Grazing Fees *versus* Stewardship on Federal Lands

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1. Introduction

Livestock grazing on Federal land has been hotly contested for more than a century. Livestock currently grazes on over 260 million acres of Federal land, 167 million acres administered by the Bureau of Land Management (BLM) and 95 million acres administered by the Forest Service (USFS) land (USDI, 2003; USDA, 2003) – a total land area larger than the Eastern seaboard plus Vermont, Pennsylvania and West Virginia. Nearly 28,000 livestock producers hold permits to graze their animals on Federal lands, roughly 3% of all livestock producers in the United States but about 22% of the livestock producers in the 11 Westernmost contiguous States (USDI-BLM, USDA-USFS, 1995). The forage grazed on Federal land accounts for approximately 2% of all feed consumed by beef cattle in the 48 contiguous States (USDI-BLM, 1992).

A major focus of the debate over livestock grazing on public lands centers around a belief that public lands ranchers are being subsidized at the expense of taxpayers, relative to the fees charged for private grazing leases in surrounding areas. Figure 1 illustrates the extent of the differences among public and private grazing fees over the period 1992-2002, in constant 2002 dollars.

A second focus of the policy debate is a belief that higher public grazing fees are linked with improvements in the environmental quality of public grazing lands. Three primary interest groups – livestock producers, recreationists and environmentalists – are at the center of the longstanding controversy over grazing on Federal lands. The primary interest of public lands ranchers is making a profit. They prefer grazing fees that are as low as possible, exclusive rights to use the public range, and minimal interference by the public agency charged with overseeing the land. They argue that Federal grazing leases and fees are not comparable to private grazing leases and lease rates. Recreationists find domestic livestock grazing competitive with recreation and, though they typically pay little in user fees on public lands, tend to argue that Federal grazing fees are too low and that it is unfair for ranchers to be subsidized for grazing the public range. Environmentalists find domestic livestock grazing to be inconsistent with environmental protection and argue that low grazing fees contribute to deteriorated range conditions and are insufficient to cover the costs of range management and environmental enhancement programs. The view that Federal grazing fees ought to be increased in order to improve the quality of the environment on public rangelands was articulated most clearly by former President Clinton's Council of Economic Advisors.

> "The controversy over rangeland reform shows the importance of integrating pricing with regulation to use the Nation's resources more efficiently and strike a better balance between economic and environmental objectives.
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> A central point of contention involves the fees that the Federal Government charges ranchers to graze animals on Federal land. These fees should reflect both the value of the forage used by an additional animal and the external environmental costs of grazing an additional animal ... Charging ranchers the marginal value of forage ... encourages efficient use of the range. By preventing overgrazing, it protects the condition of the range for future uses. It also promotes long-run efficiency in the industry ...
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> Promoting efficiency thus means both increasing grazing fees and ensuring that Federal grazing fees change from year to year in accordance with changes in rent on private grazing land."
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> *Economic Report of the President*, 1994: 182-83.

But this standard Pigouvian argument misses the target. For one thing, the BLM and USFS deal with a very large number of permits and an extremely large land area. A typical BLM ranger is responsible for nearly 400,000 acres of rangeland and many are responsible for policing over a million acres. With limited manpower and budgets, the cost to these agencies of constant and perpetual monitoring and enforcing each grazing allotment is prohibitively high. This contrasts sharply with the typical private grazing landowner, who generally tends to lease grazing privileges to a small number of tenants, usually at most one or two individuals, on a small number of parcels. Moreover, private landowners appropriate the benefits associated with effective monitoring and enforcement of their grazing leases, while the BLS and USFS do not. Therefore, both the incentive and the ability do monitor and enforce lease arrangements are much greater in the private sector than the public sector.

A second difficulty with the Pigouvian tax argument is that public grazing permits have a substantial take or pay component. A longstanding characteristic of grazing regulations on Federal lands is that on each grazing allotment, the BLM and the USFS set the allowable number of animals (the stocking rate) and the allowable period for grazing each year (the grazing season). The total annual payment to the agency by a rancher holding a grazing permit equals the grazing fee times the stocking rate times the number of months in the grazing season. Thus, federal grazing fee payments are substantially fixed costs. *Ceteris paribus*, changes in grazing fees increase the cost of compliance for ranchers with no countervailing incentive to encourage compliance with the terms of grazing leases.[1]

Third, public grazing land and the associated quality of the environment is a renewable resource. As a result, the interplay between the administrative agencies and public lands ranchers can be understood best as a dynamic game. In this dynamic resource use game there is a natural conflict of interest between the government and public lands ranchers due to the fact that public lands ranchers have no means to capture the economic benefits that flow to non-grazing users

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[1]Public lands ranchers can apply for non-use status on a periodic basis and gain some relief from grazing fee payments. However, non-use for more than two years can result in a permanent reduction in the allowable stocking rate. Johnson and Watts (1989) estimated the long-run elasticity of non-use due to an increase in the Federal grazing fee on BLM land to be less than 0.2. A 1992 GAO review of the BLM's monitoring practices indicated that nearly 45% of all public rangeland reclaimed by that agency was land ranchers failed to graze.

and arise from the environmental quality of the public land.

To further our understanding of the ways that these complications impact public resource management problems, we develop an economic theory of the dynamic games between public lands ranchers and the Federal government. The economic model centers on a mechanism design problem in which the government and public lands ranchers are economically rational. In the initial stage of the game, the government chooses a set of administrative rules (e.g., stocking rates, grazing seasons, and an intertemporal use pattern for public lands forage resources), grazing fee rates, penalty functions for failure to comply with the rules and regulations on the grazing leases, and a randomization strategy for monitoring and enforcing Federal grazing leases. These are publicly announced, known to all parties, and the government commits to the strategy throughout the foreseeable future. In subsequent stages, public lands ranchers pursue individual livestock grazing strategies that are economically rational and the administering agencies pursue monitoring and enforcement strategies consistent with their previous announcements. We focus on risk neutral agents, rational expectations, and an equilibrium to the dynamic game that is subgame perfect in every subperiod of the planning horizon for both sides.

Our first finding is that, *ceteris paribus*, an increase in grazing fees does not lead to a decrease in the number of livestock grazing on public lands. The economic intuition for this is clear. Because grazing fee payments are essentially fixed costs, keeping fees low allows ranchers to capture more of the rent from grazing on public lands and therefore increases the incentives to comply with mandated stocking rates. If the penalty function for overstocking an allotment includes permanent revocation of the grazing permit (a property of current and historical Federal grazing regulations), ranchers are less likely to risk being detected out of compliance with more valuable permits. Thus, we find that optimal public grazing contracts include grazing fees that are lower than competitive rental rates charged in the private market for grazing privileges.

A second characteristic of the optimal public lands grazing mechanism is the existence of random monitoring across space and time. A stationary Poisson process for the monitoring rule on each allotment, with monitoring on a given allotment statistically independent of monitoring on every other allotment both spatially and temporally, is one feasible way to support an optimal monitoring rule. The explanation for this property consists of two parts. First, randomness (and stochastic independence across allotments and grazing seasons) prevents learning by the ranchers about the frequency and location of agency monitoring activities. This avoids wasteful efforts to disguise grazing practices by non-compliant ranchers. Second, a stationary Poisson process for monitoring each allotment generates a stationary exponential waiting time for the next period in which each rancher will be monitored, given the entire history of previous monitoring dates. The public lands rancher is faced with an intertemporally autonomous decision about compliance with the terms of the federal grazing lease. The rancher's optimal decision regarding whether to comply or cheat on the terms of the grazing lease is the same at all points in his planning horizon. This implies that the compliance choice made in the first instant in the rancher's planning horizon is a subgame perfect Nash equilibrium strategy for the rancher throughout all subsequent periods. The advantage for the agency is that this permanently separates compliant and non-compliant ranchers on all grazing allotments, allowing the agency to discover each rancher's historical use strategy at each monitoring date.

Third, we find that the optimal incentive structure includes penalties beyond simply permanently terminating the grazing lease (another property of historical and present Federal grazing policy). Once again, the economic intuition is straightforward. Due to the environmental costs associated with overstocking the range, failure to comply with the terms of grazing permits is undesirable. Incentive compatibility for ranchers therefore requires penalties large enough to cause the present value of a compliant strategy to exceed the expected wealth of a non-compliant strategy regardless of the rancher's unobservable and idiosyncratic characteristics. The optimal penalty on each allotment is such that the rancher who would profit the most by cheating on a Federal grazing contract must earn non-positive expected net returns by choosing to do so.

The plan of the paper is as follows. In the next section we develop our model of public lands ranching and establish the natural conflict of interest between public lands ranchers and the administering agency. The third section develops the regulatory environment and analyzes the relationship between grazing fees, monitoring and enforcement activities, and the compliance versus noncompliance decisions of public lands ranchers. In the fourth section, we derive the optimal (in a second best world) mechanism for public lands grazing leases and identify several of its key qualitative properties. The fifth section summarizes draws conclusions from the analysis of the earlier sections of the paper. An appendix contains proofs, derivations and other mathematical details that underpin the arguments contained in the main paper.

2. The Dynamic Model

In this section, we develop a dynamic economic model of the signals, incentives, and conflicts between a regulatory agency and public lands ranchers. We begin with our notation, definitions, and the basic model components. Let $x(t)$ denote the stock of the forage resource – the total quantity of available forage in the allotment at time t, and let $s(t)$ denote the stocking rate – the rate of grass utilization for grazing as determined by the number of animal unit months in time t. Let A denote the set of grazing allotments managed by the public agency and I denote the set of individual rancher types. The element $i \in I$ represents the characteristics of a particular rancher such as experience and resources. For each $(a,i) \in A \times I$, let the net returns per period over variable inputs from grazing be $v(s(t), x(t), a, i)$, let the flow of net benefits to non-grazing uses of a public land area associated with allotment a be $b(s(t), x(t), a)$. We assume $v(\cdot, a, i)$ is increasing in (x, s), $b(\cdot, a)$ is increasing in x and decreasing in s, and both $v(\cdot, a, i)$ and $b(\cdot, a)$ are twice continuously differentiable and jointly concave in (x, s). Net returns to grazing depend on both the characteristics of the allotment and the rancher. Non-grazing benefits depend on the characteristics of the allotment but not directly on those of the rancher. The agency is assumed to be unable to choose or effect the rancher's characteristics on any grazing allotment.

The equation of motion for the forage resource is

$$\dot{x}(t) = f(x(t), a) - s(t), \;\; x(0) = x_0(a) \;\; \mathit{fixed}, \tag{2.1}$$

where $f(x, a)$ is twice continuously differentiable in x, with $f(0, a) = 0$, $\partial f(0, a)/\partial x > 0$, and $\partial^2 f(x, a)/\partial x^2 < 0 \;\; \forall \;\; x \geq 0$. Among other things, these conditions imply that there is a unique maximum sustainable level of forage, $x^{msy}(a) > 0$, which satisfies $\partial f(x^{msy}(a), a)/\partial x = 0$ for each $a \in A$.

An individual rancher identified by $i \in I$ is assumed to maximize the discounted present value of expected profits from grazing on allotment $a \in A$,

$$\max_{\{x(t), s(t)\}} \int_0^\infty e^{-rt} v(s(t), x(t), a, i) dt \tag{2.2}$$

subject to (2.1), where $r > 0$ is the real discount rate.

For the dynamic optimization problems considered in this paper, mathematical details are located in the Appendix. Here we characterize the optimal solution paths in relation to the economic questions of interest to this paper. For a public lands rancher's unfettered wealth maximizing private solution, the optimal path is characterized by the equation (2.1) for the time rate of change of the forage stock, and a differential equation describing the time rate of change for the stocking rate,

$$\dot{s} = \frac{(r - f_x(x,a))v_s(x,s,a,i) - v_x(x,s,a,i) - v_{sx}(x,s,a,i)(f(x) - s)}{v_{ss}(x,s,a,i)}, \tag{2.3}$$

where subscripts denote partial derivatives. The privately optimal long-run steady state, where $\dot{s} = \dot{x} = 0$, is characterized by $s^0(a,i) = f(x^0(a,i),\ a)$ and the reduced form *equilibrium value of the marginal product* condition for the grazing resource,

$$F(x^0(a,i),a,i) = v_x(f(x^0(a,i),a),x^0(a,i),a,i) +$$

$$v_s(f(x^0(a,i),a),x^0(a,i),a,i) \cdot \{f_x(x^0(a,i),a) - r\} = 0. \tag{2.4}$$

We assume that $\partial F(x,a,i)/\partial x < 0\ \forall\ x \geq 0$, which can be shown to be a sufficient condition for the rancher's private dynamic optimization problem to have a unique, globally stable saddle point equilibrium.

Consider next the socially optimal decision rule, assuming the management agency maximizes total discounted net economic benefits over an infinite planning horizon, subject to the forage growth equation (2.1). Taking $i \in I$ as given (e.g., by random selection) on each allotment, the first best socially optimal path is the solution to

$$\max_{\{s(t),x(t)\}} \int_0^\infty e^{-rt}\left[v(s(t),x(t),a,i) + b(s(t),x(t),a)\right]dt, \tag{2.5}$$

subject to (2.1), $\forall\ a \in A$. This optimal path is characterized by the equation (2.1) for the time rate of change of the forage stock, and a new differential equation describing the time rate of change for the stocking rate,

$$\dot{s} = \frac{(r - f_x)(v_s + b_s) - (v_x + b_x) - (v_{sx} + b_{sx})(f - s)}{v_{ss}}, \tag{2.6}$$

where the arguments of the right-hand-side functions have been suppressed for notational brevity. The long-run steady state is characterized by $s^1(a,i) = f(x^1(a,i),a)$ and the reduced form equilibrium social value of the marginal product condition for the grazing resource,

$$G(x^1,a,i) = v_x(f(x^1,a),x^1,a,i) + b_x(f(x^1,a),x^1,a) +$$

$$\left[v_s(f(x^1,a),x^1,a,i) + b_s(f(x^1,a),x^1,a)\right]\cdot\left[f_x(x^1,a) - r\right] = 0\,. \tag{2.7}$$

Here we assume that $\partial G(x,a,i)/\partial x < 0 \;\; \forall \; x \geq 0$, which is a sufficient condition for the first best resource management problem to have a unique, globally stable saddle point equilibrium.[2]

It is straightforward to show that $\forall\,(a,i) \in A \times I,\; x^1 > x^0$, which establishes the underlying conflict of interest between the public agency and private incentives of public lands ranchers. It follows that privately optimal stocking rates are initially higher and the long-run equilibrium forage stock levels are lower than the socially optimal levels. These results are illustrated in Figure 2.[3] The economic intuition for these differences can best be described as follows. Because the number of animals grazing on the public range has a negative marginal value to non-commodity users, the (instantaneous) value of the marginal product of *s* is everywhere lower for society than for the rancher. Similarly, because the stock of forage resources has a positive marginal value to non-commodity users, society's value of the marginal product for *x* is everywhere higher than for the rancher. Both effects work together, producing incentives for the rancher to wish to graze more intensively and harvest more of the forage resource than is socially optimal. That is to say, without additional incentives or other contractual or regulatory arrangements to internalize the benefits to non-commodity users into the rancher's grazing decisions, a perpetual difference exists between the stocking rates desired by a

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[2] The first order conditions for private and social optima are sufficient, given concavity of $v(\cdot,a,i)$, $b(\cdot,a)$, and $f(\cdot,a)$.

[3] This figure is constructed for the simple case, where $v(x,s,a,i) = \alpha(a,i)s - \frac{1}{2}\beta(a,i)s^2$, $b(x,s,a) = \gamma(a)x - \delta(a)s$, and $f(x,a) = \kappa(a)x[\overline{x}(a) - x]$, where $\alpha(\cdot)$, $\beta(\cdot)$, $\gamma(\cdot)$, $\delta(\cdot)$, $\kappa(\cdot)$ and $\overline{x}(\cdot)$ are all strictly positive real-valued functions, and the last one represents the natural (i.e., unexploited) long-run equilibrium for the forage stock.

management agency and those desired by a profit maximizing rancher. This conflict forms the basis for the mechanism design analysis that we undertake in the following sections.

3. Optimal Public Grazing Leases

Given the above conflict of interest between the agency's social goals and the privately optimal grazing strategies of public lands ranchers, we turn to the dynamic interaction between the agency and public lands ranchers in a regulatory environment. We focus on the ranchers' use of the range for livestock grazing in the presence of monitoring and enforcement efforts by the agency. If the agency fails to either monitor or enforce the terms of a federal grazing lease, there will be no risk of any penalty for pursuing the unfettered privately optimal grazing plan for the rancher. In this scenario, the differences in the objectives of the rancher and the agency clearly will be resolved in favor of the rancher.

However, monitoring and enforcement by the agency are costly activities. Even with substantial resources committed to these activities, we can see no possible way for the agency to learn or for the rancher to be somehow induced to reveal information regarding the rancher's type. Thus, in this setting, we do not attempt to design a contractual mechanism that permits the revelation principle to be applied in any form. In other words, we do not attempt to restrict the underlying nature of the grazing contract design problem so that the agency is able to present all ranchers with a generic grazing lease that induces each rancher, regardless of type, to reveal his private characteristics through his actions. Rather, we focus on grazing lease mechanisms that induce ranchers of any type to voluntarily comply with their terms.

As in the previous section, we begin with some essential definitions and notation. Let c_m be the agency's marginal cost per permit of inspecting the range, let N be the total number of leases under the agency's management, and let B_m denote the exogenously determined agency budget available for monitoring activities.[4] Then the largest number of grazing permits that can be monitored in any given period is $M = B_m / c_m \ll N$. In other words, a limited budget precludes constant and prescient monitoring on all allotments in all periods. To focus ideas, we assume that a public lands rancher's personal (and private) traits or characteristics that effect his net returns from grazing can be represented by a scalar index, $i \in I$. Assume further that the distribution of rancher types, defined by the probability distribution function $\Psi : I \to [0,1]$, is known to the agency and is time invariant. Each rancher with a grazing lease is considered by the agency to be a random draw from this distribution. We presume that the agency is unable to select *i* from among the menu of available public lands ranchers for any allotment. We also presume that the agency is unable to learn *i* regardless of the amount of resources committed to obtaining this information. Otherwise the agency would have complete information and so would be able to construct a grazing lease contract specific to the allotment and rancher that would attain the first best (given the rancher's type).

We assume that the rancher knows his type and its impact on his net returns. We assume further that both the agency and the rancher have complete knowledge of the grazing allotment and its influence on the grazing and non-grazing benefit flows. Finally, we do not assume any sort of systematic relationship (e.g., monotonicity and/or convexity) between the ranchers' type and his net returns to grazing, precluding an application of the revelation principle to this class of public resource management problems.

Although the agency cannot observe rancher types, we assume that society is risk neutral

[4] For all practical purposes, this portion of the budget is independent of grazing fees collected. As much as 50% of fees collected go to state legislatures to be distributed as "Payment in Lieu of Taxes" to the counties with public ranges. An additional 25-50% of fees collected are earmarked for range improvements. In every case, less than 25% of fees collected return to the federal treasury. By all accounts, including those of the General Accounting Office (1991) and the BLM itself, the costs of monitoring the range greatly outweigh collections.

with respect to the distribution of public lands rancher characteristics. The agency therefore is presumed to maximize the expected value of discounted net benefits on each allotment,

$$\max_{\{s(t),x(t)\}} \int_0^\infty e^{-rt}[\overline{v}(s(t),x(t),a)+b(s(t),x(t),a)]dt\ , \tag{3.1}$$

subject to the forage stock equation of motion, where on each grazing allotment the expected value of the rancher's net benefit function is taken over the distribution of rancher types,

$$\overline{v}(s(t),x(t),a)=\int_{i\in I} v(s(t),x(t),a,i)d\Psi(i)\ , \tag{3.2}$$

This leads to a public agency criterion that is independent of the public lands rancher's type.

The second best optimal long-run steady state is characterized by the steady state forage condition, $s^A(a)=f(x^A,a)$, and the reduced form equilibrium marginal value product condition for the grazing resource,

$$\begin{aligned} H(x^2,a) &= \overline{v}_x(f(x^2,a),x^2,a)+b_x(f(x^2,a),x^2,a) \\ &+\left[\overline{v}_s(f(x^2,a),x^2,a,i)+b_s(f(x^2,a),x^2,a)\right]\cdot\left[f_x(x^2,a)-r\right]=0\,. \end{aligned} \tag{3.3}$$

As before, we assume the optimal control problem has a unique, globally stable saddle point equilibrium, $H_x(x,a)<0\ \forall\ x\geq 0$. The rancher's choices for $x(t)$ and $s(t)$ are observable by the agency only if the grazing lease is monitored. *A priori*, the agency is unable to distinguish among ranchers or grazing allotments with respect to compliance. To preclude learning by ranchers, monitoring in any time period on any allotment must be stochastically independent of monitoring in other time periods and on other allotments. The agency therefore is assumed to monitor each allotment randomly, according to a time invariant Poisson process, with random monitoring choices that are stochastically independent across allotments.[5]

Let $\mu(a)$ denote the constant hazard rate for the first inspection. Under rational expectations, the typical rancher's subjective beliefs regarding the first monitoring time of the agency can be represented by the probability density function $\varphi(t,a) = \mu(a)e^{-\mu(a)t}$. As a result of random and stochastically independent monitoring, the waiting time for the first 'inspection' is exponentially distributed, and can be denoted by $\Phi(t)=1-e^{-\mu(a)t}$. Two important properties to note are that $\Phi(0) = 0$ and $\lim_{t\to\infty}\Phi(t)=1$, i.e., the cheating rancher believes he eventually will be monitored with probability one.

Once the agency monitors the rancher's current stocking behavior and the allotment's forage stock, it is assumed to have complete information.[6] For instance, if BLM observes a forage stock below the socially optimal forage level x^2, it is able to determine that $s > s^2$ during some nontrivial interval in the past. If, at monitoring date t, the agency observes a violation, then a penalty is imposed. A perfectly elastic demand for grazing fees implies no social cost for permit revocation, and therefore the optimal penalty involves, at a minimum, lease termination.[7]

3.1 Optimal Grazing Choices in a Regulated Environment

The case of most interest for the intertemporal path of range exploitation is that of a rancher who has been compliant up to the present and whose forage stock levels have reached the social

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[5] Independent and stochastic monitoring when the regulator is unable to differentiate among agents is formalized in Viscusi & Zeckhauser (1979). Recent literature focuses on regulators that target violators based on past behavior in a dynamic game of strategic play (Brams and Davis (1983), Greenberg (1984), and Harrington (1988)).

[6] Perfect detection of violations once an agent is monitored is common in the enforcement literature (e.g., Viscusi and Zeckhauser (1979)).

[7] It has been long recognized (Becker (1968), Stigler (1970),and Polinsky and Shavell (1979)) that costly monitoring and limited budgets imply enforcement strategies with low probabilities of detection and stringent penalties. Additionally, there have been instances of extreme penalties, including a recent case in Arizona where a rancher's permit was revoked and his cattle were confiscated and sold at auction.

equilibrium level x^2; hence, we assume as a starting point that $x_0=x^2$. Given this starting point, the optimal compliant strategy is the static sustained yield stocking rate $s(t) \equiv s^2$ for all $t \geq 0$. This implies that the wealth of the compliant rancher of type i on allotment a is simply the discounted present value of the certain profit flow defined by:

$$W_c(x_0(a), c(a), a, i) = \int_0^\infty [v(s^A(t;a), x^A(t;a), a, i) - p_g s^A]e^{-rt}dt\ , \tag{3.4}$$

where p_g is the grazing fee per animal unit month and $x_0(a)$ denotes the dependence of wealth on the starting point of the growth equation.

The expected wealth of a noncompliant rancher of type i on allotment a, on the other hand, is determined in part by the likelihood and timing of monitoring by the agency.[8] Since the agency knows with certainty, upon inspecting an allotment, whether the forage stock is below the socially optimal level, rational expectations by a rancher implies that a cheating strategy will be detected at the first monitoring time. This will then result in the permanent loss of the right to graze on the federal allotment.

To cheat without directly revealing the fact that she is doing so, a rancher must pay $p_g s^2$ to the agency regardless of her actual choice of $s(t)$. In other words, a non-compliant rancher will attempt to masquerade as a compliant rancher up until the time that he is monitored and a penalty is assessed. Consequently, the grazing fee payments are equivalent to a fixed cost to a cheating rancher, and the expected wealth for a noncompliant rancher is:[9]

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[8] The argument that an individual contemplates legal or contractual requirements in a rational fashion by comparing the expected benefits and expected costs of meeting such obligations was formalized by Becker (1968) and Stigler (1970). Viscusi and Zeckhauser (1979) expanded this notion to profit maximizing business enterprises.

[9] The argument that agents may wish to hide their true decisions in order to avoid suspicion on the part of a regulator is well-developed in the tax evasion literature (Sharon (1967) and Srinivisan (1973)).

$$E(W_n) = \int_0^t \phi(t) \cdot \{\int_0^t [v(x(\tau;a,i), s(\tau;a,i), a,i) - p_g s^A] e^{-r\tau} d\tau\} dt \,. \tag{3.5}$$

Integration by parts, using

$$u(t) = \int_0^t [v(x(\tau;a,i), s(\tau;a,i), a,i) - p_g s^A] e^{-r\tau} d\tau \ , \tag{3.6}$$

and $v'(t) = \varphi(t)$, as well as simple algebraic manipulation and substitution for φ and Φ as defined above, allows us to write the expected wealth of a noncompliant rancher as:

$$EW_n(x_0(a), p_g, \mu(a), a, i) = \int_0^\infty (1-\Phi(t))[v(s^0(t;a,i), x^0(t;a,i), a,i) - p_g s^A] dt$$

$$= \int_0^\infty [v(s^0(t;a,i), x^0(t;a,i), a,i) - p_g s^A] e^{-(r+\mu(a))t} dt. \tag{3.7}$$

This expected wealth function exhibits several interesting behavioral characteristics. First, with a positive real discount rate, the incentive is to cheat sooner rather than later, if at all. By inspection, it is also clear that the hazard rate $\mu(a)$ acts to augment the real discount rate for a noncompliant rancher. Thus, the hazard rate for the first monitoring time increases the incentive to trade future profits for greater current profits. Intuitively, given that a rancher is cheating, a greater probability of being detected in violation leads to a more urgent need to exploit the grazing resource in early periods.

Once again, the problem of maximizing (3.8) subject to the forage stock's equation of motion is a standard autonomous optimal control problem. The Hamiltonian is given by:

$$H = e^{-(r+\mu(a))t}[v(s(t), x(t), a, i) - p_g s^2] + \theta(t)[f(x(t), a) - s(t)], \tag{3.8}$$

where $\theta(t)$ is the shadow price for the forage stock equation of motion. However, it is convenient to work with a generalized version of the current value Hamiltonian to derive and interpret the optimal grazing decisions for a cheating rancher. Toward this end, we define the current value shadow price, λ, by $\lambda(t) \equiv \theta(t)e^{(r+\mu(a))t}$. This implies that $\partial\lambda/\partial t$ and $\partial\theta/\partial t$ are related by $\partial\lambda/\partial t = (r+\mu)\lambda(t) + \partial\theta/\partial t \cdot e^{(r+\mu(a))t}$. We can then define the generalized current value Hamiltonian by

$$\tilde{H} = [v(s(t), x(t), a, i) - p_g s^2] + \lambda(t)[f(x(t), a) - s(t)], \tag{3.9}$$

and write the first order necessary and sufficient conditions for an interior optimal solution as:

$$v_s(s(t;a,i), x(t;a,i), a, i) = \lambda(t;a,i); \tag{3.10}$$

$$v_x(s(t;a,i), x(t;a,i), a, i) + \lambda(t;a,i)\cdot f_x(x(t), a)) = (r+\mu)\lambda(t;a,i) - \dot{\lambda}; \tag{3.11}$$

$$\lim_{t\to\infty} \lambda(t;a,i)e^{-rt} = 0 \;\; \forall a \in A. \tag{3.12}$$

Differentiating (3.10) with respect to time, solving for $\partial\lambda/\partial t$, eliminating λ, and solving for $\partial s/\partial t$ implies:

$$\dot{s}(t;a,i) = \frac{[r + \mu(a) - f_x(x(t), a)]v_s(\cdot) - v_x(\cdot) - v_{sx}(\cdot)[f_x(x(t), a) - s(t;a,i)]}{v_{ss}}. \tag{3.13}$$

An important property of (3.13) is that the numerator is positive when $\mu(a) \equiv 0$, i. e., when there is no monitoring. This follows because $x^0 < x^2$ and the monotonicity of optimal paths for autonomous control problems. Therefore, when $\mu(a) > 0$ there exists an even greater incentive for ranchers to obtain higher short-run profits in periods prior to capture and eviction by overstocking.

Next, consider the long-run equilibrium for all cases in which the grazing resource is not completely exhausted in the long-run. This steady state is characterized by $s^B(a) = f(x^B,a)$ and:

$$v_s(x^B, s^{B,}, a, i) = \lambda(a, i); \tag{3.14}$$

$$v_x(s^B, x^{B,}, a, i) + \lambda(a,i)\cdot[f_x(x^B, a)) - (r + \mu(a))] = 0. \tag{3.15}$$

Note that the equilibrium stocking rate and the level of the forage resource are independent of the grazing fee. Let $r^B = r + \mu(a)$ denote the effective real discount rate. The equilibrium comparative statics with respect to r^B are given by the solution to the linear system:

$$\begin{bmatrix} v_{ss} & v_{sx} & -1 \\ v_{sx} & v_{xx}+\lambda^B f_{xx}(x^B) & f_x(x^B)-r^B \\ -1 & f_x(x^b) & 0 \end{bmatrix} \begin{bmatrix} s_r^B \\ x_r^B \\ \lambda_r^B \end{bmatrix} = \begin{bmatrix} 0 \\ \lambda^B \\ 0 \end{bmatrix}. \tag{3.16}$$

The necessary and sufficient condition for the steady state to define a unique (globally stable) saddle point equilibrium is that the determinant of the Hessian matrix of the current value Hamiltonian is positive,

$$\Delta \equiv -v_{ss}(x^B,s^B)[f_x(x^B)-r]-[v_{xx}(x^B,s^B)+\lambda^B f_{xx}(x^B)]-v_{sx}(x^B,s^B)[2f_x(x^B)-r^B]>0. \tag{3.17}$$

Assuming this condition holds, we obtain:

$$\partial s^B/\partial r^B = \text{-}\lambda^B f_x(x^B)/\Delta; \tag{3.18}$$

$$\partial x^B/\partial r^B = \text{-}\lambda^B/\Delta < 0. \tag{3.19}$$

Thus, the equilibrium grazing resource is a decreasing function of the effective discount rate. The possibility of being detected cheating and subsequently being evicted from the range leads a non-compliant rancher to pursue a more exploitive grazing strategy. This in turn implies that the initial stocking rate for a cheating strategy is an increasing function of the effective discount rate. Note, however, that the level of the grazing fee does not play any role in the determination of the optimal cheating strategy. An increase in grazing fees amounts to an increase in the *fixed costs* of compliance for a cheating rancher, and therefore fees do not factor into these ranchers' grazing choices.

3.2 Grazing Fees *versus* Compliance

We have established that the level of grazing fees plays no role in the optimal choices of stocking rates for both compliant and non-compliant ranchers at a long-run equilibrium. Clearly, the wealth of both cheating and compliant ranchers decreases with increased grazing fees, but the operational choices of these agents remain the same. We now turn to the question of whether or not changes in fees impact the initial decision to cheat or not. It is shown that rising public lands grazing fees result in greater economic incentives to violate the terms of a given permit. Increases in the fixed costs of compliance lead more ranchers to choose cheating strategies, and therefore rising grazing fees imply increased stocking rates and decreased levels of the forage stock.

But now recall that the discounted present value of a compliant strategy is:

$$W_c = \int_0^{\infty} [v(s^A(t;a), x^A(t;a), a, i) - p_g s^A] e^{-rt} dt \,. \tag{3.20}$$

Further, recall that random monitoring is required to prevent learning and that we have assumed that the monitoring strategy follows a time-invariant Poisson process. Stochastically independent monitoring yields an autonomous optimal control problem for a risk neutral non-compliant rancher, generating an initial choices regarding cheating that are subgame perfect equilibrium strategies throughout the planning horizon. The maximal expected net present value of a non-compliant strategy is therefore:

$$E(W_n) = \int_0^{\infty} [v(s^0(r+\mu(a), t; a, i), x^0(r+\mu(a), t; a, i), a, i) - p_g s^A] e^{-(r+\mu(a))t} dt \,. \tag{3.21}$$

A straightforward applications of the dynamic envelope theorem and convexity results in LaFrance and Barney (1991) imply:

$$\frac{\partial E(W_n)}{\partial \mu} = -\int_0^{\infty} t[v(s^0(r+\mu(a), t; a, i), x^0(r+\mu(a), t; a, i), a, i) - p_g s^A] e^{-(r+\mu(a))t} dt < 0, \tag{3.22}$$

$$\begin{aligned} \frac{\partial^2 E(W_n)}{\partial \mu^2} &= \int_0^{\infty} t^2[v(s^0(r+\mu(a), t; a, i), x^0(r+\mu(a), t; a, i), a, i) - p_g s^A] e^{-(r+\mu(a))t} dt \\ &- \int_0^{\infty} t \cdot \left(\frac{\partial v}{\partial x}\frac{\partial x^0}{\partial \mu} + \frac{\partial v}{\partial s}\frac{\partial s^0}{\partial \mu}\right) \cdot e^{-(r+\mu(a))t} dt > 0. \end{aligned} \tag{3.23}$$

It is also easy to show that:

$$\frac{\partial E(W_n)}{\partial p_g} = -\frac{s^A(a)}{r+\mu(a)} < 0; \tag{3.24}$$

$$\frac{\partial^2 E(W_n)}{\partial p_g \partial \mu} = \frac{s^A(a)}{(r+\mu(a))^2} > 0; \tag{3.25}$$

$$\frac{\partial^2 E(W_n)}{\partial {p_g}^2} = 0; \tag{3.26}$$

$$\frac{\partial W_C}{\partial p_g} = -\frac{s^A(a)}{r} < 0; \tag{3.27}$$

$$\frac{\partial W_C}{\partial \mu} = \frac{\partial^2 W_C}{\partial p_g \partial \mu} = \frac{\partial^2 W_C}{\partial {p_g}^2} = 0. \tag{3.28}$$

The public lands rancher's decision to cheat or comply with the terms of a given permit hinges upon the expected net benefits of adopting a cheating strategy, $R = E(W_n) - W_c$. This decision problem has the following simple characterization:

$$\mathit{If} \quad R \begin{cases} <0 & \mathit{comply} \\ =0 & \mathit{indifferent}\,. \\ >0 & \mathit{cheat} \end{cases} \tag{3.29}$$

Note that at $\mu(a) = 0$ the optimal strategy is to cheat for all $p_g \geq 0$ since there is no penalty for noncompliance. Further note that R is increasing in the grazing fee,

$$\partial R / \partial p_g = \mu s^A(a) / r(r+\mu) > 0, \tag{3.30}$$

and decreasing in the hazard rate for the first monitoring time,

$$\frac{\partial R}{\partial \mu} = \frac{\partial E[W_n](r+\mu(a);a,i)}{\partial \mu} < 0. \tag{3.31}$$

This implies that, on any given allotment, for each $\mu(a) > 0$ there exists a unique grazing fee, say $p_g(\mu(a);a,i)$, such that $R = 0$ and the rancher is indifferent between a compliant strategy and a cheating strategy. It is important to note that differences across ranchers and allotments lead to different positively valued equilibrium pairs ($\mu(a), p_g$) at which a rancher is indifferent between compliance and non-compliance. We are therefore likely, at any given time, to observe some ranchers cheating and some ranchers complying with the terms of their grazing lease.

Finally recall that the largest number of permits that can be feasibly monitored in a given period is $M = B_m/c_m << N$. Therefore, $\hat{\mu} = M/N = B_m/c_m$ is the maximum proportion of all grazing allotments that can be monitored. Since increasing grazing fees result in greater numbers of non-compliant ranchers, it is easy to see that expenditures on monitoring must increase with the grazing fee to maintain a constant incentive for rancher compliance on a given allotment a:

$$\left.\frac{\partial \mu}{\partial p_g}\right|_R = -\frac{\partial R / \partial p_g}{\partial R / \partial \mu} > 0. \tag{3.32}$$

Moreover, such expenditures must increase at an increasing rate, since:

$$\left.\frac{\partial^2 \mu}{\partial {p_g}^2}\right|_R = \frac{2(\frac{\partial R}{\partial \mu \partial p_g})(\frac{\partial R}{\partial \mu})(\frac{\partial R}{\partial p_g}) - (\frac{\partial R}{\partial \mu^2})(\frac{\partial R}{\partial p_g})^2}{(\frac{\partial R}{\partial \mu})^3} > 0. \tag{3.33}$$

A constant rate of compliance therefore requires increased expenditures on monitoring and the trade-off between such monitoring costs and grazing fees is convex.

Raising grazing fees increases the fixed costs of compliance for a public lands rancher, creating greater incentives for the rancher to overgraze. Contrary to popular belief, raising fees increases the environmental degradation on public lands. The only way increased fees could result in improved stewardship is if these fee increases were coupled with substantially greater monitoring budgets. Improved environmental conditions actually require greater public expenditures when grazing fees are raised.

4. Mechanism Design for Grazing Permits

We have just demonstrated that an increase in grazing fees, *ceteris paribus*, results in greater stocking rates and decreased levels of the forage resource. In particular, rising grazing fees were considered in the case where there exists no additional penalty for cheating other than permit revocation. The natural questions that subsequently arise are: What are the economically optimal fee and enforcement schemes and what characteristics do such schemes exhibit?

Recall our model of rancher behavior. Budget constraints preclude the enforcement agency from observing the characteristics of each rancher. However, the agency does know the distribution of rancher types given by $\Phi: I \rightarrow [0,1]$. A rancher's choices of $x(t)$ and $s(t)$ are observable only when the agency expends the effort and resources to monitor the grazing lease, and monitoring is costly. As previously discussed, monitoring must also be random across allotments and time, in order to prevent learning, prediction and avoidance by ranchers.

We now wish to consider fee payments, monitoring rules, and fines consistent with the socially optimal path. In addition to the difficulties arising from asymmetric information and costly monitoring, such a mechanism must address another complication over and above the fees, penalties, and monitoring rules that would achieve a first-best solution. As noted in the previous sections, non-compliant ranchers have an incentive to pretend to comply with the terms of their grazing lease defined by the solution to the average social value problem, while actually pursuing a privately optimal resource use strategy.

We consider mechanisms that are independent of time and stocks of animals and grass. That is, the agency sets a fee per allotment conditional on a contractual arrangement for grass quality and/or stock while monitoring to assure that the terms of such contracts are met. If at date t the agency observes that the rancher on allotment a has been departing from contractual specifications, then the grazing fee is terminated and a penalty is imposed. Let the penalty function be $P(s,x,a)$, i. e. , the level of penalty depends upon the animal and forage stock values chosen by a rancher for the allotment with characteristics a. Continue to assume that monitoring costs are financed externally, so that $M = B_m/c_m << N$ is the maximum number of allotments that can be feasibly monitored in a given period.

We emphasize that neither the hazard rate $\mu(a)$ nor the penalty function $P(s,x,a)$ depend explicitly on time, so that the control problem remains autonomous and the rancher's initial choice of compliance is subgame perfect, i.e., the initial choice remains optimal throughout the planning horizon. Therefore, consideration of mechanisms independent of time and stocks of animals and grass is sufficient. The wealth of compliant ranchers continues to be given by:

$$W_c = \int_0^\infty [v(s^2(t;a), x^2(t;a), a, i) - c(a)]e^{-rt}dt, \tag{3.34}$$

where $c(a)$ denotes the per period grazing fee on allotment a.[10] If a rancher cheats on the contract permit provisions by choosing the private optimum $\{s^B(t;a,i), x^B(t;a,i)\}$ and is subsequently caught at date t, then the present value of wealth is reduced by the penalty, i.e.,

$$E(W_n) = \int_0^\infty \phi(t)\left\{\int_0^t [v(x(\tau;a,i), s(\tau;a,i), a, i) - c(a)]e^{-r\tau}d\tau - P(s^B(t;a,i), x^B(t;a,i), a)e^{-rt}\right\}dt\ . \tag{3.35}$$

Integrating by parts, employing simple but tedious algebra, and substituting for our monitoring distributions allows us to write the expected wealth of a non-compliant rancher as:

$$E(W_n) = \int_0^\infty [v(s^0(t;a,i), x^0(t;a,i), a, i) - c(a) - \mu(a)P(s^0(t;a,i), x^0(t;a,i), a)]e^{-(r+\mu(a))t}dt\ . \tag{3.36}$$

Since non-compliance is socially undesirable, an optimal penalty function will discourage all

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[10] Of course, c(a) could be $p_g s^A$ as before, but it need not be.

ranchers, regardless of their type, from cheating. Hence, for each $a \in A$, given $(x_0(a), c(a), \mu(a))$, incentive compatibility for all rancher types $i \in I$ requires:

$$\max_{i \in I}\{W_n(x_0(a), c(a), \mu(a), a, i) - W_c(x_0(a), c(a), a, i)\} \leq 0. \tag{3.37}$$

This relation means that the penalty for non-compliance must be sufficient to discourage cheating, regardless of the rancher's type, thereby placing a lower bound on the effective penalty. The penalty must at least equal the net gains that the "worst possible" cheating rancher could have accrued. Such a penalty rule is both necessary and sufficient to discourage socially wasteful cheating on almost all allotments and almost all time periods. [11] This in turn implies that no rancher actively leasing an allotment optimally chooses to cheat, so a solution is attainable.

On the other hand, if nearly all allotments are actively leased in almost all time periods, then we must also have:

$$\min_{i \in I}\{W_c(x_0(a), c(a), a, i)\} \geq 0. \tag{3.38}$$

This relation sets an upper bound on periodic grazing fee payments,

$$c(a) \leq r\int_0^{\infty} v(s^A(t), x^A(t), a, i)e^{-rt}dt. \tag{3.39}$$

It can be shown that

$$r\int_0^{\infty}[v(s^A(t;a,i), x^A(t;a,i), a, i) - c(a)]e^{-rt}dt =$$

$$v(s^A(0;a,i), x^A(0;a,i), a, i) + \theta^A(0;a,i)\cdot\left[f(x_0(a), a) - s^A(0;a,i)\right], \tag{3.40}$$

where $\theta^A(0;a,i)$ denotes the shadow price for the forage equation of motion. The last term on the

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[11] Technically, "almost all" means all except for a set of probability measure zero.

right-hand-side is non-positive $\forall\ x_0(a) \geq x^A(a)$, due to the monotonicity of optimal paths in single state variable dynamic optimization problems. Hence, the grazing fee must be strictly less than the minimum average value product of s, and nearly all ranchers will receive what amounts to a subsidy relative to market prices.

Summary

Livestock grazing on public lands has been and promises to continue to be a source of intense conflict and debate in this country. A primary source of this conflict is the fact that there are diverse groups with incompatible interests competing for control over the use and management of public lands in the political arena. Property rights and use rights are not well-defined and it is unlikely that aspect of the problem will change given past and present political climates. A central theme of the Rangeland Reform '94 public grazing policy reform movement is that public lands ranchers are being subsidized by taxpayers and that this is unfair, inefficient, and leads to undue environmental damages.

In this paper, we have analyzed the question of how to design an optimal mechanism for public lands grazing policy in a dynamic world. We consider a dynamic economic game in which the government agency charged with administering public grazing contracts is uninformed about the idiosyncratic characteristics of individual ranchers and it is costly to monitor and enforce the terms and conditions of federal grazing leases. Our model centers on a mechanism design problem in which the government and public lands ranchers are economically rational. In the initial stage of the game, the government chooses a set of administrative rules (e.g., stocking rates, grazing seasons, and an intertemporal use pattern for public lands forage resources), grazing fee rates, penalty functions for failure to comply with the rules and regulations on the grazing leases, and a randomization strategy for monitoring and enforcing Federal grazing leases.

These are publicly announced, known to all parties, and the government commits to the strategy throughout the foreseeable future. In subsequent stages, public lands ranchers pursue individual livestock grazing strategies that are economically rational and the administering agencies pursue monitoring and enforcement strategies consistent with their previous announcements. We focus on risk neutral agents, rational expectations, and an equilibrium to the dynamic game that is subgame perfect in every subperiod of the planning horizon for both sides.

Ceteris paribus, increased grazing fees do not lead to a decrease in the number of livestock grazing on public lands. Because grazing fee payments are essentially fixed costs, keeping fees low allows ranchers to capture more of the rent from grazing on public lands and therefore increases the incentives to comply with mandated stocking rates. When the penalty function for overstocking an allotment includes permanent revocation of the grazing permit, ranchers are less likely to risk being detected out of compliance with more valuable permits. Thus, optimal public grazing contracts include grazing fees that are lower than competitive rental rates charged in the private market for grazing privileges.

A second characteristic of the optimal public lands grazing mechanism is the existence of random monitoring across space and time. A stationary Poisson process for the monitoring rule on each allotment, with monitoring on a given allotment statistically independent of monitoring on every other allotment both spatially and temporally, is one feasible way to support an optimal monitoring rule. Randomness and independence across allotments and grazing seasons prevents learning by the ranchers about the frequency and location of agency monitoring activities. This avoids wasteful efforts to disguise grazing practices by non-compliant ranchers. Second, a stationary Poisson process for monitoring each allotment generates a stationary exponential waiting time for the next period in which each rancher will be monitored, given the entire history of previous monitoring dates. The public lands rancher is faced with an intertemporally autonomous decision about compliance with the terms of the federal grazing lease. The rancher's optimal decision regarding whether to comply or cheat on the terms of the grazing lease is the same at all points in his planning horizon. This implies that the compliance choice made in the first instant in the rancher's planning horizon is a subgame perfect Nash equilibrium strategy for the rancher throughout all subsequent periods. The advantage for the agency is that this permanently separates compliant and non-compliant ranchers on all grazing allotments, allowing the agency to discover each rancher's historical use strategy at each monitoring date.

Third, the optimal incentive structure includes penalties beyond simply permanently terminating the grazing lease. Due to the environmental costs associated with overstocking the range, failure to comply with the terms of grazing permits is undesirable. Incentive compatibility for ranchers therefore requires penalties large enough to cause the present value of a compliant strategy to exceed the expected wealth of a non-compliant strategy regardless of the rancher's unobservable and idiosyncratic characteristics. The optimal penalty on each allotment is such that the rancher who would profit the most by cheating on a Federal grazing contract must earn non-positive expected net returns by choosing to do so.

One interesting aspect of these three properties is that they help to explain the failure of the Rangeland Reform '94 initiative during the Clinton Administration. But more than this, they also explain clearly the longstanding persistence of very low grazing fees on Federal lands. For all practical purposes, such a fee schedule is consistent with an optimal second best policy in a dynamic world with two-sided asymmetric information.

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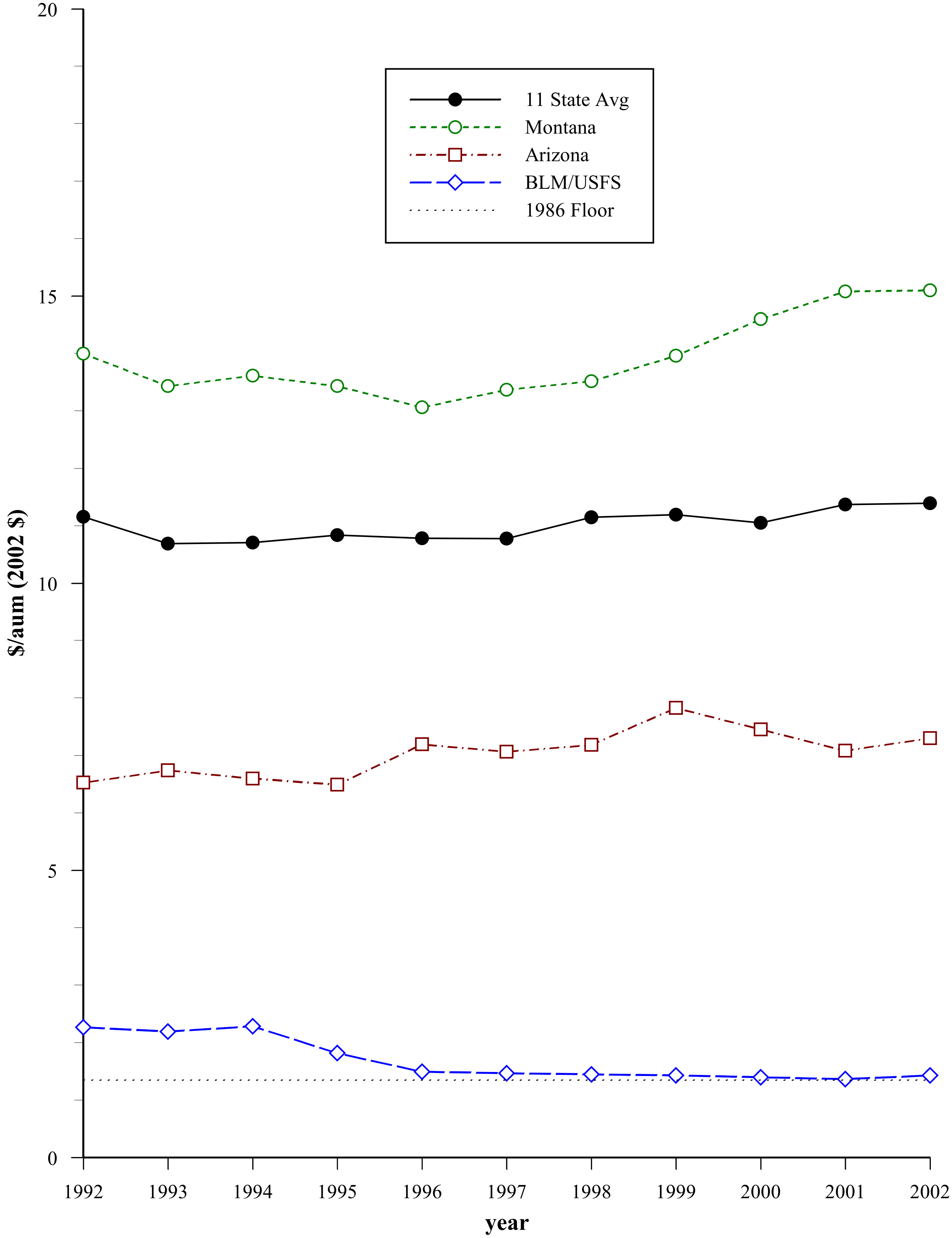
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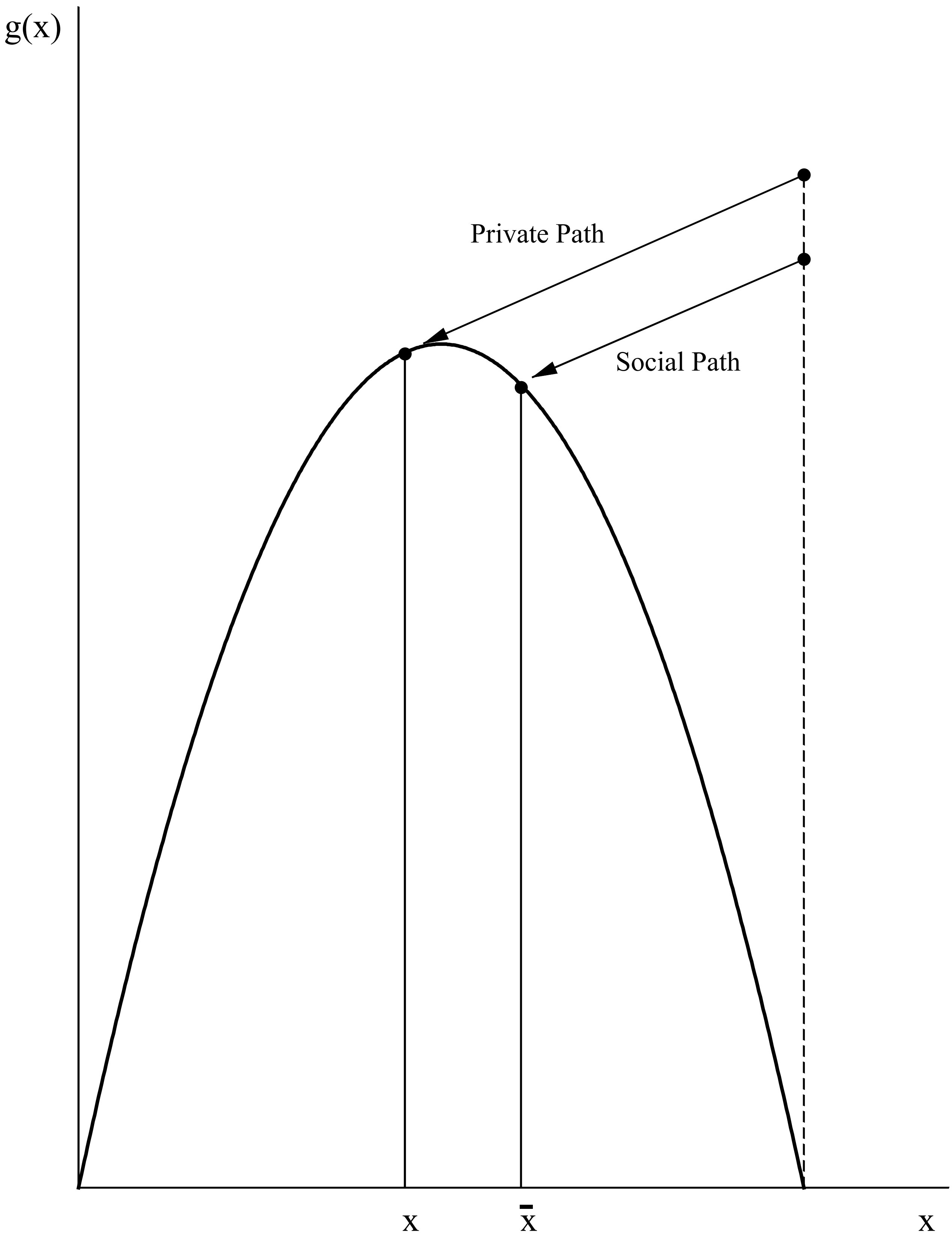
Figure 2. Public versus Private Optimal Rangeland Exploitation Paths.



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