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Original Research

Economic Effects of Federal Grazing Programs

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ABSTRACT

Livestock grazing supports a considerable amount of economic activity across the United States. Federal grazing permits support numerous ranching operations by providing relatively low-cost grazing on federal lands. While grazing supports employment, labor income, and economic activity within a given state, the extent to which federal grazing permits play a role remains uncertain. In this paper we develop a method for estimating state-level economic contributions of livestock grazing for cattle grazing, as well as sheep and goat grazing, that is applicable to both the US Forest Service and Bureau of Land Management. We report state-level direct response coefficients, defined as the economic effects per 1 000 animal unit months of grazing use. We apply our coefficients to grazing lands for both US Forest Service and the Bureau of Land Management to estimate state-level economic contributions of federal grazing, finding that the economic effects of federal grazing are highest in western states where there are large amounts of public land. The measures of economic impact produced in this study were developed for consistent nationwide analyses. These measures may be used by researchers and land managers for conducting policy impacts and analysis of livestock grazing (e.g., increases or decreases of permitted grazing on public land) but are not intended to replace project- or site-specific economic analyses.

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Introduction

Around the world, grasslands cover 25% of land area (Alkemade et al. 2013) and are often managed for livestock grazing. More than 1 billion people worldwide depend on grazing ecosystems for their livelihoods, which is usually from livestock production (Teague and Kreuter 2020). In the United States, grazing activities provide economic support to communities, particularly rural ones. For example, Maher et al. (2021) used pasture rental rate data to estimate the economic value of forage production in the United States to be $3.2 billion. Grazing on private land can be expensive for cattle, goat, and sheep ranchers; however, ranchers can use inexpensive federal lands instead of relying on renting private land. Several federal agencies administer permits and leases that authorize grazing on public lands, with the Bureau of Land Management (BLM) and US Forest Service (FS) operating the largest grazing programs (Swette and Lambin 2021). Public land makes up a large percentage of the land in many western US States (Lewin et al. 2019), which results in substantial economic contributions from federal grazing. Furthermore, grazing in general (and thus federal grazing permits) has cultural significance for its role in providing a stable economic base and way of life for rural communities across the country (Boyd et al. 2014). Federal grazing has also been a subject of controversy (Lewin et al. 2019). Federal lands available for livestock grazing are diverse and are managed for multiple uses. Some of the lands available for livestock grazing include areas that provide habitat for threatened and endangered species. Balancing grazing with other land uses and the needs of threatened, endangered, and sensitive species is an ongoing challenge for public land managers. For example, Wolf et al. (2017) find tradeoffs between recreational experiences and livestock grazing in the California coast range. In addition, Zhang et al. (2022) find a tradeoff between grazing and water pollution. Finally, Petz et al. (2014) used a global analysis to assess tradeoffs between grazing and ecosystem services generally and found increased soil erosion, carbon emissions, and declining biodiversity when considering grazing at a global scale.

For ranchers to obtain grazing privileges on federal land, they must apply for a permit or lease. There are different types of permits. The most common is the term permit, which may be issued for a period up to 10 yr from the date of issuance. Term grazing permits describe the seasons of use, number of animal unit months (AUM) authorized, and kind and class of livestock allowed to graze within a specific area of federal lands. Many ranchers who have historically used public lands for grazing their cattle have done so for generations (Jackson-Smith et al. 2005), which is evidence that

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permits are often renewed and eventually passed down to successive generations. These areas are known as *grazing allotments*. The second is a temporary permit, which may be issued for a period not to exceed 1 yr. These are offered sparingly under a limited set of circumstances. The number of AUMs authorized by each permit is a contentious policy question, which may require a careful evaluation of the ecological impacts of grazing together with the social and economic impacts. The third type of permit is a livestock use permit, which is a paid or free permit issued for not to exceed 1 yr where the primary use is for other than grazing livestock (e.g., research, management tool). This third type does not appear on land managed by the BLM. Once a grazing permit is obtained, use is authorized on an annual basis and, unless use is being made under a free livestock use permit, grazing fees must be paid for total amount of authorized use. In 2020, this fee was $1.35 per AUM (US Forest Service 2020). In addition, the FS has lands, especially in the eastern and southern United States, where the grazing fees are determined through bid procedures.

Beef cattle ranching and sheep and goat farming are typically done with a combination of allowing the animals to forage on either private or public pastureland and purchasing hay and other feed. These represent costly inputs to the rancher required to produce cattle, sheep, or goats. For foraging on either public or private land, the volume of forage is measured in terms of AUM. Though definitions for AUMs differ across agencies, it generally refers to the amount of forage consumed by a single cow in a single month. For billing purposes, agencies charge based on each month of grazing use per adult animal, if the grazing animal is weaned or 6 mo of age or older at the time of entering federal lands, or will become 12 mo of age during the permitted period of use. For fee purposes only, five adult sheep or goats are equivalent to one cow, bull, steer, heifer, bison, horse, or mule. In the case of the BLM, an AUM means the amount of forage necessary for the sustenance of one cow or its equivalent for a period of 1 mo. While there may be conversion factors for different kinds of animals, for the purposes of calculating grazing fees, an AUM is defined by one cow, bull, steer, heifer, horse, burro, mule, and five sheep or five goats older than the age of 6 mo at the time of entering the public land. No charge is made for animals younger than 6 months of age at the time they enter public lands.

A considerable amount of the literature is focused on assessing the environmental and ecological impacts of federal grazing (e.g., Runge et al. 2019). Grazing has substantial environmental impacts, both beneficial and harmful to some conservation goals (Krueger et al. 2002; Neilly et al. 2016; Neilly et al. 2018). Recently, considerable attention has focused on addressing potential changes in grazing policies on public land to preserve habitat for the greater sage grouse (Monroe et al. 2017). Typically, the policies proposed involve the reduction of AUMs on parcels of land (Wambolt et al. 2002); however, in some contexts, studies have examined the effects of increasing AUMs in a targeted way to reduce wildfire threats and preserve sage grouse habitat (Boyd et al. 2014). These reductions may have economic costs in the states in which they occur (Wambolt et al. 2002). In addition, other studies have examined the effects of changing grazing fees on federal lands (Radte et al. 1985). Grazing fees for both the FS and BLM change annually according to a set formula with the minimum value being $1.35 per AUM (Vincent 2019). This differs substantially from the competitive method or market-based method, which other agencies use to determine grazing fees (Vincent 2019). The economic impacts of these policies may be important to policy makers, land managers, and other stakeholder groups associated with grazing. By providing estimates of the economic contributions of cattle, sheep, and goat grazing on both FS and BLM lands, we demonstrate a standardized and straightforward method for calculating the economic impacts of changing AUM levels.

Given the economic, cultural, and environmental impacts of grazing, it is important to understand the overall economic contribution of grazing activity on federal lands. However, few studies have systematically quantified the economic contributions of grazing in a comparable way at a large-scale, national scale. In this study, we examine the economic contributions of federal grazing by agency and by state. We find evidence that the economic contributions of grazing differ greatly by state, likely due to differences in the relative size of the grazing industry in each state.

In order to estimate the economic contributions of grazing on federal lands, we estimate direct response coefficients (DRCs) for the number of jobs, labor income, and output for each state for cattle, sheep, and goat grazing for both BLM and FS lands Table 1. The DRCs provide estimates of economic contributions per 1 000 AUMs of grazing; these DRCs can be used to convert an amount of grazing, measured in AUMs, into an economic outcome using publicly available data (US Department of Agriculture 2017). This is in line with previous studies that have developed DRCs for other sectors of the economy, such as timber (e.g., Sorenson et al. 2016). Expanding on the approach of Sorenson et al. (2016), our results are reported on a state-by-state basis. DRCs can be used to calculate the economic impacts of grazing policies that affect public land AUM permitting. We use our DRCs to calculate the direct economic contributions of federal grazing for as many states in the United States as possible, given data constraints. We report the contributions of FS grazing and BLM grazing separately.

We examine the economic contributions with respect to the number of jobs, the amount of labor income, and the economic output per 1 000 AUMs on FS and BLM land. These three indicators relay different characteristics of economic contributions. Jobs are defined as the number of additional employed persons within the industry of interest (i.e., the beef cattle ranching industry and the sheep and goat farming industry). Labor income is defined as the additional flow of income, in dollars, to those employed within our industry of interest. Finally, total statewide direct output produced by cattle ranching, as well as sheep and goat ranching

Table 1
Construction of each direct response coefficient.

Direct response coefficient	Data needs	Equation
Animal unit mo (AUMs)	Head months (CoA) State conversion factors Cattle inventory survey Sheep and goat inventory survey	$\text{AUMs}_{\text{FS/BLM}} = \text{Head months}_{\text{CoA}} \cdot \text{Conversion factor}_{\text{FS/BLM}}$
Jobs	AUMs (see above) Job numbers (CoA)	$\text{DRC}_{\text{emp}} = \frac{\text{jobs}_{\text{NAICS}}}{\text{AUMS}_{\text{NAICS}}} \cdot 1\,000$
Labor income	AUMs (see above) Labor income (CoA) Proprietor income (CoA)	$\text{DRC}_{\text{inc}} = \frac{\text{Labor Income}_{\text{NAICS}} + \text{Proprietor Income}_{\text{NAICS}}}{\text{AUMS}_{\text{NAICS}}} \cdot 1\,000$
Output	AUMs (see above) Total Sales (CoA)	$\text{DRC}_{\text{out}} = \frac{\text{Total Sales}_{\text{NAICS}}}{\text{AUMS}_{\text{NAICS}}} \cdot 1\,000$

operations, is measured by the total sales reported by farms in our industry of interest. We find substantial differences across states and regions with respect to these economic contributions.

Several studies have used tools such as IMPLAN (IMPLAN 2018) and linear programming models to estimate the costs of grazing reductions (e.g., Taylor et al. 2019). Another study by Lewin et al. (2019) uses a social accounting matrix to examine grazing contributions in Owyhee County, Idaho. There are several state-level analyses that have been performed as well (e.g., Pearce et al. 1999). To the best of our knowledge, this is one of the few studies (e.g.,Radke et al. 1985; Lewin et al. 2019) that examines the direct national-level economic contributions of federal grazing on public lands.

This study addresses the needs of policy makers by providing per-use estimates of the economic contributions of grazing at both state and federal levels. Having access to DRCs may be important for informing policy decisions. For instance, the FS often considers land exchanges (exchanging a parcel of public land for a parcel of comparably valued private land) for a variety of reasons (Panagia 2015). However, doing so may have implications for ranchers. Factoring these effects into these policy decisions may prove important. Furthermore, they will be important for assessing the impacts of changing the number of AUMs. Decisions related to expanding or contracting grazing programs on federal land may benefit from knowledge of the economic impacts of such a policy (Lewin et al. 2019). This study presents a simple, defensible, and standardized method for calculating federal grazing contributions. In addition, given grazing's international prevalence (Teague & Kreuter 2020), the approach taken in this paper can be applied internationally as well, given data availability constraints. Such analysis would be crucial for understanding the economic impacts of international investments in either grazing (Madhusudan 2005) or restricting grazing (Wang & Lo 2022).

Data and Methods

The primary dataset used in our analysis is the Census of Agriculture (CoA), a dataset collected by the US Department of Agriculture every 5 yr (US Department of Agriculture 2017). The CoA contains voluminous detail regarding the operation, profitability, and quantity of agricultural production, including grazing, in the United States. We use data from the most recent CoA, which was conducted in December 2017. Though the CoA dataset contains a majority of the variables needed to construct the DRCs for both the FS and BLM, we also use the Cattle Inventory (USDA NASS 2021) and Sheep and Goat Inventory (USDA NASS 2022) to get accurate representations of grazing volumes at the state level.

Measuring the amount of feed requirements (AUMs)

An initial requirement of the analysis is to develop accurate estimates of the forage required to sustain beef cattle and sheep/goat herds within each state. The CoA reports state-level inventories for various categories of livestock grazing on both public and

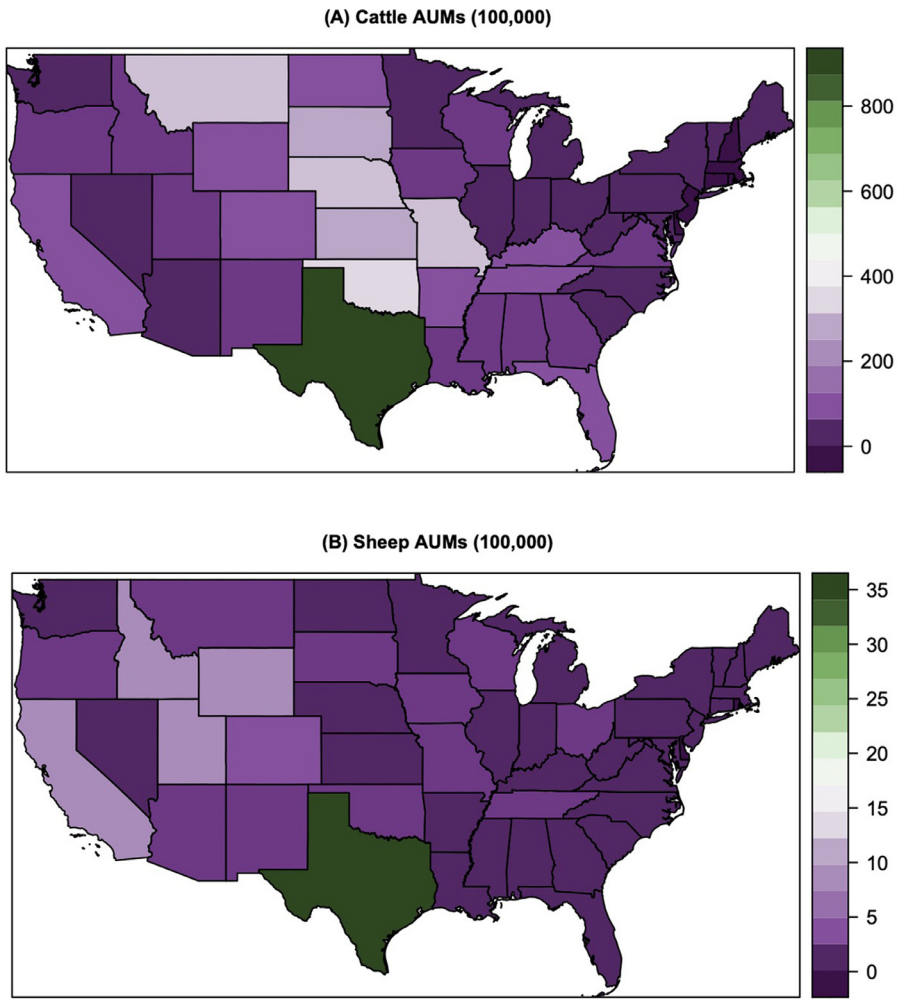

Figure 1. Animal unit months per state for cattle (A) and sheep and goats (B).

private lands. We estimated forage requirements—reported in head months (HMs)—by adjusting the state-level inventories and multiplying for 12 (for the number of mo in a yr). An HM is a count of livestock in a herd that is grazing for a month on pastureland. HMs can then be converted into AUMs using state-specific conversion factors, thereby estimating the annual amount of forage that would be required to sustain herds in any given state.

The CoA classifies each farm or ranch into an agricultural industry, based on the North American Industry Classification System (NAICS). The CoA data used in this analysis center on two ranching industries: NAICS 112111–Beef Cattle Ranching and NAICS 1124–Sheep and Goat Farming. Therefore, two sets of DRCs resulted from this study, one set for each industry. For the beef cattle ranching DRCs, the CoA's "Cattle including Calves" field was used to estimate HMs. However, this field includes counts of cows, bulls, steers, heifers, and calves. By convention, calves are not included in counts of HMs and their numbers had to be excluded from the counts listed in this field. However, there are no other fields in the CoA data that quantify the number or portion of calves included in this total. In order to remove the calves from the total count, we estimate the number of calves in the CoA livestock inventory data using the Cattle Inventory Survey (CIS) data (USDA NASS 2021). CIS data are also produced by the National Agricultural Statistical Service. Using the CIS ratio of calves to total cattle inventory, the CoA cattle inventory data are adjusted to exclude calves and result in a more accurate estimate of statewide AUM requirements. This produces an HM total for all cattle within a state, which must be converted to AUMs.

The statewide conversion factors differ between the FS and BLM. That is, each agency has a different conversion factor, with a separate methodology to arrive at that conversion factor. Though all the data used from the CoA are common across both agencies, due to the difference in statewide conversion factors, the DRCs are slightly different across agencies.

We employ a similar method for calculating AUMs within the sheep and goat farming industry. The CoA sheep and goat livestock inventory data used to produce statewide AUM estimates include lambs and young goats (called "kids"). The Sheep and Goat Inventory Survey (SIS) is used to estimate and exclude the number of lambs from the CoA sheep and goat livestock inventory data (USDA NASS 2020). However, the SIS data do not provide enough detail concerning kids (young goats) to estimate their levels; therefore, they are not excluded from the CoA goat inventory data. It is possible that ranches and farms that are categorized as producers of sheep and goats (NAICS 1124) may also produce cattle. A caveat of our approach is that because every operation is given a single NAICS code, cattle that are produced under NAICS code 1124 may be assigned as goat and sheep AUMs. Similarly, sheep and goats that are produced under NAICS code 112111 may be assigned as cattle AUMs. Applying these methods provide us with a means of calculating state-level AUMs for both cattle and sheep and goat ranching. We present these AUM calculations using the

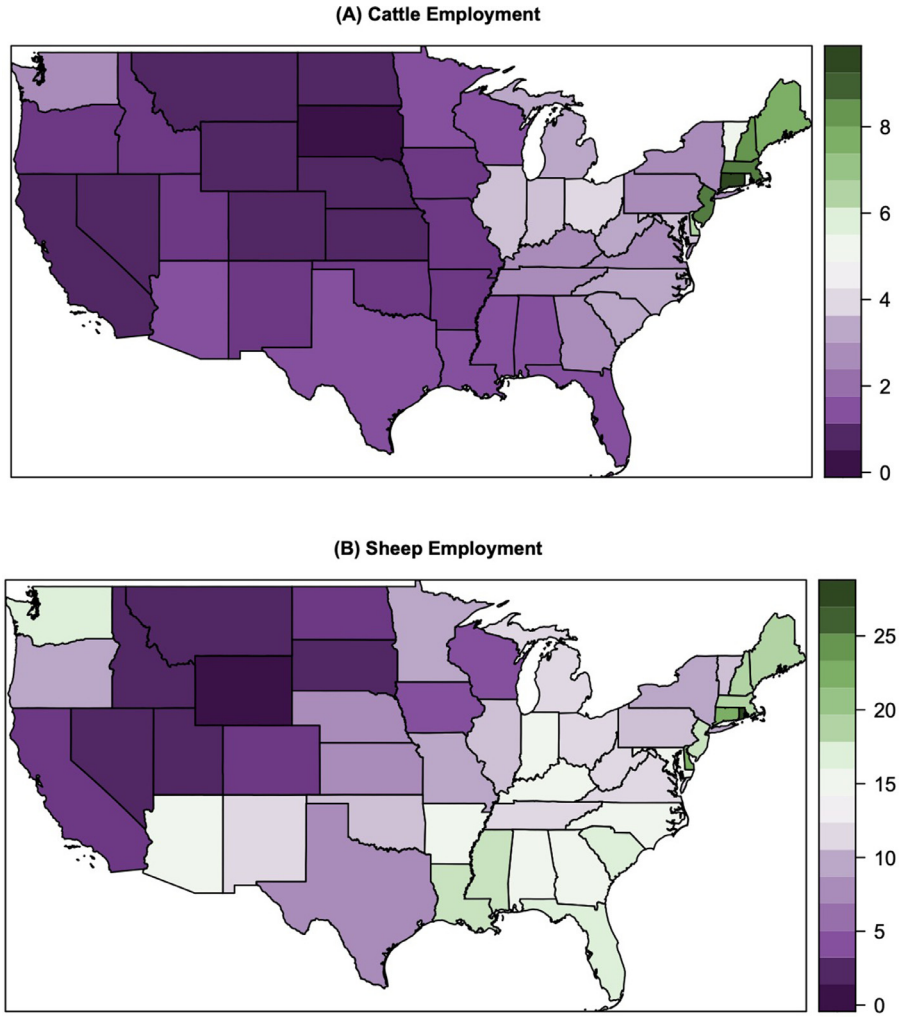

Figure 2. Employment direct response coefficients (jobs per 1 000 AUM equivalents) for A, cattle and B, sheep and goat ranching.

FS methodology in Figure 1. For the sake of parsimony, we only present figures that follow the FS methodology. This is because the BLM methodology produces figures that closely follow those of the FS methodology. The BLM DRCs are still reported separately in the following section.

Calculating direct economic contributions

Once the AUM levels have been calculated for each state for both FS and BLM, we then estimate the direct economic activity in terms of employment, labor income, and output supported by the beef cattle ranching and sheep/goat farming industries. It is important to calculate and report the DRCs separately for each agency. This is because the AUMs used to calculate the DRCs have different definitions between the BLM and FS, leading to different measurements of grazing volume on any given parcel of land. Calculation of the DRCs is done using select CoA data, which represents these variables by industry. The methodology we use for each of these is discussed later and is common across both FS and BLM. Further, this method is in line with other studies that have employed similar methods, including Sorenson et al. (2016)'s method to calculate DRCs for the USA timber industry. In the figures that follow (Figs. 2–4), we present only the FS DRCs graphically. This is due to the close similarity with figures using the BLM AUM methodology.

Employment

The CoA data report the number of hired workers in each NAICS code. Additionally, we assume that each operation within a state has one proprietor. Therefore, we calculate the number of jobs as being equal to the amount of hired labor in each state plus the number of farms in each state for each of the two industries we consider. To obtain the direct response coefficient for each state, we divide the number of jobs in each NAICS code by the estimate AUM equivalents for each NAICS code ($DRC_{emp} = \frac{jobs_{NAICS}}{AUMS_{NAICS}} * 1\,000$). This results in a DRC whose units are equal to the number of jobs supported per 1 000 AUMs. To demonstrate the magnitude of each industry's contribution to each state's labor force, Figure 2A shows the DRCs for cattle farming (NAICS 112111) and sheep and goat farming (NAICS 1124; Fig. 2B).

Labor income

Next, we estimate the impact of AUMs on the amount of labor income for each NAICS code and each state. This is entirely estimated from fields within the CoA dataset. We set labor income equal to the sum of employee compensation and proprietor income. Employee compensation is set to the expenditure levels on hired labor reported in the CoA data. Proprietor income is calculated by taking the average level of net income (revenue minus costs) for each operation and then multiplying it by the number of farms. The DRCs are obtained by dividing the labor income calculated for each state and each

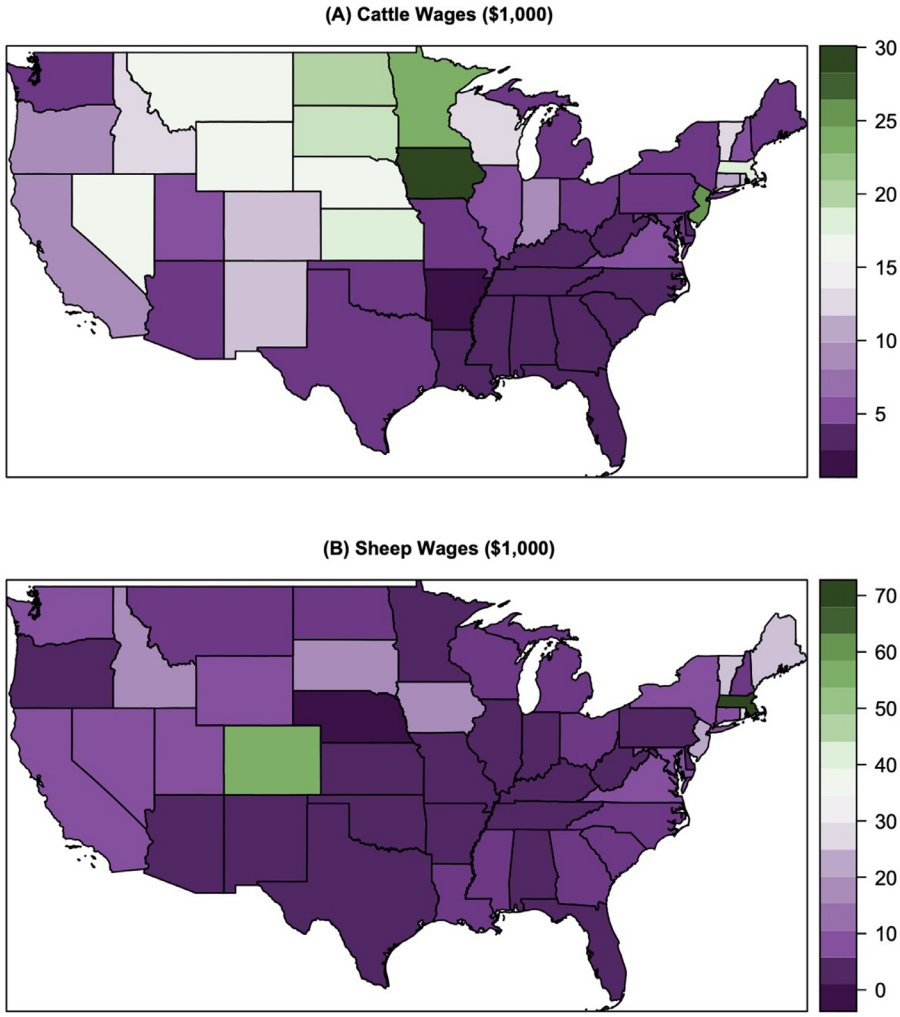

Figure 3. Labor income per 1 000 animal unit months for A, cattle andB, sheep and goat ranching.

NAICS code by the number of AUMs in each state and NAICS code ($DRC_{inc} = \frac{Labor\ Income_{NAICS} + Proprietor\ Income_{NAICS}}{AUMS_{NAICS}} * 1\ 000$). The units of the labor income DRC are dollars of labor income per 1 000 AUMs. These DRCs are shown in Figure 3.

Output

Total statewide direct output produced by cattle ranching, as well as sheep and goat ranching operations, is measured by the total sales reported by farms in each NAICS category. The CoA data include information on the number of government expenditures received by each operator. However, we use a variable that excludes these payments from our calculations. One issue is that for several states, the data on total sales are suppressed. In these cases, we employ state-level ratios from IMPLAN for labor income and output. By taking the ratio of output to labor income, we can estimate output for suppressed states by multiplying labor income by this ratio. Finally, to obtain the DRCs for output, the output calculated by the method above is divided by the number of AUMs for each state-NAICS code combination ($DRC_{out} = \frac{Total\ Sales_{NAICS}}{AUMS_{NAICS}} \cdot 1\ 000$). The units on these DRCs are dollars of total sales per 1 000 AUMs. These DRCs are presented in Figure 4.

Economic contribution of public land

Once the DRCs are calculated, we apply them to the number of FS and BLM AUMs reported by each agency for 2017. This will provide the economic contributions in terms of employment, labor income, and output supported by FS and BLM grazing. It is important to note that these do not constitute the overall economic contributions of public lands, since other land holding agencies such as the National Park Service are not included.

Results and Discussion

We report the jobs, labor income, and output supported by federal grazing for both the FS and BLM programs, calculated with the DRCs we derive earlier and report later. The employment DRC is in units of jobs per 1 000 AUMs. The DRCs for labor income and output are in units of dollars per 1 000 AUMs (2017 USD). The DRCs, as an economic metric, communicate the amount of labor income, jobs, and output associated with 1 000 AUMs. Though this is not the only metric one can use to communicate this relationship, it has the distinct benefit of functioning as a multiplier for future analysis. It is important to note that in this analysis, we report DRCs even for states that do not have federal grazing. It is also important to note that the economic contributions of the BLM and FS vary due to not only the amount of land, or AUMs for each state, but also the method of estimating AUMs.

Direct response coefficients

Cattle DRCs

The DRCs for cattle grazing (NAICS 112111) are reported by state for FS and BLM (Tables 2 and 3). Across each DRC category there

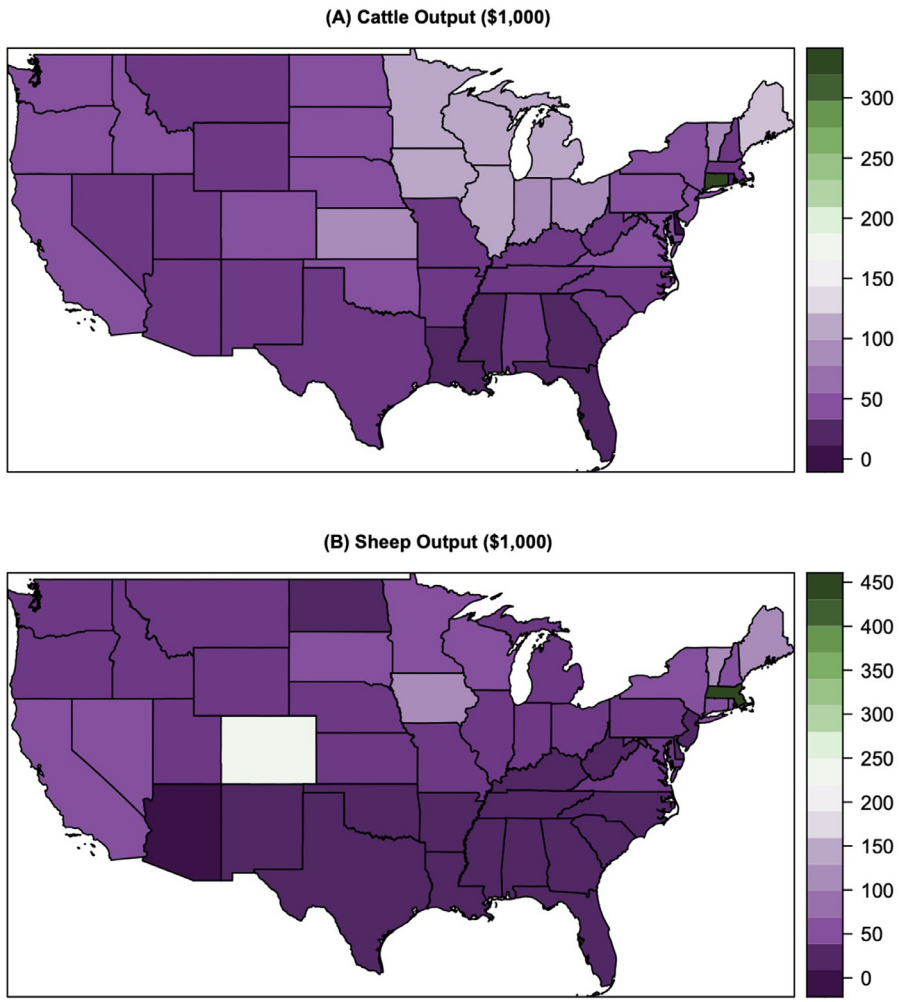

Figure 4. Direct response coefficients for output for A, cattle and B, sheep and goat ranching.

Table 2
Direct response coefficients for cattle ranching, by state per 1 000 animal unit months for the US Forest Service.

State	Employment	Labor income (2017 USD)	Output (2017 USD)
Alabama	2.3	2 862	33 560
Alaska	0.5	2 817	81 722
Arizona	2.2	5 646	36 474
Arkansas	1.7	2 486	38 753
California	1	9 535	70 616
Colorado	1.1	13 469	55 868
Connecticut	9.3	10 685	319 732
Delaware	7	2 768	10 747
Florida	1.8	4 119	29 241
Georgia	2.6	3 962	23 654
Hawaii	1	6 326	106 556
Idaho	1.1	14 129	70 965
Illinois	3.8	7 711	101 471
Indiana	3.7	9 194	80 142
Iowa	1.4	28 290	113 499
Kansas	1	17 516	95 748
Kentucky	2.4	4 258	48 748
Louisiana	2	3 066	32 735
Maine	7.7	4 645	142 374
Maryland	4	5 141	56 877
Massachusetts	8.9	17 886	44 099
Michigan	3.3	5 148	100 255
Minnesota	2	24 479	110 119
Mississippi	2.2	2 986	21 540
Missouri	1.7	5 063	45 156
Montana	0.6	16 466	52 576
Nebraska	0.6	15 750	68 540
Nevada	0.6	15 403	46 574
New Hampshire	8.2	6 203	52 171
New Jersey	9.1	24 835	60 938
New Mexico	1.4	12 060	47 865
New York	2.5	6 041	70 099
North Carolina	3.4	2 717	39 605
North Dakota	0.5	20 949	58 227
Ohio	4.8	4 770	89 019
Oklahoma	1.6	5 505	64 038
Oregon	1.8	8 985	55 714
Pennsylvania	2.9	4 467	70 867
Rhode Island	5.4	12 812	21 158
South Carolina	3.1	3 919	36 123
South Dakota	0.5	19 753	65 358
Tennessee	2.6	2 660	39 761
Texas	2.2	4 744	52 243
Utah	1.5	7 307	45 933
Vermont	5.2	15 084	86 782
Virginia	2.4	7 129	56 752
Washington	2.5	5 152	58 028
West Virginia	3.3	3 049	43 843
Wisconsin	2.1	13 904	104 284
Wyoming	0.7	16 562	54 339

Table 3
Direct response coefficients for cattle ranching, by state per 1 000 animal unit months for the Bureau of Land Management.

State	Employment	Labor income (2017 USD)	Output (2017 USD)
Alabama	2.9	3 657.30	42 891.50
Alaska	0.7	3 599.80	104 434.10
Arizona	2.8	7 122.30	46 008.10
Arkansas	2.3	3 282.90	51 172.60
California	1.3	12 348.90	91 456.80
Colorado	1.4	17 227.00	71 453.60
Connecticut	11.9	13 697.10	409 861.40
Delaware	9.1	3 559.00	13 818.10
Florida	2.4	5 437.90	38 606.20
Georgia	3.5	5 239.20	31 276.00
Hawaii	1.3	8 095.90	136 368.80
Idaho	1.5	18 554.10	93 191.50
Illinois	3.8	7 733.50	101 764.90
Indiana	4.7	11 757.00	102 488.20
Iowa	1.8	36 158.60	145 069.60
Kansas	1.2	20 473.80	111 918.40
Kentucky	3.1	5 442.60	62 308.60
Louisiana	2.6	4 040.30	43 137.90
Maine	9.9	5 946.20	182 267.10
Maryland	5.1	6 574.70	72 742.70
Massachusetts	11.5	22 963.00	56 616.80
Michigan	4.2	6 582.40	128 193.00
Minnesota	2.6	31 288.30	140 751.50
Mississippi	2.9	3 946.90	28 470.10
Missouri	2.2	6 471.80	57 719.80
Montana	0.7	20 880.80	66 672.80
Nebraska	0.7	20 062.90	87 307.30
Nevada	0.7	19 626.80	59 346.00
New Hampshire	10.5	7 941.00	66 786.70
New Jersey	11.8	31 896.30	78 265.10
New Mexico	1.8	15 476.80	61 426.20
New York	3.2	7 979.10	92 589.20
North Carolina	4.4	3 473.90	50 644.60
North Dakota	0.7	27 426.60	76 229.20
Ohio	4.9	4 790.60	89 400.80
Oklahoma	1.7	5 775.10	67 174.20
Oregon	2.3	11 769.00	72 979.50
Pennsylvania	3.8	5 712.90	90 634.00
Rhode Island	7	16 376.90	27 045.50
South Carolina	4	5 012.60	46 202.40
South Dakota	0.6	25 085.80	83 002.20
Tennessee	3.3	3 400.60	50 833.50
Texas	2.5	5 371.10	59 149.90
Utah	2	9 510.30	59 783.70
Vermont	6.7	19 294.40	111 004.90
Virginia	2.7	8 001.40	63 694.10
Washington	3.4	6 771.30	76 262.20
West Virginia	4.3	3 867.30	55 614.40
Wisconsin	2.7	17 775.50	133 321.70
Wyoming	0.8	20 189.70	66 240.20

is substantial variation between states. The DRC for employment varies dramatically from a maximum of 9.26 in Connecticut for the FS (and 11.92 for BLM) to a minimum of 0.50 in South Dakota for FS (0.64 for BLM). Similarly, there are large differences between states in labor income and output.

The variation in the levels of the DRCs requires caution when interpreting. Though it may be tempting to interpret a high employment or wage DRC as being a beneficial measure, it may also speak to the relative efficiency of the cattle grazing industry in that state. States like Texas, Wyoming, or South Dakota with large amounts of pastureland (ERS, 2012) for cattle to graze on may have low DRCs compared with states like Delaware or New Jersey, which has less pastureland but a higher density of grazing (ERS, 2012). Furthermore, the availability of public land and potential AUMs may be smaller in smaller states like New Jersey, leading to higher DRCs.

There is substantial variation in the labor income supported by AUMs in each state. The mountain west, as well as the Midwest, where states like Wyoming ($16 562 per 1 000 AUMs for the FS), South Dakota ($19 753 per 1 000 AUMs for the FS), and Wisconsin ($13 904 per 1 000 AUMs for the FS) are, feature large amounts of income supported per 1 000 AUMs. This is even though the employment DRCs for these states are low. Another region with surprisingly large labor income DRCs is New England, with states like Connecticut ($10 685 per 1 000 AUMs for FS) and Massachusetts ($17 886 per 1 000 AUMs for FS) featuring large values. Unlike other groups of states, the states within New England also have large employment DRCs, which are driving the labor income DRCs upward. The pattern that's observed with the labor income DRCs mentioned earlier holds with the DRCs for output as well. Both feature larger values in states with larger amounts of open pastureland and public land, except for states in the New England region. Due to the difference in how the FS and BLM measure AUMs, the DRCs for BLM land tend to be higher than those for FS land, but their order is retained and they have more or less the same pattern.

Table 4
Direct response coefficients for every state for sheep and goat ranching, per 1 000 animal unit months for the Forest Service.

State	Employment	Labor income (2017 USD)	Output (2017 USD)
Alabama	15.8	4 347	23 624
Alaska	18.2	3 418	48 238
Arizona	15.8	3 733	8 015
Arkansas	14.2	2 600	29 767
California	4.8	15 114	86 040
Colorado	3.7	54 586	225 141
Connecticut	21.9	12 962	96 246
Delaware	21.7	977	36 380
Florida	16	4 804	31 863
Georgia	15.1	10 152	24 825
Hawaii	8.7	20 312	19 827
Idaho	2.4	15 701	55 229
Illinois	12.1	5 259	64 343
Indiana	14.4	5 456	45 536
Iowa	6.8	17 003	123 900
Kansas	7.7	2 772	62 928
Kentucky	14.5	2 712	37 961
Louisiana	19.6	7 247	28 046
Maine	21.4	25 965	125 114
Maryland	15	10 926	40 696
Massachusetts	20.9	68 069	431 029
Michigan	13.2	8 532	68 774
Minnesota	9.1	4 544	83 583
Mississippi	18.2	7 803	21 068
Missouri	10.1	4 963	49 337
Montana	2.6	7 230	49 215
Nebraska	7.5	893	45 106
Nevada	2	15 185	68 955
New Hampshire	20.3	8 730	73 913
New Jersey	19.6	20 249	38 163
New Mexico	12.8	5 748	28 486
New York	9	12 864	82 994
North Carolina	15.1	7 042	34 531
North Dakota	4.1	5 780	14 273
Ohio	14.1	5 788	59 570
Oklahoma	11.5	4 901	31 847
Oregon	9.3	5 169	58 386
Pennsylvania	11.6	5 569	57 088
Rhode Island	27	34 233	70 394
South Carolina	16.5	8 166	20 197
South Dakota	2.4	17 756	73 651
Tennessee	13.1	4 830	32 264
Texas	7.1	5 680	26 807
Utah	2.7	14 169	56 759
Vermont	11.7	29 228	106 532
Virginia	13.1	11 121	42 424
Washington	17.4	10 687	45 046
West Virginia	14	1 723	33 710
Wisconsin	6.2	6 866	92 075
Wyoming	1.4	14 481	61 281

Table 5
Direct response coefficients for every state for sheep and goat ranching, per 1 000 animal unit months for the Bureau of Land Management.

State	Employment	Labor income (2017 USD)	Output (2017 USD)
Alabama	22.4	6 171.70	33 543.30
Alaska	26.1	4 900.20	69 147.60
Arizona	20.4	4 831.10	10 373.90
Arkansas	20	3 673.50	42 049.40
California	6.2	19 302.30	109 880.90
Colorado	5.4	79 132.00	326 382.00
Connecticut	30.9	18 325.30	136 069.10
Delaware	31.1	1 400.00	52 149.90
Florida	22.9	6 847.50	45 417.10
Georgia	21.4	14 432.90	35 294.20
Hawaii	12.5	29 116.00	28 421.80
Idaho	3.4	21 772.30	76 587.10
Illinois	17	7 389.50	90 408.20
Indiana	20.5	7 743.10	64 621.50
Iowa	9.6	23 909.90	174 234.40
Kansas	10.7	3 857.40	87 582.20
Kentucky	20.4	3 818.20	53 436.90
Louisiana	28.1	10 388.10	40 203.70
Maine	30.3	36 751.10	177 089.30
Maryland	21.3	15 507.00	57 760.00
Massachusetts	29.7	96 725.30	612 491.00
Michigan	18.6	12 034.40	97 008.70
Minnesota	12.9	6 422.40	118 122.50
Mississippi	26	11 185.40	30 200.60
Missouri	14.2	6 971.40	69 300.40
Montana	3.7	10 322.10	70 261.00
Nebraska	10.5	1 245.40	62 934.90
Nevada	2.7	20 866.10	94 750.50
New Hampshire	28.8	12 410.50	105 075.30
New Jersey	27.9	28 795.70	54 271.40
New Mexico	18.5	8 310.70	41 190.00
New York	12.8	18 289.80	117 998.20
North Carolina	21.5	9 979.00	48 929.80
North Dakota	5.8	8 207.10	20 267.30
Ohio	19.3	7 914.70	81 456.70
Oklahoma	15.4	6 557.30	42 612.10
Oregon	13.2	7 324.10	82 729.30
Pennsylvania	16.4	7 890.30	80 878.00
Rhode Island	38.7	49 071.90	100 908.40
South Carolina	23.5	11 609.80	28 715.40
South Dakota	3.6	25 861.50	107 269.60
Tennessee	18.5	6 799.70	45 418.60
Texas	9.8	7 834.60	36 974.40
Utah	3.9	20 539.60	82 281.30
Vermont	16.7	41 479.60	151 186.40
irginia	18.1	15 284.80	58 305.70
Washington	25.8	15 830.50	66 725.80
West Virginia	19.4	2 400.60	46 976.30
Wisconsin	8.7	9 750.00	130 752.60
Wyoming	1.9	19 859.80	84 044.90

Sheep and goat DRCs

We perform a similar exercise for sheep and goat grazing (NAICS code 1124). The DRCs for NAICS code 1124 can be found in Table 4 for FS and Table 5 for BLM.

When comparing the sheep and goat grazing DRCs with those from cattle grazing, in general, the employment DRCs are higher for sheep and goat grazing. Typically, sheep and goat farming is a more intensive process, requiring more specialized care for the animals and greater numbers of employees. For this reason, the employment DRC is drastically higher across the board. Within sheep and goat grazing, the employment DRCs follow the same pattern as the cattle grazing DRCs. We notice that in agriculturally intensive states such as Iowa or Texas, the employment DRCs are low; however, they are lowest in states such as Idaho that have substantial amounts of public land. Though not a perfect relationship, the more efficient an industry is in a given state, the lower the employment, labor income, and output DRCs will be. This is because a more efficient ranching sector will be able to ranch more livestock with fewer resources. For that reason, states with large amounts of AUMs, both public and private, can typically take advantage of economies of scale, which will reduce the per-AUM inputs required to ranch. We see large employment DRCs in the New England region, where there is less land to graze sheep and goats (ERS, 2012). Generally, the DRCs for labor income follow the same pattern as those for employment, with respect to their regional differences. This is also a reason why, typically, the sheep and goat DRCs are larger in magnitude than the cattle DRCs.

The DRCs in Tables 2 through 5 communicate an average economic impact at the state level for marginal changes of AUMs within that state. Although these coefficients can be used in numerous ways, several limitations are important to note. First, these coefficients are aggregated to the state level, which limits their application at higher resolution, such as at the county level. Second, there are limitations to how these coefficients can be used throughout time. The data used for this analysis are from the 2017 agricultural census. It is important to note that features of both the

Table 6
Estimates of the economic contributions of cattle ranching by agency, by state, for the yr 2017.

State	Forest Service employment	Labor income ($10 000)	Output ($10 000)	BLM employment	Labor income ($10 000)	Output ($10 000)
Arizona	1 990.60	511	3 300	1 265	322	2 078
Arkansas	7.7	1	17	0	0	0
California	296	288	2 133	154	149	1 102
Colorado	809.8	965	4 004	401	477	1 979
Florida	1.5	0	2	0	0	0
Georgia	0.5	0	0	0	0	0
Idaho	598.2	741	3 724	1 378	1 697	8 523
Illinois	29.1	6	78	0	0	0
Kansas	31.1	55	301	0	0	0
Louisiana	0.6	0	1	0	0	0
Mississippi	0.1	0	0	0	0	0
Montana	259.2	736	2 349	835	2 358	7 530
Nebraska	61	166	721	0	1	4
Nevada	103.4	284	860	896	2 458	7 432
New Mexico	991.6	854	3 390	2 520	2 163	8 585
New York	24.9	6	71	0	0	0
North Dakota	278.9	1 124	3 123	6	25	70
Ohio	2.5	0	5	0	0	0
Oklahoma	23.7	8	96	0	0	1
Oregon	682.3	350	2 172	1 734	885	5 487
South Dakota	203.7	805	2 663	36	143	472
Texas	38.3	8	90	0	0	0
Utah	701	344	2 161	1 326	646	4 059
Virginia	16.1	5	38	0	0	0
Washington	180.3	36	410	93	19	211
West Virginia	18	2	24	0	0	0
Wyoming	280.8	705	2 312	948	2 373	7 784

Table 7
Estimates of economic contributions of sheep and goat ranching on public land by agency for the yr 2017.

State	Forest Service employment	Labor Income ($10 000)	Output ($10 000)	BLM employment	Labor income ($10 000)	Output ($10 000)
Arizona	399	9	20	11	0	1
California	144	45	256	64	20	114
Colorado	354	516	2 128	276	402	1 657
Idaho	279	181	638	215	140	492
Montana	21	6	39	73	20	138
Nevada	82	62	282	282	214	971
New Mexico	34	2	8	1 360	61	303
Oregon	198	11	124	61	3	39
South Dakota	2	2	7	36	26	109
Utah	378	201	803	620	329	1 316
Washington	66	4	17	16	1	4
Wyoming	64	68	289	256	272	1 151

cattle, sheep, and goat industries change over time, so the further from 2017 the analysis is performed, the less accurate it may be. Future research could calculate DRCs for each year of the agricultural census to observe the rate of change for these DRCs, given that the CoA is collected every 5 yr. Third, the DRCs are likely underestimates of the economic contribution of grazing on the economy. The economic contributions of grazing are not limited to the direct economic contributions shown in Tables 2–5. There is also a considerable ripple effect that may take place due to the additional economic activity. These secondary effects can be calculated using economic input-output models, such as IMPLAN, which estimate the ripple effects stemming from the direct economic activity. This kind of exercise can be useful for generating estimates for local impacts on specific industries, especially those related to the ranching sector such as veterinary services, agricultural equipment suppliers, and others. Future research may quantify the effect of public land on supporting grazing on private land to see whether public grazing provides a subsidy to grazing production.

Economic contribution of federal grazing

The results for this exercise for cattle grazing on FS and BLM lands are reported in Table 6, whereas the results for sheep and goat grazing are reported in Table 7. In addition, it is the case that there is also limited grazing on national park lands; however, we do not consider National Park Service lands in this current analysis.

Though differences between the DRCs drive differences in economic contributions, the overwhelming driver of economic effect is the number of AUMs in any given state. For this reason, states that feature a large amount of FS or BLM land have the largest contributions. Regionally, this pertains to many states in the west, specifically the mountain west, such as Colorado, Arizona, and New Mexico. The southwest has the highest number of jobs supported by FS AUMs. Given the smaller population of New Mexico, this represents a larger percentage of New Mexico's workforce. Labor income is driven by the number of jobs supported, as well as the wages in that state.

In Tables 6 and 7, large employment and labor income DRCs typically correspond to lower DRCs for output. However, because most of the variation in economic effect is, in fact, driven by the AUM level instead of the DRCs themselves, the output for each state follows a similar pattern as those for employment and labor income. Typically, states with the largest AUM numbers (and correspondingly the largest amounts of public land) have the largest contribution. We excluded states that did not have any contribution, or an economic contribution < 0.05 jobs, $5 000 in labor income, or $5 000 in output.

Table 7 reports the economic contribution of sheep and goat grazing on FS and BLM lands at the state level. There are

substantially fewer states with enough sheep and goat AUMs to produce a usable result. We find that the overall contribution of jobs from sheep and goat grazing for the entire country is under one third of that of cattle. Even though sheep and goat grazing typically requires more workers per AUM compared with cattle grazing, resulting in higher employment DRCs, there are substantially fewer AUMs on FS and BLM lands for sheep and goat grazing when compared with cattle grazing. Like the case of cattle grazing, the largest contributions for sheep and goat grazing are in western states that have substantial amounts of public land. In the case of sheep and goat grazing, the state in which the FS supports the most sheep and goat grazing is Utah. Overall, we see a recurring pattern in which large western states with substantial amounts of public land feature the largest FS-driven economic contributions of grazing for both cattle and sheep/goat grazing.

We find that the magnitude of economic contributions varies drastically by state. Although driven primarily by the quantity of public grazing land, the DRCs also drive outputs in several cases. One goal of this analysis is to compare the economic contributions of federal land across states. For instance, the state with the largest labor income is North Dakota, while the state with the largest economic output is New Mexico. The output and labor income for sheep and goat grazing are both highest in Colorado.

Conclusion

We have used our DRCs to estimate the economic contributions of federal grazing, by government agency. A large portion of work done on federal grazing addresses the social impacts of federal grazing programs. Our work opens the door for further analysis of these impacts by producing a set of simple-to-use coefficients for converting reductions (or increases) in authorized AUMs into direct economic impacts. On top of contributing to the analysis of social impacts of grazing, these coefficients could also be used in policy or impact analysis (e.g., assessing the costs and benefits of reducing the prevalence of invasive species, such as knapweed, on pasturelands and the resulting economic impact of increased forage availability). In addition, climate change (e.g., shifts in long-term precipitation trends) is expected to impact many regions in the United States and around the world. As a result, there might be changes in the amount of grazing on an international scale. Although in some areas, climate change might increase available forage, it might also be restricted as other existing resources (e.g., water) become scarcer.

Several areas of future study are related to the economic impacts of federal grazing. First, a detailed analysis of the secondary effects could be produced. The economic impacts of federal grazing have ripple effects throughout the greater economy. Though applied practitioners can use software like IMPLAN to estimate DRC-like values, a detailed study of the secondary effects may also be helpful, given some of IMPLAN's limiting assumptions. The DRCs calculated in this paper can also be used in cost-benefit analyses related to the addition or removal of livestock grazing AUMs on federal land. In addition, there is considerable spatial variability in the economic impacts of federal grazing, and studying the cause of that spatial variation may be policy relevant. And finally, many ranchers and farmers use both private and public lands while grazing their herds. As a result, the estimates shown in this study are likely underestimates of the economic impact. A study that explores the relationship between public and private grazing, as well as any dependencies that may exist, would be able to help improve the accuracy of economic impact estimates in the future.

Previous work has highlighted the environmental impacts of grazing (e.g., Vincent 2019). Grazing on federal land comes with a mix of costs, such as declines in water quality (Delrose et al. 2020) and emissions (Wang et al., 2020), but may also have environmental benefits such as reductions in the risk of wildfire (Davies et al., 2016; Davies et al. 2022). The coefficients reported in this paper can help further evaluate the costs and benefits of federal grazing, as well as expand to other sectors of the economy.

Livestock ownership and ranch life bind communities and families. For most ranching families, raising livestock is more of a tradition than a job. Although many families may only rely on livestock production for a portion of their income, this tradition is deeply rooted in their personal history and a sense of responsibility toward land and livestock are often enmeshed in family values. Continuing this way of life maintains these values and connects people to traditional lands and heritage. Many ranching operations and families rely on public lands as a necessary source of forage for livestock grazing. Although forage provided by federal lands may account for only a small portion of the feed needed to support local herds, public land forage is used part of the year to offset more expensive hay and grain feed. This is also true internationally (e.g., Brazil), where many ranching operations involve interactions of private grazing and public land (Alston et al. 2011). Therefore, though the coefficients produced here are with respect to the United States, the methodology can be used in other countries to calculate the economic effects of public grazing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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