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Federal Grazing Reform and Avoidable Risk

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Recent rangeland reform attempts have increased ranchers' uncertainty of retaining grazing permits on federal land. This uncertainty is analyzed with a model of grazing on federal land. Ranchers facing this uncertainty will behave differently than if they were guaranteed the renewal of grazing permits at constant real grazing fees. It is shown that the socially optimal outcome may be achieved by adding avoidable risk through targeted rangeland reform. Rangeland reform attempts that create unavoidable risk can make both ranchers and environmental groups worse off.

Key words: avoidable risk, grazing, public lands

Introduction

When government-owned natural resources are used by private interests, there is often a divergence between the public and private interests. The Bureau of Land Management (BLM), the United States Forest Service (USFS), and the National Park Service (NPS) are responsible for managing the public lands with a multiple-use objective. Ranchers, environmental groups, and sports enthusiasts are all interested in controlling the public lands in the West. The growing western population has aggravated this conflict. According to Arruda and Watson, "The federal government faces a growing demand for uses of public lands (including grazing, minerals, recreation, water, and preservation) that outpaces supply" (p. 422). Ranchers and miners utilize but do not own the public lands. To ranchers, grazing is a productive use of a natural resource. Environmental groups, such as the National Wildlife Federation, are concerned about damage caused by grazing. They assert that the cattle can damage wildlife and their habitat by overgrazing indigenous plants, defecating in streams, and spreading disease. They also argue that suppression of fire and introduction of exotic plants on overgrazed land threaten habitats (National Wildlife Federation). Other groups claim that overgrazing has destroyed cultural and historical artifacts. Sports enthusiasts contend that overstocking prevents people from enjoying fishing, hunting, and hiking (Nelson).

Another controversial aspect of public grazing is the level of grazing fees. Congress sets uniform grazing fees on public lands across all locations. These fees are about one-fourth as high as grazing fees on private lands. The ranchers' perspective is that the low grazing fees are at least partially justified because the ranchers often maintain and improve the land (LaFrance and Watts). Lambert and Shonkwiler show that these

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nonfee utilization costs shift the cost of using the range upward. Critics argue that the low fees make it profitable to run cattle on marginal grazing land (Stein and Sahagun). In addition, the revenues from grazing fees fail to cover the operating costs of the grazing program.

There are two principal types of possible rangeland reform: reducing the number of permits and increasing the grazing fees. If rangeland reform occurs, there will be a redistribution of wealth. Ranchers who acquired grazing permits at a value that capitalizes the expected benefits from low grazing fees will suffer large financial losses if grazing fees are substantially increased or permits are expropriated. However, if the reform is targeted at the ranchers who are causing the most damage, then ranchers who are not targeted may actually see increases in their permit values. Increased tenure security for good stewards was one of the objectives of the Cooperative Management Agreement (CMA) program;[1] however, this program was struck down by a district court.[2]

Researchers have argued that the stocking rates and the sustained forage level desired by public-land ranchers are divergent from the rates and levels which maximize the multiple-use criteria. Huffaker, Wilen, and Gardner propose an offsetting fee system in order to align the public-land rancher's objective function with the multiple-use objective. Egan and Watts also note that ranchers' objectives are different from those of other would-be users of public lands. They model the conflict between ranchers and environmentalists in their demand for public land use. As in the model presented here, Egan and Watts' analysis considers the utility of environmental groups. In contrast to our emphasis on rangeland reform, their focus is on property rights. They model the market for public lands and assert that if grazing permits were transferable, they would go to the highest value use. Therefore, as demand for uses other than raising livestock increases, the number of permits used for grazing declines, but permit values do not fall.

To analyze the effect of risk caused by rangeland reform attempts, we present a model of grazing on federal land. The rancher creates an externality by reducing the available forage, which affects the utility of environmental groups. The possibility of losing grazing permit values from rangeland reform means that the rancher will behave differently than if he/she were certain of retaining the grazing permits at a constant real grazing fee. We wish to show that the use of avoidable risk can bring the public and private interests into alignment. Clarke and Reed solve a dynamic optimization problem that maximizes utility with an avoidable risk of irreversible environmental damage. We apply this avoidable risk approach to decision making under the uncertainty of rangeland reform and extend their results by showing that avoidable risk can be used to achieve the social optimum in a model with an externality. In a sense, the avoidable risk modifies the rancher's dynamic optimization problem so that it is incentive compatible with the socially optimal solution. This is similar to the idea of an incentive-compatible contract.[3]

A rancher faces avoidable risk of reform if his or her actions can affect the probability of reform occurring. Ex ante, avoidable risk of reform can cause the entities that create

[1] 43 C.F.R. sec. 4100 (1984).

[2] For a discussion of the CMA program, see Huffaker, Wilen, and Gardner.

[3] For a discussion of incentive-compatible contracts, see Grossman and Hart.

negative externalities, such as damage from overgrazing, to act in the public good. Our results demonstrate that targeted grazing reform attempts have two opposing effects on the incentives ranchers face. The first—the discounted future effect—causes ranchers to increase their stocking rates, while the second—the avoidable risk effect—causes ranchers to decrease their stocking rates. The avoidable risk associated with reform acts like a Pigouvian tax instrument, causing ranchers to internalize the externality costs of overgrazing. In the public debate over grazing reform, both policy makers and environmental groups have overlooked the avoidable risk effect. Consequently, the potential impacts of possible regulatory changes have been misunderstood. If policy makers and environmental groups were considering the avoidable risk effect of grazing reform, then there would be much more discussion about targeting reform based on damages.

Background

Collectively, the BLM, USFS, and NPS administer 270 million acres of public lands where grazing permits have been issued (Egan). Grazing on public lands was established by the Taylor Grazing Act (TGA) of 1934.[4] The TGA established a bureaucracy (now the BLM and USFS) for deciding who grazes livestock on public lands, how many livestock can graze, and the grazing fees. The TGA created grazing advisory boards, composed of local ranchers, that make most of the important decisions on public land grazing management. The Federal Land Policy and Management Act of 1976[5] gave the BLM permanent authority to manage lands for multiple uses and called for permanent retention of public lands by the federal government (Arruda and Watson).

Federal grazing permits allow the permit holder to graze a specified number of animal units on the property for a set time period. Grazing fees are usually denominated in animal unit months (AUMs), which is equivalent to the amount of forage required to provide for the grazing of a mature cow with a calf for one full month. BLM permits are renewed every 10 years. When the permit expires, the current holder has a preferred right of renewal. With this right of renewal, the current holder of a permit can control the grazing rights on federal lands for an indefinite period of time. The majority of permits are acquired with the purchase of property (Sunderman and Spahr). Although the government must approve transfer of grazing rights, these transfers are rarely refused.[6] Ranchers may choose not to exploit their leases to their fullest extent in an attempt to avoid a political conflict with environmental groups. As a result of Rangeland Reform '94, the BLM adopted a provision which allows ranchers to retain their permits while temporarily discontinuing grazing to enhance conservation objectives for up to the entire 10-year term ("BLM Grazing . . .").

Traditionally, ranchers controlled public lands, but alternative uses for public lands have grown in popularity and value over time. It has been noted that the BLM

[4] 48 Stat. 1269; 43 U.S.C. 315.

[5] 43 U.S.C. §§ 1701–1784 (1994).

[6] For federal grazing permits under the current system, transaction costs of permit transfers between ranchers and environmental groups may be infinite because environmental groups cannot bid on grazing permits and they cannot pay ranchers not to use their grazing permits. Accordingly, the Coasian argument that a Pareto-efficient level of environmental damage can be achieved given property rights and no transaction costs is not applicable.

historically has been a captured agency (Arruda and Watson) in the sense of Stigler, or partially captured as in Peltzman. Stigler argued that the self-interested political activity of the regulated is generally the source of regulation, and therefore the regulatory agency may consider the regulated parties to be its constituency and become "captured" by them. As a result, the regulatory agency often serves the regulated parties' interests. The BLM's history of grazing advisory boards, made up entirely of ranchers, is consistent with a captured-agency argument. If the BLM was captured or partially captured, then ranchers could have influenced the agency to set the AUM quotas higher than the socially optimal level. Alternatively, the increased demand for other uses of public land may have changed the socially optimal AUM quota. Gardner writes, "The primary commodity user groups, grazers and timber harvesters, have declined in importance whereas conservationists and recreationists have gained" (p. 12).

In recent years, there have been many attempts at rangeland reform. For example, in 1994, Secretary of the Interior Bruce Babbitt unsuccessfully attempted to reduce damage from overgrazing by revoking permits on arid lands and increasing the price of permits. Egan and Watts argue that potential losses to ranchers through proposed regulation creates uncertainty about the stability and longevity of income streams, which in turn lowers the value of grazing permits. The value of public land permits has declined. Watts and LaFrance suggest that a possible cause is the increased uncertainty of having desirable permits in the future. Winter and Whittaker found that the presence of public grazing permits did not affect ranch sales, concluding that the stream of expected higher returns was no longer being capitalized owing to increased uncertainty about the tenure of grazing privileges.

An economic argument is that the risk of reform will increase overgrazing because adding exogenous uncertainty (unavoidable risk) makes expected future profits lower, and hence the rancher will care less about the future and the long-term state of the resource. Increased uncertainty makes the rancher willing to trade short-term gains for long-term reductions. Therefore, with unavoidable risk, the rancher will choose a higher stocking rate.[7] However, that argument does not present the complete picture of the possible effects of rangeland reform efforts because it ignores avoidable risk. Revoking grazing rights on arid lands or increasing fees on arid lands creates an avoidable risk effect. The risk of expropriation or a significant fee increase may encourage overgrazing and thereby the aridation of marginal lands. An across-the-board price increase provides an unavoidable risk because it would be imposed on everyone regardless of the condition of the land.

The potential for reform exists if the stocking rate set by the BLM is greater than the rate that environmental groups desire. There is a large body of literature (including previously cited articles) documenting that environmental groups view stocking rates as too high. For example, the National Wildlife Federation and the National Resources Defense Council report that public grazing is hurting wildlife and soil and water quality. Also, since 1988, the U.S. General Accounting Office (GAO) has issued several reports claiming that public lands grazing is damaging riparian areas, deserts, and wildlife due to management that neglects wildlife values and emphasizes commodity production (see,

[7] That adding exogenous uncertainty is equivalent to an increase in the discount rate in a dynamic optimization problem is shown to hold in our model. This result was reported by Rausser and Freebairn and many others, including Heal in the case of an extractive resource.

e.g., U.S. GAO 1988, 1991). This potential conflict provides at least some incentive for a rancher to graze fewer animals than permitted.

Our model assumes that although ranchers face an upper bound imposed by their AUM quotas, they can choose their own stocking rates and modify those rates in response to changes in the incentives created by reform attempts. Empirical evidence supports the premise that ranchers choose the number of cows they graze on public lands (Johnson and Watts; Lambert and Shonkwiler; Bhattacharyya et al.). Johnson and Watts found that the demand for public grazing AUMs is downward sloping with a price elasticity of about -0.2. Similarly, Lambert and Shonkwiler reported -0.25. According to Johnson and Watts, if fees on BLM land increase so much that the grazing permits are negatively valued, then ranchers will either apply for nonuse or lower their stocking levels.[8] Ranchers may choose to understock their allotments in order to avoid a political conflict with environmental groups. In the recent past (before nonuse for conservation purposes was allowed), ranchers were unlikely to report this decision since it could lead to a permanent reduction in the permit level, which would lower the option value and hence the market value of their permits. Such behavior is consistent with the findings of Johnson and Watts, which are based on reported stocking rates obtained from government documents.

The Model

The rancher is presumed to have well-defined beliefs regarding reform timing. Accordingly, we consider the rancher's maximization problem that includes a probability density function which reflects beliefs relating to the timing of reform. The resulting exogenous uncertainty is equivalent to an increase in the discount rate in the dynamic optimization problem of maximizing the rancher's profits subject to the equation of motion for available forage (Rausser and Freebairn). As a result of the uncertainty, the rancher cares less about the future and chooses higher stocking rates. Consequently, the steady-state level of the available forage is lower than the corresponding risk-free state. In this context, the exogenous probability of reform can be represented as an *unavoidable* risk to the rancher.

The rancher faces an *avoidable* risk when his/her subjective probability density function for reform is a decreasing function of available forage. If the avoidable risk is sufficiently large, the rancher will choose lower stocking rates. Consequently, the steady-state available forage is higher than in the corresponding risk-free state. When an environmental externality exists, it is socially optimal for the rancher to reduce the stocking rate. We show that the steady-state available forage with avoidable risk can be equivalent to the socially optimal steady-state available forage in the risk-free state.

We develop a model of a rancher whose stocking rates create an externality that diminishes the available forage of federal lands in order to analyze the implications of the uncertainty associated with rangeland reform. For the purposes of this model, reform is defined as either the expropriation of grazing permits or a significant increase of grazing fees so that it could no longer be profitable to utilize the permits. For

[8] Although the number of permits is set, the rancher is only charged for actual stocking.

simplicity, we assume that reform will make the ranch worthless.[9] We also assume that the effects of the reform are irreversible. Available forage is defined as the number of animal units per month (AUMs) that can be supported by the forage. The available forage of the federal lands is viewed as a renewable resource in this context. The choice variable in the dynamic optimization problem is the time path of the rancher's stocking rate in AUMs, $R(t) \geq 0$. The profit function is defined by

$$\pi(R(t), c(t)) = \left[P_b W(c(t), R(t)) - P_p\right] R(t), \tag{1}$$

where P_b is the price of beef per pound (constant), P_p is the price of grazing permit per head of cattle, $c(t)$ is the quantity of forage available, and $W(c(t), R(t))$ is the average weight per head of cattle, with $W_c \geq 0$ and $W_R \leq 0$. Without loss of generality, all other marginal costs are assumed to be zero. We assume that $\partial\pi(R, c)/\partial c \geq 0$ in the relevant range, and that the profit function is jointly concave in $R(t)$ and $c(t)$. The sign of $\partial^2\pi(R, c)/\partial c \partial R$ is generally indeterminate. We assume that it is not both negative and large in absolute value. The function $R(t)$ reduces the available forage by the quantity $-z(R(t))$, where

$$-z(0) = 0, \quad -z(R) \leq 0, \quad -z'(R) \leq 0, \quad -z''(R) \leq 0. \tag{2}$$

The functional $z(R(t))$ is the quantity of forage harvested by grazing. The rate at which available forage recovers can be represented by the growth function $g(c(t))$, where

$$g(0) = 0, \quad g(c) \geq 0, \quad g''(c) \leq 0. \tag{3}$$

Although we allow for $g'(c) \leq 0$, we assume that $g'(c) \geq 0$ holds in the relevant range. The equation of motion for available forage is the sum of these two effects (grazing and forage growth), i.e.,

$$\dot{c} = -z(R(t)) + g(c(t)). \tag{4}$$

Stated in narrative form, the equation of motion is the change in available forage due to grazing and forage growth. We assume that there is a constant interest rate of r. Finally, in the rancher's problem, there is an upper bound on the stocking rate, R_U, imposed by the BLM's AUM quota.[10]

The Social Optimum Without Uncertainty

The social planner can achieve a social optimum by choosing a stocking rate, $R(t)$, to maximize a function which is a linear combination of the rancher's profits and an environmental group's (representative agent) utility. The environmental group's utility

[9] It would not be difficult to add a salvage value, which could include the value of selling off the ranch or the expected present value of profits after the reform has occurred.

[10] The effectiveness of BLM enforcement of the quota is debatable.

is a function of available forage,[11] with $u'(c(t)) \geq 0$, and $u''(c(t)) \leq 0$. In Egan and Watts' analysis of markets for public land, livestock-free public lands are an argument in environmentalists' utility functions. The social welfare function can be expressed as $\pi(R(t), c(t)) + \alpha u(c)$, with $\alpha \geq 0$. A specific case of this function is a Bergson social welfare function, where α is equal to one. In contrast, in the rancher's problem, the value of α is zero, which means that the rancher's objective function is the present value of expected profits. We assume that the social planner cares about the long-term future, so we use an infinite planning horizon. An infinite planning horizon also can be justified in the rancher's problem if the ranch and grazing permits can be bequeathed to the rancher's descendants. The social planner's control problem is specified as:

$$\text{(5)} \qquad \max_{R(t)} \int_0^\infty e^{-rt}\big(\pi(R(t), c(t)) + \alpha u(c(t))\big)\, dt$$

$$\text{s.t.:} \quad \dot{c} = -z(R(t)) + g(c(t)),$$

$$c(0) = c_0.$$

The associated present-value Hamiltonian is written as:

$$\text{(6)} \qquad H = e^{-rt}\big(\pi(R(t), c(t)) + \alpha u(c(t))\big) + \lambda\big(-z(R(t)) + g(c(t))\big).$$

The necessary conditions for optimization (assuming an interior solution) are as follows:

$$\text{(7)} \qquad e^{-rt}\pi_R(R(t), c(t)) - \lambda z_R(R(t)) = 0,$$

$$\text{(8)} \qquad \dot{\lambda} = -e^{-rt}\big(\pi_c(R(t), c(t)) + \alpha u_c(c(t))\big) - \lambda g_c(c(t)),$$

$$\text{(9)} \qquad \dot{c} = -z(R(t)) + g(c(t)),$$

and

$$\text{(10)} \qquad \lim_{t\to\infty} e^{-rt}\lambda(t)c(t) = 0.$$

Differentiating (7) and substituting into (8), we get two differential equations in $R(t)$ and $c(t)$ that, when set equal to zero, describe the steady state. Assuming an equilibrium $(\overline{R}, \bar{c})$ exists, it satisfies the following equations:

$$\text{(11)} \qquad z(\overline{R}) = g(\bar{c})$$

and

$$\text{(12)} \qquad (r - g_c(\bar{c}))\pi_R(\overline{R}, \bar{c}) - z_R(\overline{R})\big(\pi_c(\overline{R}, \bar{c}) + \alpha u_c(\bar{c})\big) = 0.$$

Our first result is that the steady-state available forage is higher in the social planner's problem than in the rancher's problem. In order to show that this is the case, we must consider how a change in the weighting assigned to the environmental group's utility affects the steady-state available forage. Recall that in the rancher's problem, the

[11] We are assuming that the environmental groups care about the state of the range.

value of α is zero. Therefore, the sign of the derivative $d\bar{c}/d\alpha$ is critical. By linearizing equations (10) and (11), which describe the steady state, we get a system of equations in the matrix form $\mathbf{A}dR = \mathbf{b}d\alpha$:

$$(13)\quad \begin{bmatrix} -z_R & g_c \\ \pi_{RR}(r-g_c) - z_R\pi_{cR} - (\pi_c + \alpha u_c)z_{RR} & -\pi_R g_{cc} + (r-g_c)\pi_{Rc} - z_R(\pi_{cc} + \alpha u_{cc}) \end{bmatrix} \begin{bmatrix} d\bar{R} \\ d\bar{c} \end{bmatrix} = \begin{bmatrix} 0 \\ z_R u_c \end{bmatrix} d\alpha.$$

Using Cramer's Rule, the derivative $d\bar{c}/d\alpha$ is calculated as:

$$(14)\quad \frac{d\bar{c}}{d\alpha} = \frac{-u_c z_R^2}{\det \mathbf{A}}.$$

Assuming u_c is sufficiently large, we can sign the determinant of $\mathbf{A}$ as negative. The numerator, $-u_c z_R^2$, is negative, so $d\bar{c}/d\alpha$ must be positive. Intuitively, this result says that when the value of the available forage to the environmental groups is considered, the optimal steady-state value of the available forage must increase. The reduction in the available forage caused by maximization of the rancher's private objective function imposes an externality on environmental groups because the rancher only considers how the change in the available forage affects profits. Similarly, the environmental group's objective imposes an externality on the rancher because the environmentalists do not consider the rancher's profits. If it is the case that the upper bound on the stocking rate (R_U) imposed by the BLM's AUM quota is so low that it is lower than the social optimum, then adding risk of further reductions would only make society worse off.

The Rancher's Problem with Risk of Reform

In this problem, we assume that the rancher can affect the probability that reform will occur over time through his/her choice of stocking rate. Accordingly, grazing reform is an avoidable risk to the rancher. The random variable τ is defined to be the time when the reform occurs, and $S(t)$ is defined as the probability that no reform occurs in the period $[0, t]$. $S(t)$ is a "survivor" function, which is specified to have the exponential distribution[12] parameterized by h. The complement of $S(t)$ is $F(t)$, which is then defined as the probability that reform occurs by time t. By definition, $F(t) = 1 - S(t)$. It is possible to show that adding exogenous uncertainty of reform is equivalent to increasing the discount rate by h (Clarke and Reed), where h is a conditional probability function that can be expressed in terms of $F(t)$ and $F'(t)$:

$$(15)\quad h = -\frac{\dot{S}}{S} = \frac{\dot{F}}{1-F} = \frac{\text{prob. of reform over next } dt}{\text{prob. of no reform by } t}.$$

[12] The exponential distribution is required for a steady state to exist.

Here h is a hazard function, which can be interpreted as the conditional probability of reform, given that the reform has not yet occurred. Reform is the "hazard" that the rancher wants to avoid.

The probability of reform is a function of the available forage. The effect of environmental groups or policy makers targeting ranchers whose stocking rates cause low forage levels is represented by the following rule:

$$h(t) = \Psi(c(t)), \tag{16}$$

where

$$\Psi(0) = 1, \quad \Psi(\infty) = 0, \quad \Psi(c(t)) \geq 0, \quad \Psi'(c(t)) \leq 0. \tag{17}$$

Defining y as $-\ln(S)$, $\Psi(c(t))$ can be expressed as $\Psi(c(t)) = \dot{y}$. Following Kamien and Schwartz, the variable y is a state variable in the control problem. Expected profits can be calculated as:

$$\int_0^\infty \left\{ \int_0^\tau e^{-rt} \pi(R(t), c(t))\, dt \right\} \frac{dF}{d\tau}\, d\tau. \tag{18}$$

Using $F(0) = 0$ and $F(\infty) = 1$ from the definition of an exponential distribution, and $1 - F(t) = S(t) = e^{-y(t)}$, the expected profit can be expressed as:

$$\int_0^\infty e^{-rt-y(t)} \pi(R(t), c(t))\, dt,$$

and the resulting control problem is:

$$\begin{aligned} &\max_{R(t)} \int_0^\infty e^{-rt-y(t)} \pi(R(t), c(t))\, dt, \\ &\text{s.t.: } \dot{c} = -z(R(t)) + g(c(t)), \quad c(0) = c_0, \\ &\qquad \dot{y} = \Psi(c(t)), \quad y(0) = 0, \\ &\qquad R(t) \leq R_U. \end{aligned} \tag{19}$$

The associated current-value Hamiltonian is:

$$\begin{aligned} H_{CV} = {} & e^{-y(t)} \pi(R(t), c(t)) + \mu_1(-z(R(t)) + g(c(t))) \\ & + \mu_2(\Psi(c(t))) + \mu_3(R_U - R(t)). \end{aligned} \tag{20}$$

The necessary conditions for optimization are:

$$e^{-y(t)} \pi_R(R(t), c(t)) - \mu_1 z_R(R(t)) = 0, \tag{21}$$

$$\mu_3 \geq 0, \quad R_U - R(t) \geq 0, \quad \mu_3(R_U - R(t)) = 0, \tag{22}$$

$$\dot{\mu}_1 = r\mu_1 - e^{-y(t)} \pi_c(R(t), c(t)) - \mu_1 g_c(c(t)) - \mu_2 \Psi_c(c(t)), \tag{23}$$

$$\dot{\mu}_2 = r\mu_2 + e^{-y(t)} \pi(R(t), c(t)), \tag{24}$$

(25) $$\dot{c} = -z(R(t)) + g(c(t)),$$

(26) $$\dot{y} = \Psi(c(t)),$$

and

(27) $$\lim_{t\to\infty} e^{-rt}\mu_1(t)c(t) = \lim_{t\to\infty} e^{-rt}\mu_2(t)y(t) = 0.$$

If we define $\rho_2 = e^y\mu_2$, we can write the necessary conditions for an interior solution as three ordinary differential equations (ODEs) in R, c, and ρ_2. Setting these three ODEs equal to zero gives us the steady-state values. If an interior solution equilibrium $(\overline{R}, \bar{c}, \bar{\rho}_2)$ exists, the steady-state values are given by:

(28) $$z(\overline{R}) = g(\bar{c}),$$

(29) $$\left[r + \Psi(\bar{c}) - g_c(\bar{c})\right]\pi_R(\overline{R}, \bar{c}) - z_R(\overline{R})\pi_c(\overline{R}, \bar{c}) + \frac{z_R(\overline{R})\Psi_c(\bar{c})\pi(\overline{R}, \bar{c})}{r + \Psi(\bar{c})} = 0,$$

and

(30) $$\bar{\rho}_2 = \frac{-\pi(\overline{R}, \bar{c})}{r + \Psi(\bar{c})}.$$

Equation (28) is the requirement that in a steady state the reduction in forage due to grazing equals the growth in forage. Equation (29) is the marginal condition. Equation (30) requires that the probability of reform is constant in a steady state. The steady-state level of the available forage, $\bar{c}$, is given by the solution to

(31) $$\left[r + \Psi(\bar{c}) - g_c(\bar{c})\right]\pi_R\left(z^{-1}(g(\bar{c})), \bar{c}\right) - z_R\left(z^{-1}(g(\bar{c}))\right)\pi_c\left(z^{-1}(g(\bar{c})), \bar{c}\right) = \frac{-z_R\left(z^{-1}(g(\bar{c}))\right)\Psi_c(\bar{c})\pi\left(z^{-1}(g(\bar{c})), \bar{c}\right)}{r + \Psi(\bar{c})},$$

while the steady-state level of the stocking rate, $\overline{R}$, is given by

(32) $$\overline{R} = z^{-1}(g(\bar{c})).$$

Equation (31) is derived from (28) and (29). Equation (32) is obtained from (28) and uses the result that an inverse function for $z(R(t))$ exists because of the assumption that the function $z(R(t))$ is monotonic in $R(t)$.

Our second result is that in comparison with the corresponding risk-free state, the interior solution steady-state available forage: (*a*) will be lower if the probability of reform does not depend on the available forage, and (*b*) will be higher if the probability of reform decreases with an increase in the available forage, and the marginal probability of reform at the steady state, $\Psi_c(\bar{c})$, is sufficiently large in absolute value at the steady state.

To show that this result holds, we examine the steady-state equilibrium equations that determine available forage for both the avoidable risk and no-risk cases. The

steady-state value of the available forage, c_1, in the avoidable risk case satisfies (31), and the steady-state value of the available forage, c_0, in the no-risk case satisfies

$$(33) \qquad (r - g_c(\bar{c}))\pi_R(z^{-1}(g(\bar{c})), \bar{c}) - z_r(z^{-1}(g(\bar{c})))\pi_c(z^{-1}(g(\bar{c})), \bar{c}) = 0.$$

Given our assumptions, the left-hand side of (33) is increasing in c. It follows that c_1 will be less than c_0 if

$$(34) \qquad -\frac{\pi_R(z^{-1}(g(\bar{c}_1)), \bar{c}_1)}{z_R(z^{-1}(g(\bar{c}_1)))\pi(z^{-1}(g(\bar{c}_1)), \bar{c}_1)} < \frac{\Psi_c(\bar{c}_1)}{\Psi(\bar{c}_1)(r + \Psi(\bar{c}_1))},$$

and c_1 will be greater than c_0 if

$$(35) \qquad -\frac{\pi_R(z^{-1}(g(\bar{c}_1)), \bar{c}_1)}{z_R(z^{-1}(g(\bar{c}_1)))\pi(z^{-1}(g(\bar{c}_1)), \bar{c}_1)} > \frac{\Psi_c(\bar{c}_1)}{\Psi(\bar{c}_1)(r + \Psi(\bar{c}_1))}.$$

In the static profit-maximization problem, the rancher would choose R so that $\pi_R = 0$. However, in the dynamic problem when the change in the available forage $\{\dot{c} = -z(R(t)) + g(c(t))\}$ is recognized, the rancher will choose a time path of $R(t)$ so that $\pi_R \geq 0$. Consequently, the left-hand sides of both equations (34) and (35) are always nonpositive. Equation (34) will hold when the probability of reform does not depend on the available forage. In this instance, the marginal probability of reform, $\Psi_c(\bar{c})$, is equal to zero. Equation (35) will hold if this marginal probability of reform is negative and sufficiently large in absolute value.

Intuitively, with the inclusion of a hazard function, the rancher cares less about maintaining the forage for future use because grazing permits eventually may be lost. The potential loss of grazing permits effectively increases the discounted future effect and encourages the rancher to increase stocking rates. This is the only effect in the unavoidable risk case. The increased stocking rates lower the available forage by equation (4). As a result, in the case of unavoidable risk of reform, the steady-state available forage will be lower than in the risk-free state. Therefore, in the steady state, both the available forage and the rancher's stocking rate will be lower than in the corresponding risk-free state. Hence, with an unavoidable risk of reform under a steady state in which reform has not yet occurred, both the rancher and the environmental groups are worse off than in the risk-free state.

This result highlights the discounted future effect and the avoidable risk effect that are present when avoidable risk is added to the problem. The avoidable risk effect provides an incentive for the rancher to lower his/her stocking rate in order to reduce the probability of grazing permit losses. The avoidable risk effect can offset the discounted future effect that creates an incentive for the rancher to increase the stocking rate. The second result is valid if the avoidable risk effect is sufficiently large to offset the discounted future effect. If the marginal decrease in the probability of reform is small, then reducing the stocking rate will give the rancher little benefit in terms of reducing the probability of reform. On the other hand, if the marginal decrease in the probability of reform is large, then the rancher will benefit a great deal from a reduction in stocking rate.

If the solution is a boundary solution rather than an interior solution, the rancher sets the stocking rate at $R(t) = R_U$. The effect of this choice on the available forage compared with the risk-free state depends on the magnitude of the quota relative to the rancher's profit-maximizing rate in the risk-free state, and may also depend on both the discounted future effect and the avoidable risk effect. If the quota is higher than the rancher's profit-maximizing rate in the risk-free state, then part (*a*) of the second result holds, but the rancher is limited by the amount the stocking rate can be increased in response to the incentives created by the discounted future effect.

In the second case, when the quota is lower than the rancher's profit-maximizing rate in the risk-free state, then in either the risk-free state or the risky state where the rancher is at the boundary solution, the stocking rate will equal the quota level. One must keep in mind, however, that in many areas the monitoring by the agency charged with oversight is insufficient to ensure that ranchers are not stocking above the permitted quota. Therefore, it may be profitable for a rancher to choose stocking rates which violate the quota.[13] This is a controversial topic because ranchers may feel morally bound to respect the quota.

Our third result is that if the marginal probability of reform at the interior solution steady state, $\Psi_c(\bar{c})$, is sufficiently large in absolute value at the steady state, then the steady-state available forage can be equivalent to the socially optimal steady-state available forage in the risk-free state. To show that this result is true, we assume that the effect of environmental groups or policy makers targeting ranchers with low available forage for reform is embedded in the rule $h(t) = \theta\Psi(c(t))$, where $\theta \geq 0$. Then when θ equals zero, we have the corresponding risk-free state. Including θ in the control problem gives us the steady-state values in $(\bar{R}, \bar{c})$ determined by:

$$z(\bar{R}) = g(\bar{c}), \tag{36}$$

$$\left[r + \theta\Psi(\bar{c}) - g_c(\bar{c})\right]\pi_R(\bar{R}, \bar{c}) - z_R(\bar{R})\pi_c(\bar{R}, \bar{c}) + \frac{z_R(\bar{R})\theta\Psi_c(\bar{c})\pi(\bar{R}, \bar{c})}{r + \theta\Psi(\bar{c})} = 0. \tag{37}$$

Recall the equations describing the steady state for the social planner's problem:

$$z(\bar{R}) = g(\bar{c}), \tag{38}$$

$$\left(r - g_c(\bar{c})\right)\pi_R(\bar{R}, \bar{c}) - z_R(\bar{R})\left(\pi_c(\bar{R}, \bar{c}) + \alpha u_c(\bar{c})\right) = 0. \tag{39}$$

Equations (36) and (38) are identical, while (37) and (39) have many terms in common. Rearranging (37) and (39) so that their left-hand sides are identical yields:

$$\left[r - g_c(\bar{c})\right]\pi_R(\bar{R}, \bar{c}) - z_R(\bar{R})\pi_c(\bar{R}, \bar{c}) = z_R(\bar{R})\alpha u_c(\bar{c}), \tag{40}$$

[13] One could remove the quota constraint and add the probability of detection (given a violation of the quota) to this problem.

$$(41)\qquad \left[r - g_c(\bar{c})\right]\pi_R(\overline{R}, \bar{c}) - z_R(\overline{R})\pi_c(\overline{R}, \bar{c}) = -\theta\Psi(\bar{c})\pi_R(\overline{R}, \bar{c}) - \frac{z_R(\overline{R})\theta\Psi_c(\bar{c})\pi(\overline{R}, \bar{c})}{r + \theta\Psi(\bar{c})}.$$

Therefore, to demonstrate that the steady-state forage can be equal to the socially optimal level, we need to show that for any positive, finite α, there exists a θ such that

$$(42)\qquad z_R(\overline{R})\alpha u_c(\bar{c}) = -\theta\Psi(\bar{c})\pi_R(\overline{R}, \bar{c}) - \frac{z_R(\overline{R})\theta\Psi_c(\bar{c})\pi(\overline{R}, \bar{c})}{r + \theta\Psi(\bar{c})}.$$

Solving for α in terms of θ and the steady-state values gives

$$(43)\qquad \theta = \frac{-\left[(z_R\alpha u_c + \pi_R r)\Psi + z_R\Psi_c\pi\right] + \left[\left((z_R\alpha u_c + \pi_R r)\Psi + z_R\Psi_c\pi\right)^2 - 4\Psi^2\pi_R z_R\alpha u_c r\right]^{1/2}}{2\Psi^2\pi_R},$$

which is a positive, real number if Ψ_c is sufficiently large in absolute value. Therefore, for any positive weighting between ranchers' profits and environmental groups' utility, a policy maker can determine an appropriate amount of avoidable risk to obtain a socially optimal solution.

Given a model with externalities, the possibility of reform without avoidable risk can be in the public's interest only if the reform is successful—that is, the reform limits the activity. However, it will not be the first-best outcome. If activists are successful and reform occurs, there will be increased stocking rates up until the time when the reform is enacted. The first-best outcome limits stocking rates so that the social marginal benefit of the activity equals the social marginal cost. An outright ban of grazing generally will not be the first-best outcome. While this model focuses on rangeland reform, it could be applied to many possible reform situations in which the firm can influence whether a reform will occur.

Conclusion

We have shown that attempts at rangeland reform can have two opposing effects on ranchers' incentives: (*a*) the discounted future effect, which causes ranchers to increase their stocking rates, and (*b*) the avoidable risk effect, which causes ranchers to decrease their stocking rates. Policy makers and environmental groups have ignored the avoidable risk effect. The bulk of rangeland reform attempts have promoted across-the-board fee increases, which is an unavoidable risk. This increase in unavoidable risk could explain the drop in the value of grazing permits on public lands in recent years.

To analyze the impact of the risk of reform, we presented a model of grazing on public lands in which a rancher's choice of stocking rate creates an externality. We showed if the probability of reform has an inverse relationship with the available forage, and the marginal probability of reform at the steady state is sufficiently large, then in the steady state the available forage is higher relative to the risk-free state. Also, if the marginal probability of reform is sufficiently large in absolute value, policy makers can determine

an appropriate amount of avoidable risk for ranchers to obtain the first-best solution. The BLM quotas serve as an upper bound on the stocking rate that ranchers can choose.

More generally, environmental activism can bring public and private interests into alignment. For this to happen, environmental activism must link the quality of resource in question to possible consequences such as reform efforts, litigation, or negative publicity; in other words, the activism must create avoidable risk. In the case of grazing on public lands, if activists call for across-the-board increases in grazing fees, there is some probability that the increases will happen. However, if reform does not occur and stocking rates increase, then forage damage will be magnified. One caveat is that targeting specific environmental requirements to individual land parcels will be expensive and could be perceived as arbitrary if they depend on the values of local government officials. In practice, this cost must be weighed against the potential benefits.

If policy makers and environmental groups can more directly target ranchers based on the condition of the land, they benefit in two ways: there is still a probability that reform will occur, and they cause ranchers to reduce their stocking rates (as opposed to increasing their stocking rates, as is the case with across-the-board reform). If rangeland reform is to be debated, it should be targeted based on some measure of damage. Only then can public and private interests be aligned.

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