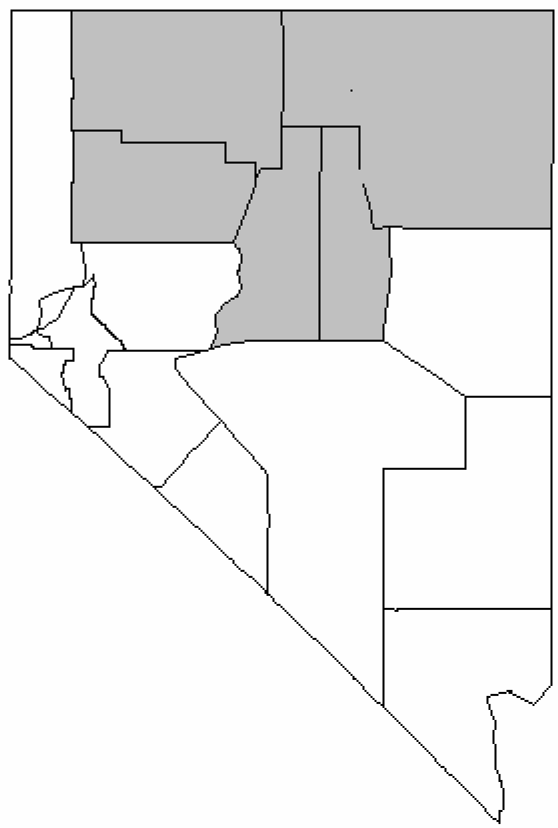

Figure 1. The Five-County Study Area in Nevada.

Eureka County, a much smaller county, has also realized increased population, growing form 1,547 in 1990 to 1,651 in 2000 or a population increase of 6.72 percent over the past ten years (U.S. Department of Commerce 2001a). The expansion of the Eureka County economy can be attributed to the expansion of gold mining activities. For Eureka County, the Mining Sector accounted for 82.5 percent of total county employment in 1999 (U.S. Department of Commerce, 2001b). However, since most of the mining developments have occurred in northern Eureka County, where little or no housing is available, most of the county job force resides in Elko County.

Lander County was only one of four counties in Nevada that realized population decline from 1990 to 2000. Population for Lander County declined from 1990 to 2000. Population for Lander County declined from 6,266 in 1990 to 5,794 in 2000 or a population decrease of 7.53 percent over the past ten years (U.S. Department of Commerce, 2001a). The decrease in population is due to closures and decreased operations by the Mining Sector in Lander County. Even though operations by the local mining sector have declined, the Mining Sector makes up 33.1 percent of total employment in Lander County in 1999 (U.S. Department of Commerce, 2001b).

Humboldt County is the second largest county in the study area by population size. Population in Humboldt County increased from 12,844 in 1990 to 16,106 in 2000 or a population increase of 25.4 percent over the past ten years (U.S. Department of Commerce, 2001a). Like many of the northern Nevada counties, the mining sector plays a prominent role in the local economy. Even though mining operations have declined over the past few years, the Mining Sector makes up 17.8 percent of total employment in Humboldt County in 1999 (U.S. Department of Commerce, 2001b).

Pershing County, like many of the counties in the state of Nevada, realized population growth between the census years. Population in Pershing County grew from 4,334 in 1990 to 6,693 in 2000 or a 54.4 percent increase in population from 1990 to 2000 (U.S. Department of Commerce, 2001a). Similar to other northern Nevada study area counties, the mining sector is an important segment in the local economy. Employment in the Mining Sector in Pershing

County accounts for 25.4 percent of total county employment even though Mining Sector operations have declined over the past few years. (U.S. Department of Commerce, 2001b).

Model Specification

CGE models are based on the Walrasian general equilibrium structure, which was formalized in the 1950's by Kenneth Arrow, Gerard Debreu, and others. The models explicitly incorporate supply constraints, identify prices and quantities separately and have smooth, twice differentiable production and preference surfaces. Thus, substitution effects in production and in consumption are allowed in CGE models. Factor and commodity markets attain their equilibrium through the adjustment of prices. Procedures to derive CGE models for regional analysis are found, for example, in Seung et al. (1997), Waters et al. (1997), Hoffman et al. (1996), Kraybill et al. (1992) and Berck et al. (1991). Surveys of existing regional CGE models are found in Kraybill (1991) and Partridge and Rickman (1998).

Most of the regional CGE models mentioned above are static. However, policy evaluations based on a single period, static equilibria can be misleading (Ballard et al. 1985) since in the real world dynamic elements abound. For a regional economy where many dynamic elements, such as interregional population movements and capital accumulation are observed, it is more appropriate to employ a dynamic specification of a CGE model. This study explicitly incorporates such dynamics into the CGE model. The structure of the dynamic model used in this analysis is based on Adelman et al. (1979), Robinson (1976), Ballard et al (1985) and Seung and Kraybill (1999).

Rangeland Fire CGE Model

In this section, the main features of the wildfire CGE model are described. In the equations presented below, time subscripts are omitted unless they are needed to clarify time periods.

Production

There are ten production sectors in the present model. Five of them are agricultural sectors:

1. Range and Ranch Livestock Sector
2. Sheep, Lambs and Goats Sector
3. Other Livestock Sector
4. Hay and Pasture Sector
5. Other Crops Sector

The other five sectors are

6. Mining Sector
7. Construction, Manufacturing, Transportation and Public Utilities Sector (CMTPU)
8. Trade Sector
9. Finance, Insurance, and Real Estate Sector
10. Services Sector

Production technology in each sector is represented by a Cobb-Douglas (CD) value added function. Also intermediate inputs are used in fixed ratios. Agricultural sectors use labor, capital and land as primary production inputs. The production technology in agricultural sectors is represented by:

$$X_i = \Phi_i L_i^{\alpha_i} K_i^{\kappa_i} N_i^{\eta_i} \qquad (1)$$

where:

X_i is output in agricultural sector i;

Φ_i is the shift parameter;

L_i, K_i and N_i are labor, capital, and land used in sector i, respectively; and α_i, κ_i and η_i are labor, capital and land income shares in sector i, respectively.

The wildfire will reduce land use in the range and livestock sector. Non-agricultural sectors use only labor and capital as primary factors of production.

Consumption

Following IMPLAN (IMpact analysis for PLANning; Alward et al., 1989), households are grouped into three types. They are (i) high, (ii) medium, and (iii) low income households. Preferences of the households are represented by a constant elasticity of substitution (CES) utility function. Each type of household is assumed to consume locally produced goods and imported goods from outside of Northern Nevada. Utility maximization for each type of household subject to its budget constraint yields the demand function for each good.

Factor Mobility

In the dynamic CGE model used in this study, it is assumed that labor is homogeneous and is perfectly mobile across sectors and partially mobile across regions. The assumption that labor is partially mobile across regions implies that there exist interregional wage rate differentials resulting from policy shocks. These wage rate differentials disappear when the local labor market adjusts completely in the long run. The net migration of labor into Northern Nevada is determined as follows:

$$LMIG_t = LSTK_t\left[\left(\frac{W_t}{WROW}\right)^{LME} - 1\right] \quad (2)$$

where: $LMIG_t$ denotes the net in-migration of labor in period t;
$LSTK_t$ is the aggregate stock of labor given at the beginning of period t;
W_t is the average wage rate in the five county study area in period t;
WROW is the average wage rate in the rest of the world (ROW) in period t; and
LME is the labor migration elasticity.

Physical capital is sector-specific and once the physical capital is installed in a sector it is not mobile. However, the investible fund is perfectly mobile both intersectorally and interregionally. Capital in each sector is accumulated in the following manner:

$$K_t = K_{t-1} + NI_t \quad (3)$$

where:

K_t is the capital stock given at the beginning of period (t + 1);

K_{t-1} is the capital stock given at the beginning of period t; and

NI_t is net investment in period t.

Investment

The net output price of the good produced in sector i in time t ($PV_{i,t}$), the output level ($X_{i,t}$) and the return to capital ($R_{i,t}$) can be computed for a given value of installed capital ($K_{t-1,i}$) carried over from period (t - 1) into period t. By substituting these values into the capital demand function, the desired level of capital, $KD_{i,t}$ is computed each period as follows:

$$KD_{i,t} = \frac{\kappa_i PV_{i,t} X_{i,t}}{R_{i,t}} \tag{4}$$

where κ_i is the income share of capital in sector i. Net investment in each sector is given by

$$NI_{i,t} = \lambda_i (KD_{i,t} - K_{i,t-1}) \tag{5}$$

with $K_{i,t-1}$ given at the beginning of each period. The parameter λ_i represents the speed of stock adjustment. The value of this parameter depends on tow kinds of cost - forgone profits and capital adjustment costs (Griliches, 1967; Plaut, 1981). Equation (5) indicates that net investment is determined by the speed of adjustment multiplied by the disparity between the desired level of capital and its actual level.

The partial adjustment of net investment represented by equation (5) is consistent with the partial adjustment dynamics of labor migration represented by equation (2) above. Thus, wildfire reduces the amount of land used in range and ranch livestock sector, lowering the sector's output. This lowers the desired level of capital in the sector through equation (4), leading to lower net investment in the sector through equation (5).

The investment determined via equation (5) is independent of domestic regional savings. Since regions are highly open economies and investment funds appear to be geographically mobile in the United States, it seems appropriate to treat the inflow of external savings as a residual that responds to the level of investment in the region. So if the region has more savings than needed for investment, surplus savings flow out of the region, and vice versa.

Dynamics

The structure of the dynamic model in this study is similar to that of Adelman et al. (1979), a description of which is found in Robinson (1976). In the present study, there are two kinds of adjustment behavior to be considered (Robinson, 1976). First, in the goods market, the adjustments of prices and quantities occur in a short period, say in a year, reducing excess demand to zero (Walrasian equilibria). Second, in factor markets, adjustment takes multiple periods because of lagged responses of factor supplies, represented, for example, by the labor migration elasticity in equation (2) and the adjustment coefficient in the investment function (equation 5) in the present model.

Static equilibria are sequenced through time to reflect a change in capital stock, which is due to investment, and a change in labor stock, which is due to labor migration and population growth. The calculation of equilibrium in each period begins with an initial capital endowment in each sector and a labor endowment for the economy as a whole. In this study, the sequence of equilibria generated without any policy implementation is called "continuous benchmark" while that generated with a policy shock is called "continuous counterfactual." The policy impacts are calculated by comparing the continuous counterfactual with the continuous benchmark.

Labor income is provided by the IMPLAN data set as employee compensation and proprietor income. All other income is aggregated into an "other property income" category. For the agricultural sectors, it was necessary to allocate other property income into income due to land and capital.

Land endowments were estimated using information on land use and valuation from Nevada county governments in the study area. Land acreage and the assessed valuation of that land are available for each county. Income from land or rental value of the annual use of land was inputted from the value of land based on assessed values.

Income from land was subtracted from "other property income" category with the remainder assigned to capital. The result allowed sector factors to be assigned to land, labor, and capital for the analysis.

The labor force is assumed to grow at the same rate as the population, and net investment is assumed to be sufficient to make the capital stock grow at the same rate as the population, and net investment is assumed to be sufficient to make the capital stock grow at the same rate. The State of Nevada Demographer's Office (Hardcastle, 2000) forecasts population growth rate for the five-county area to be 1.4 percent. Labor is assumed to be mobile between sectors, while capital is sector-specific. Land is assumed fixed in supply so this factor becomes scarce over time, especially during the fire season.

Empirical Implementation

Data and Calibration

IMPLAN is used to make 1996 social accounting matrix (SAM) for Northern Nevada. The 528 sectors in the SAM are aggregated into ten sectors in this study. Calculating the effects of policy changes in a CGE model requires specific parameter values for the model equations. Some parameters such as elasticities of substitution and elasticities of transformation are specified on the basis of econometric research. The remaining parameters such as share parameters are then determined by solving the model equations with the base-year observations for model variables and the exogenous parameters substituted in the model. In this study, the adjustment coefficient in the net investment function (equation 5) is set at 0.08 (Treyz, 1993). Annual population growth rate for Northern Nevada is set at 2.5 percent.

Data Description

Burned Area Emergency (BAER) teams were established by Congress as a means of providing support to communities within urban and suburban wildland and wildfire interface areas. The BAER teams are comprised of specialists that create sub teams that are charged with analyzing natural disasters and then developing a comprehensive plan to address the losses associated with the disaster. These are basically first response teams that develop plans that are then fast tracked to Congress for funding.

In response to the large Nevada fire disaster, various teams of professional were organized to address numerous impacts relating to fire. In order to predict economic losses, as requested by federal agencies, state and local elected officials and private landowners, a survey team with expertise in ranch and community economics was formed. The economic survey team included representatives from the University of Nevada Cooperative Extension, USDA's Natural Resource Conservation Service (NRCS) and Eureka County Public Lands Department. Additional information was provided to the team by Nevada Farm Bureau, Nevada Cattlemen's Association, USDI Bureau of Land Management, Nevada Division of Wildlife, BAER reports and local county officials. This local team was formed at the onset of the fires and was charged with gathering needed information and generating economic impacts.

The economic team utilized a survey instrument to solicit information from private and public landowners and/or managers concerning losses and damages resulting from the fires. The instrument was designed to gather information concerning major losses yet still allow for a quick response time. Survey categories and their corresponding questions were designed in cooperation with those people impacted, to determine what economic losses would be measured, what amount was lost and for how long would that loss be continued. For example, the instrument included questions on animal unit months (AUM) of forage impacts, miles of fence lost or damaged, type of structures damaged, livestock killed or injured, and ranch inputs devoted to fighting the fires (i.e. labor, supplies, equipment, etc.) Once the instrument was designed, personnel at the county level were assigned to gather the information. Given emergency constraints, all methods of data collection, telephone surveys, mail in surveys, producer meetings, etc. were incorporated to gather the needed information. The methods used depended on resources available in each county. Current data from University enterprise budgets, commodity market reports and input prices were used to assign monetary value.

County data were sent to University of Nevada Cooperative Extension offices in Pershing, Humboldt and Eureka Counties where it was compiled into spreadsheets. Cooperative Extension then generated and distributed economic impact reports to other agencies and public officials.

Data derived from surveys found that, total AUM's lost due to the rangeland fires were approximately 133,810. The estimated value of these lost AUM's was $4,730,184. It is assumed that this loss occurred during the year of the fire (1999). It is also assumed that the rangeland used for grazing range cattle will not be used for the first two years of rehabilitation. After these two years, cattle will be gradually introduced back on to the public lands. For the first year (2002) only 25 percent of the AUM's will be allowed, followed in 2003 with 50 percent, following in 2004 by 75 percent and finally by 2005, the rangeland is assumed to be rehabilitated to support AUM's similar to before the rangeland fires.

Date was also collected on Federal spending for fire suppression and rangeland rehabilitation. It was assumed that fire suppression and rangeland rehabilitation expenditures occurred during the first year of the rangeland fire 1999). Table 1 shows the federal expenditures on rangeland fire suppression and rehabilitation activities within the five-county study area.

Table 1. Federal expenditures for rehabilitation and fire suppression by sector

Sector	Rehabilitation Expenditures	Fire Suppression Expenditure	Total Expenditure by Sector
CMTCPU [1]	$19,685.74	$223,519.55	$243,205.29
Trade	$118,296.91	$887,896.15	$1,006,193.06`
FIRE [2]	$117,637.31	0.0	$117,637.31
Services	$3,383,656.54	$5,092,208.13	$8,475,864.67
Total	$3,639,276.5	$6,203,623.83	$9,842,900.33

[1] CMTCPU refers to the Construction, Manufacturing, Transportation, Communication and Public Utilities Sector.

[2] FIRE stands for Finance, Insurance and Real Estate Sector

RESULTS

Tables 2 and 3 show the cumulative ten-year impacts of the rangeland fire in the five Northern Nevada counties. Table 2 indicates that the total output difference between rangeland fire and no fire was an approximate decrease in total study area output of 0.04 percent. The agricultural sectors were impacted greater with a loss of production of 1.36 percent. Given the loss of AUM's caused by the rangeland fire and that cattle were not allowed on public range for two years, output for the Range and Ranch Cattle Sector declined by 3.14 percent compared to no rangeland fire. All economic sectors in the five-county study area were impacted negatively by the rangeland fire except the Service Sector.

Table 3 shows the cumulative ten-year impacts to sectoral employment from the rangeland fire. Total employment declined by 0.09 percent versus the no rangeland fire scenario for the entire five county study area. The Agricultural Sector was negatively impacted with the Range and Ranch Livestock Sector realizing a 4.18 percent decrease in employment over ten years due to the rangeland fire. As with production responses, all economic sectors in the five-county study are were impacted negatively by the rangeland fire except the Service Sector.

Table 2. Cumulative Impacts of 1999 Rangeland Fire on Sectoral Output Over a Ten-Year Period

Sector	Benchmark (in million dollars)	Counterfactual (in million dollars)	% Change
Range and Ranch Livestock	472.356	457.516	-3.14
Sheep, Lambs and Goats	25.125	24.998	-0.51
Other Livestock	98.384	97.894	-0.50
Hay and Pasture	377.403	375.518	-0.50
Other Crops	487.242	484.784	-0.50
Total Agricultural Output	1460.51	1,440.71	-1.36
Mining	23,695.296	23,695.449	0.00
CMTCPU	8,115.208	8,111.390	-0.05
Trade	3,723.337	3,722.014	-0.04
FIRE	2,795.338	2,794.935	-0.01
Services	10,968.525	10,972.396	0.04
Total Nonagricultural Output	49,297.704	49,296.184	-0.00
Total Output	50,758.214	50,736.255	-0.04

Table 3. Cumulative Impacts of 1999 Rangeland Fire on Sectoral Employment Over a Ten-Year Period

Sector	Benchmark (in million dollars)	Counterfactual (in million dollars)	% Change
Range and Ranch Livestock	3,232	3,097	-4.18
Sheep, Lambs and Goats	570	561	-1.58
Other Livestock	471	463	-1.70
Hay and Pasture	8,247	8,113	-1.62
Other Crops	8,453	8,316	-1.62
Total Agricultural Output	20,973	20,550	-2.02
Mining	101,582	101,583	0.00
CMTCPU	64,936	64,896	-0.06
Trade	83,883	83,840	-0.05
FIRE	11,855	11,848	-0.06
Services	221,350	221,429	0.04
Total Nonagricultural Output	483,605	483,596	-0.00
Total Output	504,579	504,146	-0.09

CONCLUSIONS

This paper presents a dynamic CGE model of business losses and recovery efforts associated with 1.6 million acres rangeland fire covering a five-county northern Nevada study area. Dynamic CGE models are especially adept at analyzing the role of markets and prices in the extent of mitigation of economic losses due to the 1.6 million acre rangeland fire.

This paper is only a preliminary application of CGE analysis for potential estimation of rangeland fire impacts. Other applications for future analysis would be to complete a similar analysis but use fixed-price input-output procedures. This could potentially show the advantages of CGE analysis for rangeland fires impact estimation. The results might also support findings by Rose and Guha (1999) who found that typical CGE model, even based on short-run versus long-run substitution elasticities, was far too flexible and is likely to understate impacts of a natural disaster. Therefore, Rose and Guha (1999) suggest that deliberate efforts should be taken to incorporate real world rigidities as well as resiliency in the typical CGE model for natural disaster impact estimation.

Also additional analysis could investigate the impacts and welfare impacts of added federal fire fighting expenditures. Following procedures by Seung et al. (2000) and Schreiner et al. (1996), the costs-benefits of the added federal fire fighting expenditures could be estimated. For this example, there was little if any recreation on the public lands of this 1.6 million acre fire. However, if outdoor recreation existed, the impacts of reduced outdoor recreation would have to be included in the analysis. Also, labor was assumed mobile between all sectors; another analysis might assume agricultural labor and non-agricultural labor separate or not mobile between these two sectors. Lastly, improved rangeland production data would greatly enhance the production responses to rangeland fires that are primary input to the CGE analysis.

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