College of Business and Public Policy
UNIVERSITY of ALASKA ANCHORAGE

Department of Economics Working Paper
WP 2011-05
August 2011

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Abstract

A ranch-level economic model is linked to a social accounting matrix (SAM), a.k.a. LP-SAM, to investigate the impact of wildfire on the regional economy. This study is the expansion of Alevy and Harris (2008) with a stochastic wildfire model based on historical wildfire data. The LP-SAM model is used to estimate the impact of wildfire in southeast Oregon. Wildfire limits ranchers' access to public grazing land and causes the economic losses of $20 million ~ $65 million per year in the near future, equivalently about 0.2%~0.5% of the total value of regional production. Cattle and ranching sector loses $7 million ~ $20 million per year (3% ~ 8% of total sectoral production) per year. The value of agricultural and hay production decrease by $1.7 million ~ $5.1 million directly due to wildfire and indirectly due to reduction of cattle sector production. This study suggests that the wildfire loss can be substantial and efforts to reduce wildfire damage to public lands should be expanded.

Keywords

Public grazing, Regional economic impact, Social Accounting Matrix, Southeast Oregon, Wildfire

INTRODUCTION

Measuring, modeling, and managing public grazing land and wildfire risk are essential and challenging tasks for rangeland managers in the western U.S., especially in the Great Basin area, where the invasion of cheatgrass increases the risk of wildfire[1] (Torell et al., 1981; Knapp, 1998; Link et al., 2006). Following a wildfire, ranchers' access to public grazing land is restricted, typically for two years[2]. Limited access to public grazing land due to wildfire has substantial economic impacts on the regional economy because public grazing is a major source of forage for cattle and thus an important input for ranching businesses in most regions of the western United States (US Government Accountability Office, 2005, p. 61). This study attempts to model and measure the wildfire damage in terms of the regional economic loss from delayed grazing on burned areas.

Assessment of the regional economic impacts can be accomplished using either Input-Output (IO) inter-industry analysis or a social accounting matrix (SAM) analysis that also values household sector impacts. While these approaches can generate important insights, they have significant limitations for the wildfire study because they do not include the complete set of ranchers' activities and options; changes in herd size, changes in animal production mix and/or alternative forage sources (buying hay) are all potential responses to the occurrence of wildfire that are not amenable to analysis through the IO or SAM methodologies. To examine the regional economic impacts more completely the IO or SAM models need to be integrated with a

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[1] Cheatgrass invasion increases the frequency of wildfires (fire cycle), the wildfire size (fire intensity), and decreases the wildfire return interval.

[2] For public land management agencies, delaying grazing on burned areas for a minimum of 2 years is the standard policy. Bruce et al. (2007) pointed out that "the 2-year grazing moratorium" has not been validated by research.

ranch-level economic model. The integration of the ranch-level economic model, IO and SAM analyses is the main topic of the paper. The model we construct measures economic damages due to delayed grazing on burned areas; damages that include the reduction of sectoral production, decreases in earnings and the distributional impacts over various income groups (households) in the region.

It is worthwhile to review previous works to examine regional economic impacts from wildfire. There are efforts to evaluate the impacts using the naïve IO model (Riggs et al., 2001) and the dynamic Computable General Equilibrium (CGE) model (Harris et al., 2002). Both studies investigated the regional economic impacts from the wildfire in northern Nevada in 1999 that damaged 1.6-million acres of rangeland. Riggs et al. (2001) quantified the loss from the wildfire using survey data and computed the regional impacts using the multipliers from the IO model[3]. Harris et al. (2002) measured the regional economic impacts using the dynamic CGE which overcomes some drawbacks in the IO model. Results showed that the livestock sector lost 3% of the sectoral production and 0.04% in total regional production (equivalently $22 million) (Table 3 in Harris et al., 2002).

Another recent study is Alevy and Harris (2008). This study used a model that coupled aranch-level linear programming (LP) model with the SAM model. This model captured the regional economic impacts from the reduction in grazing allotment in ranch sector from the wildfire. The basic model used in Alevy and Harris (2008) was developed in Harris et al. (2008) based on the theoretical supports from Everett and McCarl (1976), Brink and McCarl (1977), and

[3] 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. The IO analysis can be summarized as the multiplier analysis, which outlines individual changes in final demand through the regional economy over short periods of time.

Bowker and Richardson (1989). The latter three papers showed how to link the firm (or farm) level LP model with the IO model in order to derive firm and regional level economic impacts simultaneously. We called this model the LP-IO. Harris et al. (2008) expanded the LP-IO framework to incorporate institutional impacts, including impacts to households, employment and regional government to the model, in what we termed the LP-SAM[4].

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 public grazing land. Results showed that sectors that face the most significant impacts from the wildfire include trade and services in addition to the direct impacts on ranching and agriculture. For instance, under the scenario of intensive fire cycle (10-year fire cycle, that is, three wildfires in 40 year time horizon), the cattle sector lost $25 million, the trade sector lost $10 million and the service sector experienced about $5 million in losses. One drawback in Alevy and Harris (2008) is that the wildfire profile is simple and unrealistic, which means the regional economic loss from the wildfire might be underestimated. One of the goals of this study is to extend the work of Alevy and Harris (2008) using a stochastic wildfire model based on dynamics associated cheatgrass invasion. The related literature identifies cheatgrass invasion as one of the key factors associated with increases in wildfires in Great Basin area (Knapp, 1998; Link et al., 2006).

In short, this paper has two research goals. The first is to strengthen the theoretical approach to linking a ranch-level economic model to a regional SAM model that assesses the regional economic impacts from the wildfire. The second is to develop the stochastic model linking the incursion of cheatgrass to the incidence and intensity of wildfire. The paper consists

[4] To authors' best knowledge, this is the first attempt to develop LP-SAM.

of three sections to achieve these goals. The study area is introduced in the next section and the analytical approaches to examine the regional economic impacts follow. Empirical results are presented and a discussion section concludes the study.

STUDY AREA AND WILDFIRES

Southeast Oregon was selected as the study area. The study area is located on the northern edge of the Great Basin area (Figure 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, 2011). As a consequence, this area has frequent wildfire occurrences.

Four counties are included in 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 sectors recorded an output of $258 million (calculated from IMPLAN database for 2006) which was 4.3% 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) cattle-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 wildfires 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).

Wildfire data for the region is collected from the National Fire and Aviation Management website maintained by National Interagency Fire Center (https://fam.nwcg.gov/fam-web/). Figure 2 shows, in blue bars, the number of wildfires during 1999 – 2010 in the study region. 17 wildfires occurred each year in the region on average. The number of wildfires peaked in 2006

(38 times) and 2007 (24 times). The number of wildfires has a positive trend over time (correlation between the number of wildfires and the time trend is 0.35 with t-value 1.2). The average burned area per fire, or *wildfire size*, is reported as 4,665 acres per fire per year and it fluctuates widely. Figure 2 presents wildfire size as a solid red line. Wildfire size also has a positive trend over time but the relationship is weak and not statistically significant (correlation between the fire size and time trend is 0.02. and t-value is 0.08).

REGIONAL IMPACT MODEL

The LP-SAM model is used to investigate the wildfire risk in terms of the regional economic losses from the damage to the public grazing land due to the wildfire through the cattle-ranching business. A ranch level LP model is introduced in the next section.

A Ranch Level Dynamic Linear Programming (LP) Model

The rancher's 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, public grazing allotment quantities, input and output prices, and resource transfers between periods (especially breeding cows). The LP model considers almost all of rancher's decision variables in the typical western US ranches including seasonal forage supply and demand (Torell et al., 2002). The model is a discrete-time optimal control problem.

Let x_t denote the herd size at the beginning of year t. Herd dynamics are represented as:

$$x_{t+1} = (1+\beta)x_t - s_t \qquad \textbf{[1]}$$

where β is the net reproduction rate including death rate and s_t is cattle sales. Both the herd-size and cattle-sales variables in the model contain different types of cattle differentiated by age and sex. For simplicity of presentation, animals of different age-sex classes are not differentiated here. Without supplementary feeding during the grazing season, the herd size in a given year is limited by the available public grazing land;

$$x_t \leq \alpha(1-z_t)L_t \qquad \textbf{[2]}$$

where L_t is the total public grazing land area available in year t and α is the carrying capacity of the range. L_t is influenced by wildfire, z_t (0 or 1). When $z_t = 0$ there is no fire and all the grazing land is available to the rancher. When $z_t = 1$ there is a fire and all the public grazing is delayed for two years.

The rancher has other resources such as private pasture, other types of rangelands, labor, machines, and so on. The resource availability is introduced as the usual LP type restrictions;

$$\mathbf{D}x_t \leq \mathbf{b}_t \qquad \textbf{[3]}$$

where x_t is the herd size (various types of cattle as mentioned above), **D** is the matrix of technical coefficients and $\mathbf{b}_t$ is the vector of resource availability. The profit (π) is comprised of revenue from cattle sales (s_t) and costs of the herd (x_t) maintenance such that

$$\pi_t = q(s_t) - c(x_t)\,. \qquad \textbf{[4]}$$

Finally, assuming risk-neutrality, the rancher's decision problem is given by

$$\max_{s} \quad \sum_{t=0}^{T}(1+r)^{-t}\pi_t\,, \ \text{s.t.} \ (1), (2), \text{and } (3)\,, \qquad \textbf{[5]}$$

where r is the proper discount rate.

It is noteworthy that the rancher has the option to grow or purchase alfalfa hay. The solution of the ranch LP model provides 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)
- Value of financial activities - principal and interest payments and repayment of a short-term loan.

The LP model has the flexibility to alter parameters and provides results on either an annual basis, or 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 and also using calibration in Maher (2007). 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.

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

The Input-Output (IO) method is based on the interrelationship between sectors in the economy and how each sector is affected by a change in the final demand for its output. For a regional economy of n sectors (industries or business) the standard IO model is represented by $\mathbf{x} = \mathbf{y} + \mathbf{Ax}$ or $(\mathbf{I}_n - \mathbf{A})\mathbf{x} = \mathbf{y}$, where $\mathbf{x}$ is an n-element vector of sector output, $\mathbf{y}$ is and n-element vector of the final demand, $\mathbf{I}_n$ is an $n \times n$ identity matrix, and $\mathbf{A}$ is an $n \times n$ direct requirement matrix (technical coefficients).

Elements of matrix $\mathbf{A}$, 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 $\mathbf{y}$ and its indirect uses in intermediate production $\mathbf{Ax}$. The $(\mathbf{I}_n - \mathbf{A})$ matrix is called the direct requirements or the Leontief matrix. Provided the $(\mathbf{I}_n - \mathbf{A})$ matrix is nonsingular, the above linear system can be solved for the amount of output necessary to support a given level of final demand as:

$$\mathbf{x} = (\mathbf{I}_n - \mathbf{A})^{-1}\mathbf{y}\,, \qquad \textbf{[6]}$$

where $(\mathbf{I}_n - \mathbf{A})^{-1}$ is called the Leontief inverse matrix. This relationship can be interpreted as $\Delta\mathbf{x} = (\mathbf{I}_n - \mathbf{A})^{-1}\Delta\mathbf{y}$, which means changes in total industry output are predicted using the Leontief inverse matrix. Thus the column sum of $(\mathbf{I} - \mathbf{A})^{-1}$ is interpreted as the total changes in output from the changes in final demand, which is called output multiplier:

$$\boldsymbol{\alpha}' = \mathbf{i}'(\mathbf{I}_n - \mathbf{A})^{-1}, \qquad \textbf{[7]}$$

where $\boldsymbol{\alpha}$ is the output multiplier column vector and $\mathbf{i}$ is an $n\times 1$ column vector of ones. Thus, the kth element in $\boldsymbol{\alpha}$, α_k, gives the exogenous change in final demand for the kth sector's output. Using the multiplier we analyze the regional economic impact from the (final demand) changes.

In the IO analysis, only the inter-industry linkages are formally specified. Industry transactions are read easily through the IO table. The linkages between household income and spending, government revenues and expenditure, and the linkage between saving and investment are not defined in the IO analysis. The Social Accounting Matrix (SAM) permits industry/household linkages to be specified with the same precision that inter-industry linkages are specified in the IO model. IMPLAN system provides for the construction of social accounting matrices at the regional level (MIG, 2006).

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

$$\begin{bmatrix} \mathbf{x} \\ \mathbf{v} \\ \mathbf{h} \end{bmatrix} = \begin{bmatrix} \mathbf{ex} \\ \mathbf{ev} \\ \mathbf{eh} \end{bmatrix} + \mathbf{S} \begin{bmatrix} \mathbf{x} \\ \mathbf{v} \\ \mathbf{h} \end{bmatrix} \qquad \textbf{[8]}$$

where, **S** is a matrix of SAM direct coefficients, analogous to **A** in the IO model, **x** is a vector of sector supply (row sum of activities or industries), **v** is a vector of value-added by categories (row sum of value-added), **h** is a vector of household incomes (row sum of households). **ex, ev, eh** are vectors of exogenous final demand, exogenous value added, and exogenous household income, respectively. The matrix of direct SAM coefficients, **S**, is given by

$$\mathbf{S} = \begin{bmatrix} \mathbf{A} & \mathbf{0} & \mathbf{C} \\ \mathbf{V}^* & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{Y}^* & \mathbf{H} \end{bmatrix} \qquad \textbf{[9]}$$

where, **A** is a matrix of input-output coefficients, $\mathbf{V}^*$ is a matrix of value-added coefficients, $\mathbf{Y}^*$ is a matrix of value-added distribution coefficients, **C** is a matrix of expenditure coefficients, and **H** is a matrix of institutional and household distributional coefficients. Equation (7) can be rewritten as

$$\begin{bmatrix} \mathbf{x} \\ \mathbf{v} \\ \mathbf{h} \end{bmatrix} = (\mathbf{I} - \mathbf{S})^{-1} \begin{bmatrix} \mathbf{ex} \\ \mathbf{ev} \\ \mathbf{eh} \end{bmatrix} \qquad \textbf{[10]}$$

where, $(\mathbf{I} - \mathbf{S})^{-1}$ represents the matrix of SAM inverse coefficients. The interpretation of $(\mathbf{I} - \mathbf{S})^{-1}$ is similar to the interpretation of $(\mathbf{I} - \mathbf{A})^{-1}$ in the IO model (equation (7)) since the households and other institutional linkages are endogenous[5]. Using the SAM model and its multipliers, we can investigate regional economic impacts from the external shock to the exogenous sectors.

Integrated Linear Programming and Social Accounting Matrix Model

To derive distributional impacts of wildfire on the regional economy, the ranch level LP model should be integrated to the SAM model. We call this LP-SAM model[6]. Theoretical background to integrate the LP model and the IO model is explored in Everett and McCarl (1976), Brink and McCarl (1977), and later Bowker and Richardson (1989). These studies showed how to connect the firm level LP with the IO model to assess the economic impacts from the firm level to the regional level. Harris et al (2008) expanded the previous efforts to consider the institutional impacts to incorporate LP model into SAM account. Alevy and Harris (2008) examined the regional economic impacts from the wildfire for Elko County, Nevada using the model as briefly discussed in the above section.

The LP-SAM model provides the regional *direct*, *indirect* and *induced* effects of changes in sector outputs (changes in output in cattle sector due to wildfire here)[7]. In addition, the LP-SAM model can generate changes in employment as well as income distribution in the region. The basic structure is given by equation (11):

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

[6] An alternative to the LP-SAM is to link a Computable General Equilibrium Model (CGE) with a SAM. Although CGE, particularly linked to SAM models, has its own individual strengths due to its ability to incorporate nonlinearities, it is not capable of incorporating some county/regional requirements such as limitations on the level of resources, and the need to find an optimum solution which is a particular advantages of the LP approach. However, optimal solutions which show household income distributional impacts are not available through LP-IO modeling. Thus, an integrated LP-SAM model has a distinct advantage compared to other modeling approaches.

[7] Supply driven SAM analysis (Papadas and Dahl, 1999; Seung and Waters, 2006) should be introduced because the wildfire causes internal sector (cattle and ranching) production change not exogenous final demand. We ignore the forward linkage effects in this study.

$$\max_{s,y} \left[\sum_{t=0}^{T}\sum_{i=1}^{I}(1+r)^{-t}\pi_{it} + \omega\sum_{t=0}^{T}\sum_{n=1}^{N}(1+r)^{-t} y_{nt} \right]$$

$$\begin{aligned}
s.t.\quad & \pi_{it} = q(s_{it}) - c(x_{it}) \\
& x_{i,t+1} = (1+\beta)x_{it} - s_{it} \\
& x_{i,t} \le \alpha(1-z_t)L_{it} \qquad\qquad \textbf{[11]} \\
& \mathbf{D}\mathbf{x}_{it} \le \mathbf{b}_{it} \\
& y_{"cattle",t} - \sum_{i=1}^{I} s_{it} \le 0 \\
& (\mathbf{I}-\mathbf{S})\mathbf{y} \le \mathbf{y}^0
\end{aligned}$$

where, i is a ranch index, n represents the economic sectors in SAM account, $\mathbf{y}$ is the sectoral output vector, **S** is a matrix of SAM direct coefficients, and $\mathbf{y}^0$ is a vector of exogenous final demand, value added and household income (**ex**, **ev** and **eh** in equation (10)). The objective function is the sum of ranchers' profit (first part of the objective function) and discounted value of regional output. ω is the weighting factor for the total output activity in the SAM model. ω provides a method for the regional decision-maker to weight the relative importance of total economic output (Everett and McCarl, 1976). In the empirical analysis we use the equal weight which means ω = 1.

The first constraint is the profit equation for ranch i which is the same as in equation (4). The second constraint is the herd-size dynamics as in equation (1). The third and fourth constraints are the ranch i resource availabilities as in equations (5) and (6). The fifth is the cattle industry production which is the sum of each individual rancher's cattle sale. The final constraint is the SAM relationship as in equation (10).

The SAM model in equation (11) can be calibrated using the IMPLAN database. Aggregation of the study area data in IMPLAN is based on 2 digit NAICS (North American Industry Classification System) code, with the following exception; cattle and hay sectors are disaggregated and to be distinct from other agriculture activities. After the aggregation, a SAM table can be generated by IMPLAN. See Table 1 for the sector aggregation.

Stochastic Wildfire

The public grazing allotment for rancher *i*, L_{it}, would be affected by the wildfire as in equation (11), which puts a constraint on the cattle stock, $x_t \le \alpha(1-z_t)L_t$. Note that the wildfire size and public grazing land do not have *i* subscripts here because we assume the social planner operates all the ranches in the region (*single ranch assumption*). Also note that z_t is not simply 0 or 1 but $0 \le z_t \le 1$ at the regional level.

The regression approach is used to generate more realistic wildfire profile. The trend regression is adopted to describe the wildfire size over time as in equation (12):

$$\tilde{A}_t = b_0 + b_1 T + b_2 Rain + b_3 Temp + \tilde{\varepsilon}_t , \qquad \textbf{[12]}$$

where tilde on variables indicate stochastic variables. The variable A_t represents the burned area, *T* is time index (1 to 12 for the 12 years for which wildfire data is available), *Rain* represents the precipitation during the wildfire season, from June through August and *Temp* is the mean temperature during the summer wildfire season. $\tilde{\varepsilon}$ is the pure stochastic part and is assumed to follow a normal distribution, with mean zero. The regression should capture the relationship between cheatgrass invasion and wildfire size through the trend variable, *T*, which means that the coefficient b_1 is expected to be positive (Knapp, 1998 and Link et al., 2006). Equation (12) is estimated using ordinary least squares;

$$\tilde{A}_t = -2053.5 + 88.1T - 53.0Rain + 34.1Temp, \quad R^2 = 0.167, \; DW = 1.85 \qquad \textbf{[13]}$$
$$\quad (0.52) \quad (0.62) \quad (0.58) \qquad (0.48)$$

where numbers in parentheses are p-value. Estimated coefficients have the expected sign but are not statistically significant. Also R^2 is 0.167. These results suggest that crucial explanatory variables such as the amount of fuel stock (stock of cheatgrass, for instance) and the intensity of wildfires are omitted from the regression. Unfortunately these variables are not available.

Equation (13) is used to generate random area burned, $\tilde{A}_t$, and, in turn, the random fire size, $\tilde{z}_t = \frac{\tilde{A}_t + \tilde{A}_{t-1}}{\bar{L}_t}$, where $\bar{L}_t$ is the public grazing land in the region (around 1.5 million acres from Agricultural Census 2007 and US GAO (2005)). $\tilde{A}_{t-1}$ is added to the computation of the random fire size because the ranchers may not access to the public grazing land for two years.

Using the Monte Carlo simulation, the random fire size in the near future is generated using the results in equation (13). The rainfall and the summer temperature are fixed at mean value. Figure 3 shows the simulated burned area from the wildfire in the near future. The average projected area burned over 1000 iterations in the region ranged from 171,000 acres to 250,000 acres. These are equivalent to 11% ~ 30% of the public grazing land in the region that would not be available to ranchers.

RESULTS AND DISCUSSION

The LP-SAM model simulates outputs over a 25-year period (and report 10 years to avoid biases from any terminal conditions). The LP-SAM model is iterated for 1,000 times with stochastic wildfires that allow us to generate proper annual economic impacts distribution (average and standard deviation). The General Algebraic Modeling System (GAMS) with BDMLP solver is used to run the model.

Figures 4 presents the three major sectors which face the largest economic losses: cattle, service, and agriculture & hay sectors (see also Figure 5). This stresses that spillover outside cattle sector is important which should be relevant to policy makers. The loss is the difference between the value of production in 2006 (calibrated from IMPLAN) and the value of production under the conditions generated by the wildfire simulation. The loss from the cattle sector varies from $7.0 million to $21.5 million, depending on the size of the wildfire. The loss from the agriculture and hay sectors varies from $1.6 million to $5.1 million. The 95% confidence intervals for sectors are shown with dotted lines in Figure 4. The reduction of production value decreases over time (negative sloped) because the wildfire size keep increasing as depicted in equation (13).

Table 2 and Figure 4 show the regional economic impact in the region including direct and indirect economic losses from the wildfire using the SAM structure. In figure, other primary sector includes agriculture, hay and mining sectors. Secondary sector represents utilities, construction, and manufacturing sectors. Tertiary sector is the sum of trade and service sectors. The cattle sector has the largest regional impact from the wildfire, which is $14.8 million per year on average (5.7% of the value of the cattle sector production). The hay sector loses $2.3

million annually on average (0.7% of the value of the hay sector production). The agriculture sector loses $1.3 million annually (0.4% of the total value of production). The service sector is another sector which suffers a large impact from wildfire. The loss is reported as $6.5 million (0.2% of total value). The losses in the service sector come from the interrelationships between the cattle sector and the service sector, for example, cattle and meat transportation, restaurants, grocery stores and so on. The manufacturing sector experiences $2.7 million loss annually, probably due to the reduction in the livestock processing production. In total, regional output decreases by $29.4 million annually (0.5% of the value of the total regional production). Table 2 and Figure 5 also contain the institutional impact from the wildfire. Employee compensation is reduced by $5.3 million and in turn household income decreases by $5.9 million because of the wildfire.

In short, Southeast Oregon (four counties) is expected to pay $45.0 million annually on average as the cost of wildfire in the near future (with estimates varying from $21 million to $65 million) (Figure 5). The most vulnerable sector is cattle sector, value added and tertiary sectors in the region. It should be noted that these values are conservative estimates because additional losses, such as environmental and ecological effects, reductions in recreational access, direct wildfire suppression costs and so on, are not considered. .

CONCLUSION

There are three major findings in the study. First, this study suggests that losses from wildfire can be substantial. The wildfire damage is far greater than the wildfire suppression cost and the damage to rangeland. The average annual economic impact of wildfire in Southeast Oregon over a 10-year period is estimated as $45 million. Nearly 0.4% of the regional value of production in Southeast Oregon area would be lost. Rangeland managers need to consider the regional economic impact as a part of the future public land management plan. Second, cattle, service and manufacturing sectors, and value added are the sectors largely suffered. Third, distributional effects imply that the median income group is the most vulnerable to wildfire.

Two caveats should be mentioned. First, the model in the study assumes perfect information. This means that regional ranchers know the wildfire incidents in advance and they can take actions before or at the wildfire occurrence to reduce their damage (optimization). If imperfect information is considered, economic impacts from wildfires could be larger. Second, the single ranch assumption does not permit us to investigate substitution effects. It is plausible that the large commercial ranchers are not as vulnerable to delayed grazing on burned area as small ranchers. In addition, some of the small ranchers may go bankrupt under the severe wildfire. Some degree of substitution, in which the large commercial rancher produces more, is expected. The model used in the study may not detect this possibility. The future plan for this study includes incorporating imperfect information and heterogeneity in rancher type into the analysis.

LITERATURE CITED

Alevy, J.E. and T.R. Harris. 2008. Stochastic availability of grazing permits due to wildfire: A simulation of economic impacts in Elko County, Nevada. Presented at Western Regional Science Association Annual Meeting, HI, February 17-20, 2008.

Brink, L. and B.A. McCarl. 1977. Input-output analysis, linear programming and the output multiplier. *Canadian Journal of Agricultural Economics* 25(3):62-67.

Bruce, L.B., P.A.S. Perryman, B.K. Conley, and K. McAdoo. 2007. Case study: grazing management on seeded and unseeded post-fire public rangelands. *The Professional Animal Scientist* 23:285-290.

Bowker, J. M. and J.W. Richardson. 1989. Impacts of alternative farm policies on rural communities. *Southern Journal of Agricultural Economics* 21:33-46.

Cornelius, J., D. Holland, E. Waters, and B. Weber. 2000. Agriculture and the Oregon economy. Special Report 1014, Oregon State University Extension Service.

Everett, H.W. and B.A. McCarl. 1976. Regional economic planning: A methodology for integrating linear programming and input-output analysis, Journal Paper Number 5798, Purdue Agricultural Experiment Station.

Harris, T.R., C.K. Seung, T. Darden, and W.W. Riggs. 2002. Rangeland fires in norther Nevada: An application of computable general equilibrium modeling. *Western Economic Forum* 1(2):3-10.

Harris, T.R., J.E. Alevy, M-K. Kim, and B. Fadali. 2008. Development and initial application of an integrated linear programming-social accounting model: Rangeland livestock application. Presented at Southern Agricultural Economic Association Annual Meeting, Dallas, TX, February 2-6, 2008.

Holland, D. and P. Wyeth. 1993. SAM multipliers: Their decomposition, interpretation and relationship to input-output multipliers. Research Bulletin XB 1027, College of Agriculture and Home Economics Research Center, Washington State University

Knapp, P.A. 1998. Spatio-temporal patterns of large grassland fires in the intermountain west, U.S.A. *Global Ecology and Biogeography Letters* 7:259-272.

Link, S.O., C.W. Keeler, R.W. Hill, and E. Hagen, E. 2006. *Bromus tectorum* cover mapping and fire risk. *International Journal of Wildland Fire* 15:113-119.

Maher, A. 2007. Economic impacts of sagebrush steppe wildfires on an eastern Oregon ranch [thesis]. Corvallis, OR, USA: Oregon State University. 159 p.

[MIG] Minnesota IMPLAN Group, Inc 2006. *IMPLAN Professional Social Accounting and Impact Analysis Software*. MIG, Inc Stillwater, Minnesota.

[NOAA] National Oceanic and Atmospheric Administration. 2011. Satellite and Information Service: U.S. Climate at a Glance, Available at http://lwf.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html

Papadas, C.T., and D.C. Dahl. 1999 Supply-driven input-output multipliers. *Journal of Agricultural Economics* 50(2):269-285.

Riggs, W.W., D. Breazeale, and G. Myer. 2001. Measuring the economic impacts from wildland fire. *Journal of the ASFMRA* 64(1): 39-42.

Seung, C.K., and E.C. Waters. 2009. Measuring the economic linkages of Alaska fisheries: A supply-driven social accounting matrix (SAM) approach. *Fisheries Research* 97(1-2):17-23.

Torell, L.A., J.R. Garret, and C.T.K. Ching. 1981. The economic effects of three changes in public lands grazing policies. *Journal of Range Management* 34(5):373-376.

Torell, L.A., J.A. Tanaka, N.R. Rimbey, and T. Darden. 2002. A user manual for a ranch planning and policy analysis LP model. Regional Research Project W-192, Policy Analysis Center for Western Public Lands.

US GAO (US Government Accountability Office). 2005. Livestock grazing – Federal expenditures and receipts vary, depending on the agency and the purpose of the fee charged. Reports to Congressional Requesters, GAO-05-869, Washington, DC.

List of Figures

Figure 1. Southeast Oregon: Harney (HA), Lake (LK), Klamath (KL) and Malheur (MH) Counties

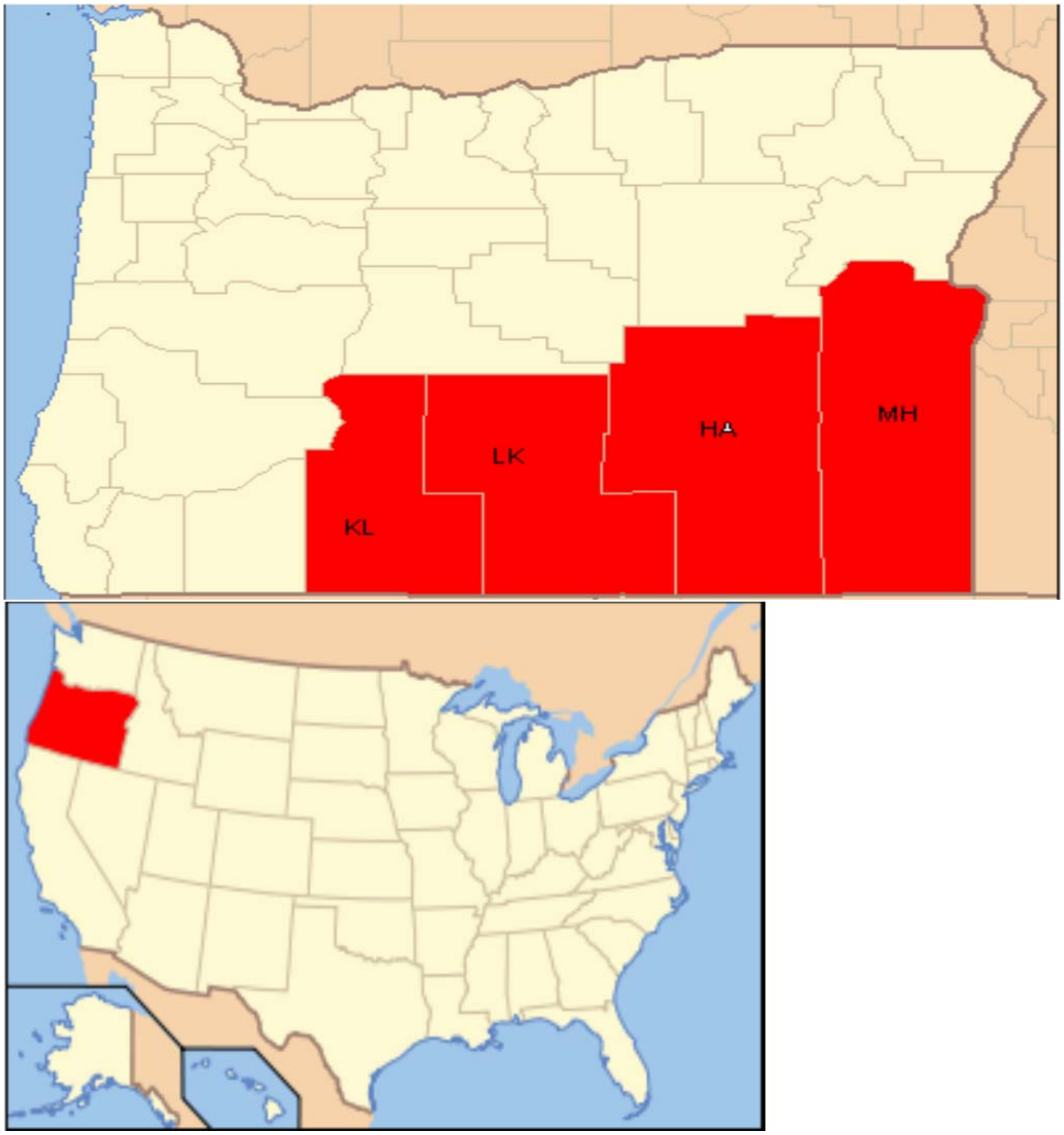

Figure 2. Number of Wildfires and Size in Southeast Oregon Area (4 Counties)
Source: National Fire and Aviation Management http://www.fs.fed.us/fire

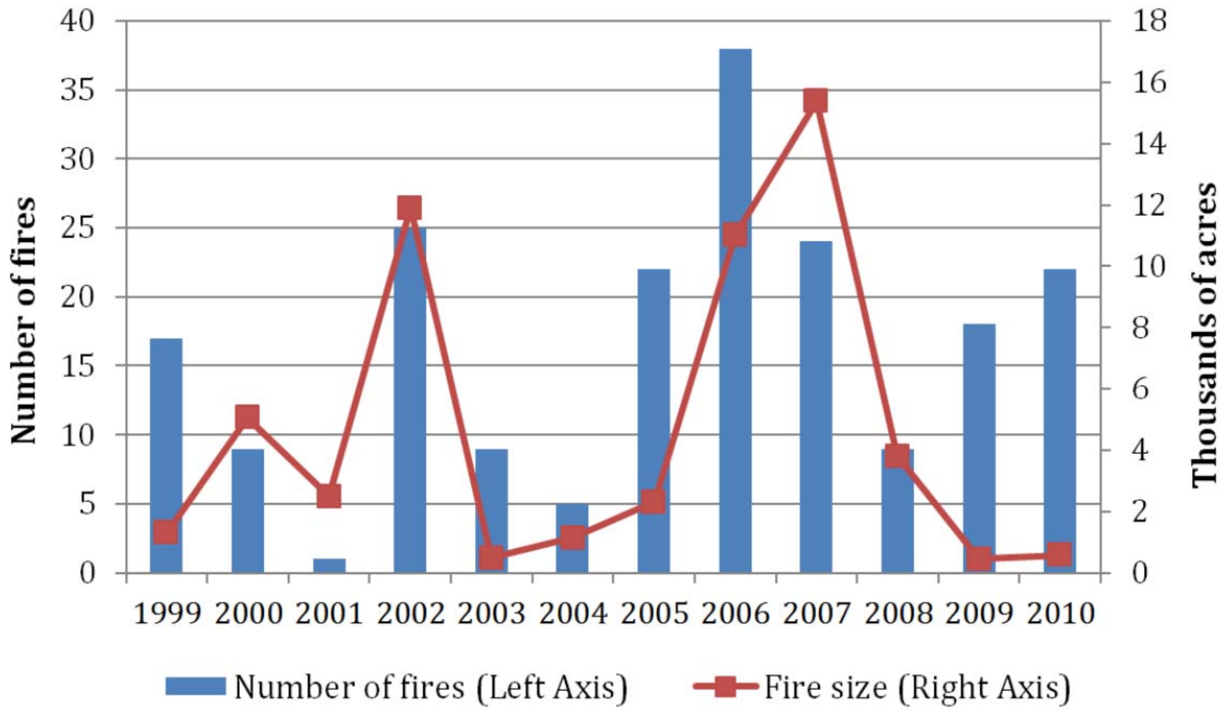

Figure 3. Simulated Area Burned due to Wildfire and 95% Confidence Interval
Note: Red solid line represents observed area burned from the wildfire between 1999 and 2010; blue solid line represents predicted and projected area burned from the wildfire using the regression in equations (12) and (13)

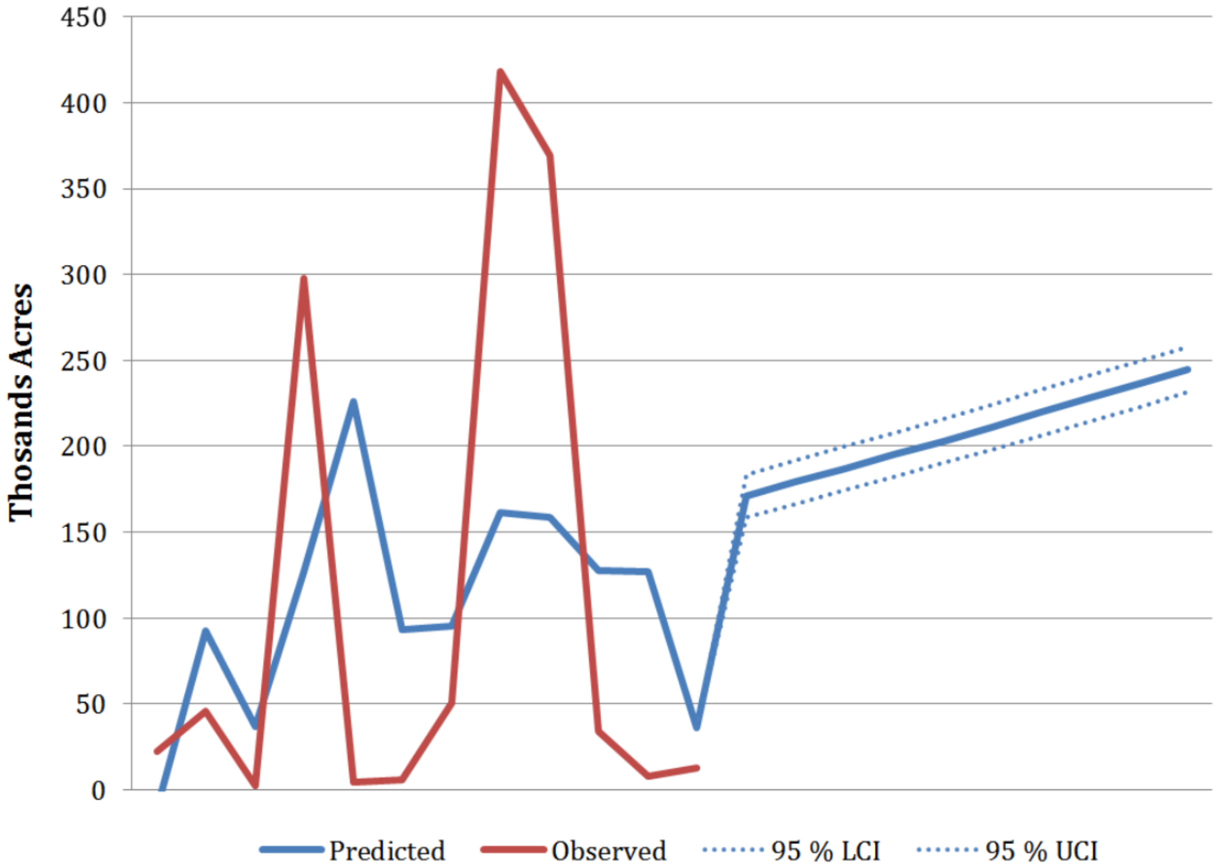

Figure 4. Losses in Selected Economic Sectors from Wildfires in Southeast Oregon
Note: Loss is the difference between the value of production in 2006 and the value of production under wildfires in the near futures. Dotted lines are 95% confidence bands from 1000 simulations.

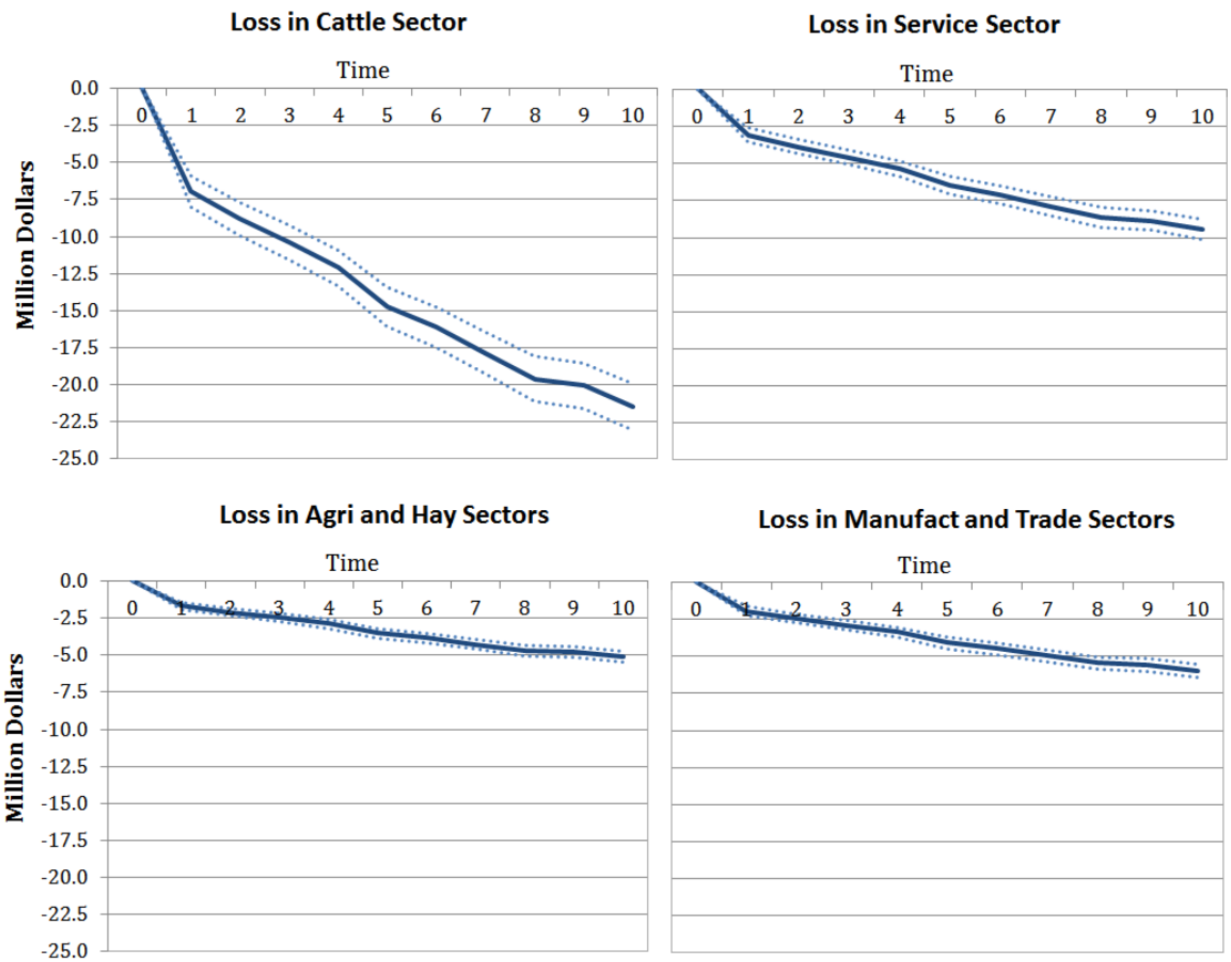

Figure 5. Regional Economic Impact from Wildfires in Southeast Oregon

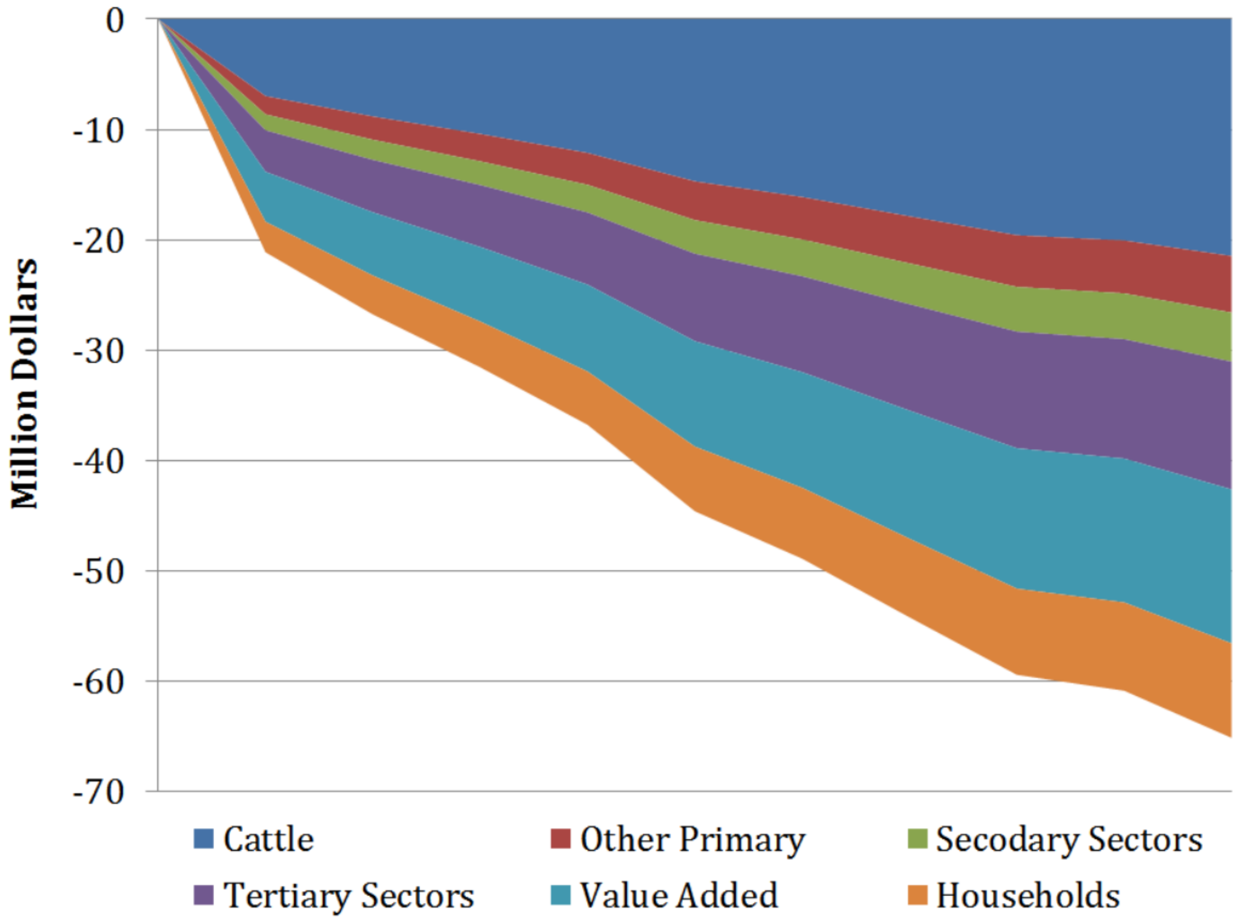

Table 1. Aggregation for economic sectors

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	Employee Compensation	Value Added (**V**)
6001	Proprietary Income	
7001	Other Property Type Income	
8001	Indirect Business Taxes	
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+	

Table 2. Regional Economic Impacts – Reduction of Value of Production[1]

	Sector	Direct and Indirect Economic Loss	
		$ in million	% of value of production
Activities	Agriculture	1.256	0.42
(X)	Hay	2.280	0.72
	Cattle	14.812	5.74
	Mining	0.004	0.01
	Utilities	0.301	0.33
	Construct	0.109	0.04
	Manufacturing	2.656	0.21
	Trade	1.468	0.25
	Service	6.527	0.23
Activities total		29.412	0.49
Value Added	Employee Compensation	5.340	0.29
(V)	Proprietary Income	0.668	0.28
	Other Property Type Income	2.810	0.30
	Indirect Business Taxes	0.812	0.41
Households	Less than 10k	0.101	0.05
	10k to 15k	0.179	0.09
(HH)	15k to 25k	0.555	0.14
	25k to 35k	0.693	0.15
	35k to 50k	1.057	0.17
	50k to 75k	1.620	0.22
	75k to 100k	0.761	0.20
	100k to 150k	0.530	0.21
	150k plus	0.414	0.21
Total Value added & households		15.540	0.23
Total		44.952	0.36

[1] Ten-year average