Grazing Fees *versus* Stewardship on Federal Lands

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Livestock grazing on public lands continues to be a source of intense conflict and debate. We analyze this problem using a dynamic resource use game. Low grazing fees let ranchers capture more rent from grazing. This increases the incentive to comply with federally mandated regulations. Optimal grazing contracts therefore include grazing fees that are lower than competitive private rates. The optimal policy also includes random monitoring to prevent strategic learning by cheating ranchers and avoid wasteful efforts to disguise noncompliant behavior. The optimal policy includes a penalty for cheating beyond terminating the grazing lease. This penalty must be large enough that the rancher who would profit the most from cheating experiences a negative expected net return.

Livestock grazing on federal land has been hotly contested for more than a century.

Livestock 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).

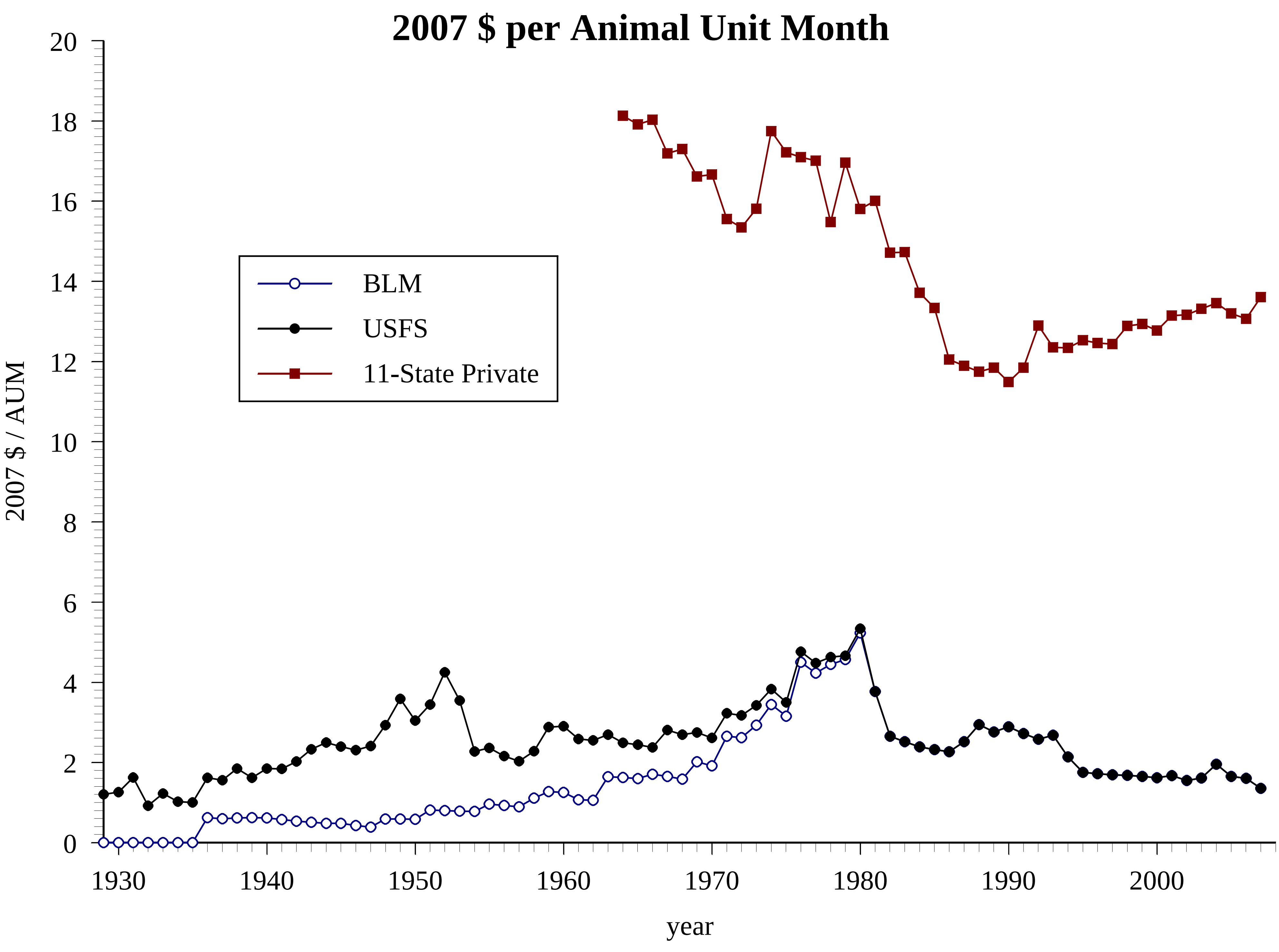
Nearly 28,000 livestock producers hold permits to graze their animals on federal lands, roughly 3% of all livestock producers in the United States but about 22% of the livestock producers in the eleven Western contiguous States (USDI-BLM, USDA-USFS, 1995).

The forage grazed on federal land accounts for approximately 2% of all feed consumed by beef cattle in the United States (USDI 1992).

A major focus of the debate over public grazing is the argument that public lands ranchers are being subsidized relative to grazing fees on private lands.

Figure 1 illustrates the extent of this discrepancy in eleven western states during the period 1900-2008, in constant 2008 dollars, using the implicit price deflator for gross domestic product to adjust for inflation.

Figure 1. Real Public and Private Grazing Fees.



The BLM and USFS deal with a large number of grazing permits and an even larger land area.

A typical BLM ranger is responsible for nearly 400,000 acres of rangeland and many are responsible for over a million acres.

With limited manpower and budgets, the cost of continuously monitoring all grazing allotments is high.

In contrast, a typical private landowner tends to lease grazing privileges to a small number of tenants on a small number of parcels.

Private landowners also capture all of the benefits from monitoring and enforcing their grazing leases.

Employees of the BLS and USFS personally can capture little, if any, of the benefits from monitoring and enforcing public lands grazing leases.

The BLM and the USFS determine the stocking rate on each allotment. The annual payment by a public lands rancher is the grazing fee times the allowed stocking rate, a fixed cost.

Public grazing land is a renewable resource. As a result, public agencies and public lands ranchers play a dynamic economic game. In this game there is a conflict of interest between society at large and ranchers because ranchers can not directly capture the benefits to non-grazing users.

Economic model of the game:

In the first stage of the game, the government chooses the administrative rules, grazing fees, penalties for failing to comply with grazing regulations, and a monitoring strategy.

These are announced publicly.

The government commits to this policy regime for all time.

In each later stage, each rancher chooses a stocking rate and the government chooses its monitoring actions.

All parties are risk neutral and form rational expectations.

The government is unable to choose the rancher on any allotment nor able to learn the rancher's idiosyncratic characteristics that influence his resource use choices.

The focus is on the subgame perfect Nash equilibria on all allotments.

Let $x(t)$ be the stock of forage and let $s(t)$ be the stocking rate, which determines forage harvest.

Let A denote the set of grazing allotments and I the set of rancher types.

For each $(a,i) \in A \times I$ the net return from grazing is $v(s(t),x(t),a,i)$ and the net benefit to non-grazing use is $b(s(t),x(t),a)$.

$v(\,\cdot\,, a, i)$ is increasing in (x, s), $b(\,\cdot\,, a)$ is increasing in x and decreasing in s

$v(\,\cdot\,,a, i)$ and $b(\,\cdot\,, a)$ are twice continuously differentiable and concave in (x, s).

Non-grazing benefits do not depend on the characteristics of the rancher.

The agency cannot choose or affect the rancher's type.

Equation of motion for the forage resource

$$\dot{x}(t) = f(x(t),a) - s(t), \;\; x(0) = x_0(a) \;\; fixed, \tag{1}$$

$f(x,a)$ is twice continuously differentiable in x, $f(0,a) = 0$, $\partial f(0,a)/\partial x > 0$, and $\partial^2 f(x,a)/\partial x^2 < 0 \;\; \forall \;\; x \geq 0$.

A unique forage level, $x^{msy}(a) > 0$, satisfies $\partial f(x^{msy}(a),a)/\partial x = 0 \;\forall\; a \in A$.

Rancher $i \in I$ would like to maximize the discounted present value of profits from grazing on allotment $a \in A$,

$$\max_{\{x(t),s(t)\}} \int_0^\infty e^{-rt} v(s(t), x(t), a, i)dt \tag{2}$$

subject to (1), where $r > 0$ is the real discount rate.

Rancher's privately optimal wealth-maximizing use path satisfies (1) and

$$\dot{s} = \frac{(r - f_x)v_s - v_x - v_{sx}(f - s)}{v_{ss}}. \tag{3}$$

Long-run steady state satisfies $\dot{s} = \dot{x} = 0$, so that $s^0(a,i) = f(x^0(a,i),\ a)$, and the private value of the marginal product condition,

$$\begin{aligned} F(x^0(a,i),a,i) = v_x(f(x^0(a,i),a), x^0(a,i),a,i) + \\ v_s\left(f(x^0(a,i),a), x^0(a,i),a,i\right)\cdot\left[f_x(x^0(a,i),a) - r\right] = 0. \end{aligned} \tag{4}$$

$\partial F(x,a,i)/\partial x < 0 \ \forall \ x \geq 0$ is sufficient for a unique, globally stable saddle point.

Socially optimal decision rule includes the rancher's and non-grazing benefits,

$$\max_{\{s(t),x(t)\}} \int_0^\infty e^{-rt} \left[v(s(t), x(t), a, i) + b(s(t), x(t), a) \right] dt. \tag{5}$$

This path satisfies (1) and

$$\dot{s} = \frac{(r - f_x)(v_s + b_s) - (v_x + b_x) - (v_{sx} + b_{sx})(f - s)}{v_{ss}}. \tag{6}$$

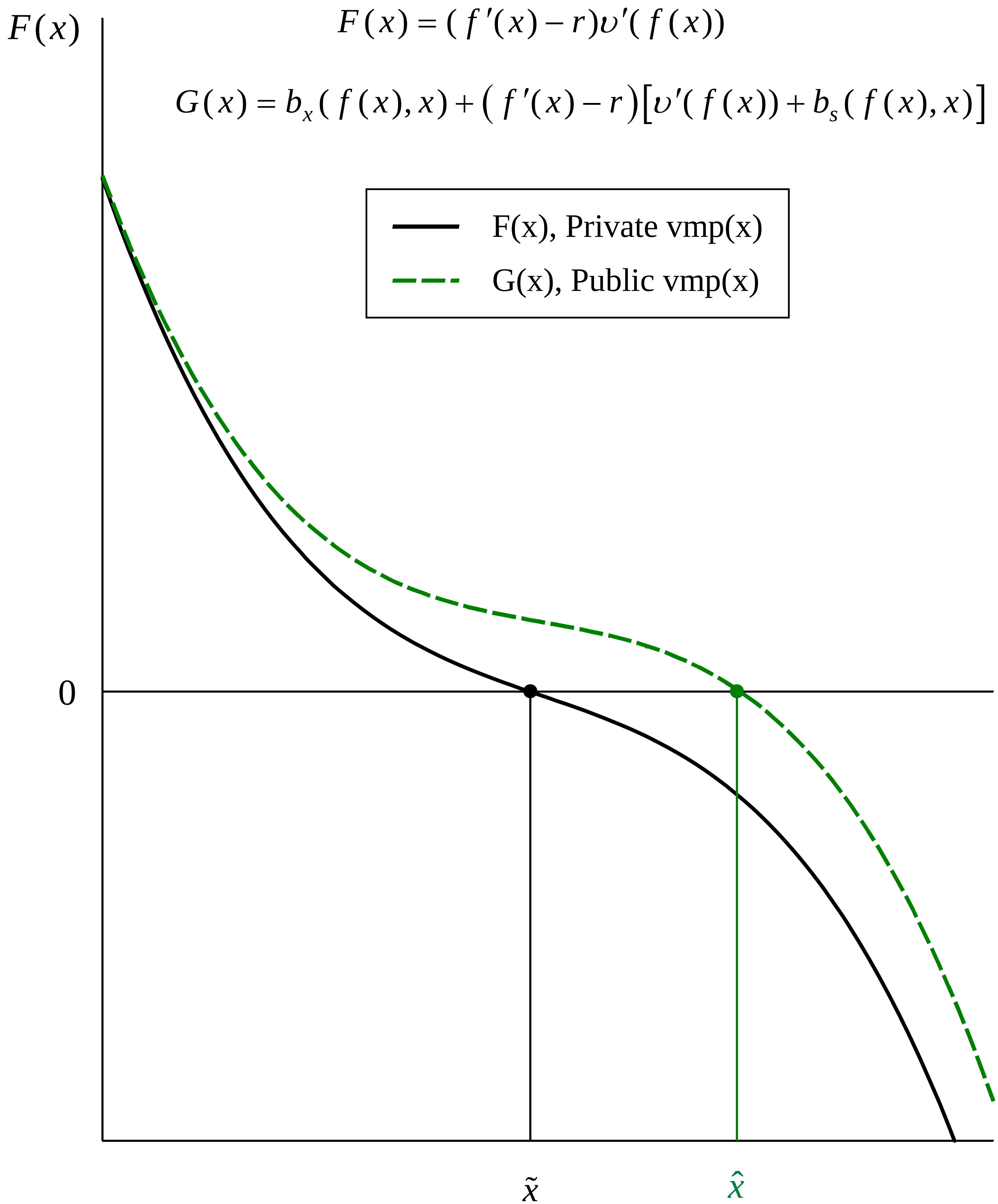
Steady state now satisfies $s^1(a,i) = f(x^1(a,i),a)$ and

$$\begin{aligned} G(x^1(a,i),a,i) &= v_x(f(x^1(a,i),a), x^1(a,i),a,i) + b_x(f(x^1(a,i),a), x^1(a,i),a) \\ &+ \left[v_s(f(x^1(a,i),a), x^1(a,i),a,i) + b_s(f(x^1(a,i),a), x^1(a,i),a) \right] \\ &\times \left[f_x(x^1(a,i),a) - r \right] = 0. \end{aligned} \tag{7}$$

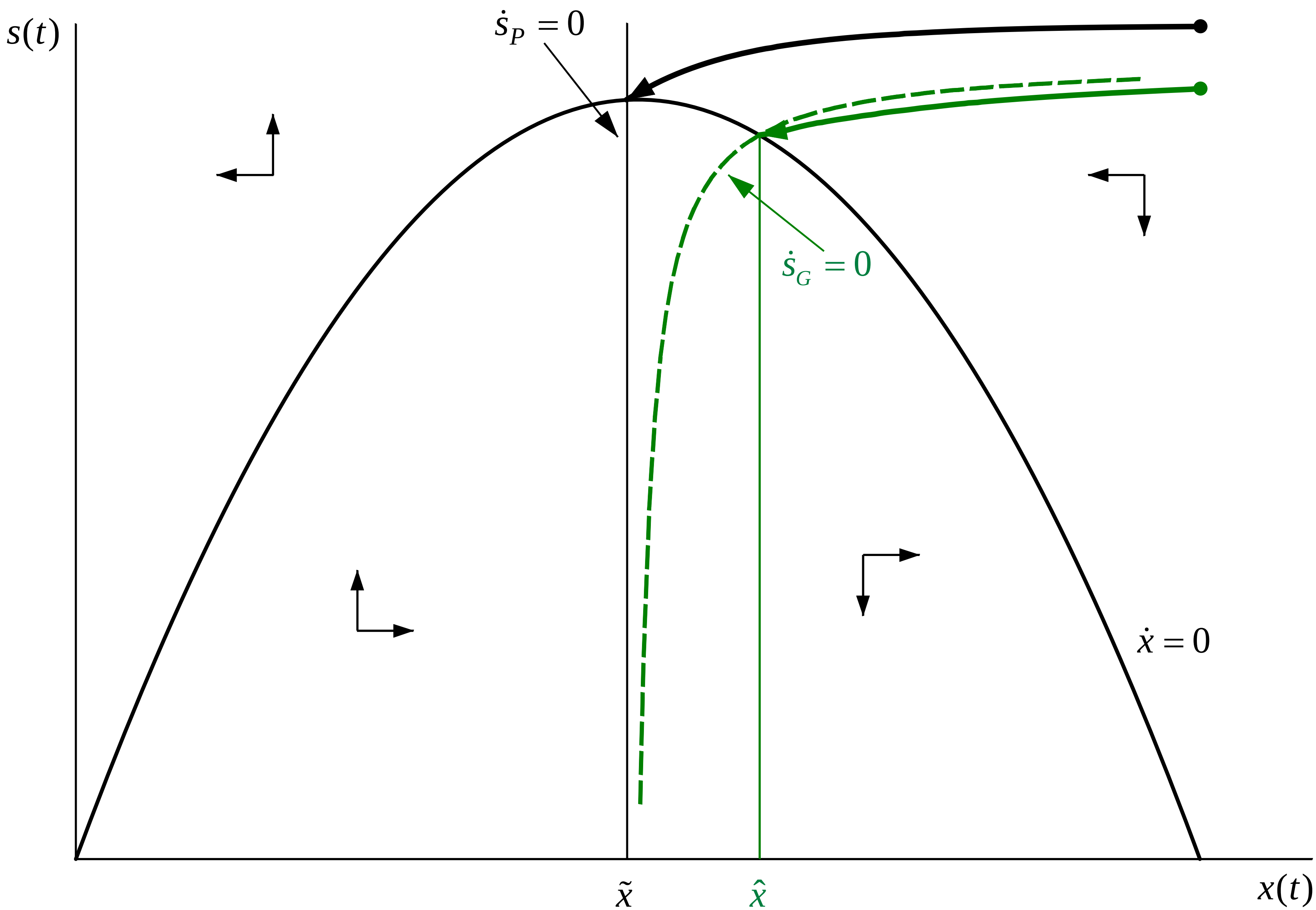
$\partial G(x,a,i)/\partial x < 0 \;\; \forall \;\; x \geq 0$ is sufficient a unique, globally stable saddle point.

It is straightforward to show that $\forall \; (a,i) \in A \times I, \;\; x^1 > x^0$ (Figure 2).

Long-Run Equilibrium Dynamic vmp(x).



Phase Diagram for Public and Private Optimal Grazing Paths.



Optimal Public Grazing Leases

If the agency could hand pick the rancher on each allotment and fully control his grazing activities, then $\forall a \in \mathcal{A}$, the ***first best decision rule*** is to choose the most attractive rancher type from society's perspective,

$$\sup_{i \in \mathcal{I}} \left\{ \max_{\{s(t),x(t)\}} \int_0^\infty e^{-rt} \left[v(s(t),x(t),a,i) + b(s(t),x(t),a) \right] dt \right\}.$$

This is not contrary to U.S. statute and infeasible as a practical matter.

In general, when $i \in \mathcal{I}$ is a vector, there is no one-to-one and onto mapping from the space of rancher "types" to the extensive form game space (well-known).

No mechanism exists leading to the revelation principle to overcome this issue.

For a rancher of an unknown "type", if the agency does not monitor and enforce the lease, there is no penalty for pursuing a privately optimal grazing plan.

Monitoring and enforcement are costly.

The distribution of rancher types, $\Psi : I \rightarrow [0,1]$, is known to the agency and is time invariant.

Each rancher with a public grazing lease is considered by the agency to be a random draw from this distribution.

The agency is unable to select i for any allotment.

The agency is unable to learn i regardless of resources committed to seeking this information.

A risk neutral agency will then seek to maximize the expected discounted net benefits on each allotment,

$$\max_{\{s(t),x(t)\}} \int_0^\infty e^{-rt}[\bar{v}(s(t),x(t),a)+b(s(t),x(t),a)]dt, \tag{8}$$

subject to (1), with the expectation taken over the distribution of "types,"

$$\bar{v}(s(t),x(t),a) = \int_{i\in I} v(s(t),x(t),a,i)d\Psi(i). \tag{9}$$

Long-run steady state satisfies $s^2(a) = f(x^2(a), a)$ and

$$
\begin{aligned}
H(x^2(a),a) = {} & \overline{v}_x(f(x^2(a),a), x^2(a), a) + b_x(f(x^2(a),a), x^2(a), a) \\
& + \left[\overline{v}_s(f(x^2(a),a), x^2(a), a, i) + b_s(f(x^2(a),a), x^2(a), a)\right] \\
& \times \left[f_x(x^2(a),a) - r\right] = 0.
\end{aligned}
\tag{10}
$$

$H_x(x,a) < 0 \ \forall \ x \geq 0$ is sufficient for a unique, globally stable saddle point.

The rancher's choices for $x(t)$ and $s(t)$ are observed by the agency if, and when, the grazing lease is monitored.

Let $\mu(a)$ denote the hazard rate for inspection times.

A constant hazard rate across time generates an autonomous control problem for the rancher, which is necessary and sufficient for a stationary decision rule (no cycling).

The rational expectation of the distribution of agency monitoring times is the exponential pdf, $\varphi(t,a) = \mu(a)e^{-\mu(a)t}$.

Once the agency monitors the allotment, it has complete information.

If the agency observes a forage stock or stocking rate that deviates from the the 2^{nd} best socially optimal level, the permit has been violated.

In that case, the agency permanently terminates the lease and imposes a penalty.

Ranchers' Decisions in a Regulated Environment

The optimal compliant strategy is $s(t,i) \equiv s^2(a) \ \forall \ t \geq 0$ and the wealth of a compliant rancher of type i on allotment a is

$$W_c(a,i) = \frac{1}{r}\left[v(s^2(a), x^2(a), a, i) - p_g s^2(a) \right], \tag{11}$$

where p_g is the grazing fee.

The expected wealth of a noncompliant rancher is determined by the frequency and timing of monitoring.

To mask their cheating, noncompliant ranchers pay $p_g s^2(a)$.

The expected wealth for a noncompliant rancher is

$$\begin{aligned}\bar{W}_n(a,i) &= \int_0^\infty \varphi(t)\left\{\int_0^t \left[v(x(\tau;a,i),s(\tau;a,i),a,i) - p_g s^2(a)\right]e^{-r\tau}d\tau\right\}dt \\ &= \int_0^\infty \left[v(s(t;a,i),x(t;a,i),a,i) - p_g s^2(a)\right]e^{-(r+\mu(a))t}dt.\end{aligned} \quad (12)$$

A noncompliant rancher's optimal control path satisfies (1) and

$$\dot{s} = \frac{[r+\mu(a) - f_x]v_s - v_x - v_{sx}(f-s)}{v_{ss}}. \quad (13)$$

The numerator is positive with no monitoring by $x^0 < x^1$.

Monotonicity of autonomous optimal paths $\Rightarrow$ $\mu(a) > 0$ increases overstocking in the short run.

Equilibrium stocking rate and forage level are independent of the grazing fee.

The equilibrium forage stock is a decreasing function of the hazard rate.

The rancher's decision to cheat or comply hinges on $R \equiv \overline{W}_n - W_c$.

$$\partial \overline{W}_n / \partial \mu < 0; \tag{14}$$

$$\partial^2 \overline{W}_n / \partial \mu^2 > 0; \tag{15}$$

$$\partial \overline{W}_n / \partial p_g = -s^2(a) / \left[r + \mu(a)\right] < 0; \tag{16}$$

$$\partial^2 \overline{W}_n / \partial p_g \partial \mu = s^2(a) / \left[r + \mu(a)\right]^2 > 0; \tag{17}$$

$$\partial^2 \overline{W}_n / \partial {p_g}^2 = 0 \tag{18}$$

$$\partial Wc / \partial p_g = -s^2(a) / r < 0; \tag{19}$$

$$\partial W_c / \partial \mu = \partial^2 W_c / \partial p_g \partial \mu = \partial^2 W_c / \partial p_g^2 = 0. \tag{20}$$

If $\mu(a) = 0$, the optimal strategy is to cheat for any $p_g \geq 0$ (no penalty).

$$\partial R / \partial p_g = \mu(a) s^2(a) / r\left[r + \mu(a)\right] > 0, \tag{21}$$

$$\partial R / \partial \mu = \partial \overline{W}_n / \partial \mu < 0. \tag{22}$$

For all $\mu(a) > 0$, a unique $p_g(\mu(a), a, i)$ (may be negative) satisfies $R = 0$:

$$\left.\partial \mu / \partial p_g\right|_{R=R^o} = -\frac{\partial R / \partial p_g}{\partial R / \partial \mu} > 0. \tag{23}$$

Monitoring rate must increase at an increasing rate:

$$\left.\frac{\partial^2 \mu}{\partial p_g^2}\right|_{R=R^o} = \frac{2\left(\frac{\partial^2 R}{\partial \mu \partial p_g}\right)\left(\frac{\partial R}{\partial \mu}\right)\left(\frac{\partial R}{\partial p_g}\right) - \left(\frac{\partial^2 R}{\partial \mu^2}\right)\left(\frac{\partial R}{\partial p_g}\right)^2}{\left(\frac{\partial R}{\partial \mu}\right)^3} > 0. \tag{24}$$

A constant compliance rate with higher grazing fees requires greater monitoring and monitoring costs are strictly convex in the grazing fee.

At date t the agency observes that rancher i on allotment a has been cheating, the lease is terminated and the penalty $P(s(t), x(t), a)$ is imposed.

$\mu(a)$, $P(s(t), x(t), a)$ independent of time $\Rightarrow$ rancher's problem is autonomous.

Expected wealth of a cheating rancher,

$$\begin{aligned}\bar{W}_n &= \int_0^\infty \phi(t)\left\{\int_0^t \left[v(x(\tau), s(\tau), a, i) - p_g s^2(a)\right] e^{-r\tau} d\tau - P(s(t), x(t), a) e^{-rt}\right\} dt \\ &= \int_0^\infty e^{-(r+\mu(a))t}\left[v\big(s(t), x(t), a, i\big) - p_g s^2(a) - \mu(a) P\big(s(t), x(t), a\big)\right] dt.\end{aligned} \tag{25}$$

Optimal penalty:

$$\sup_{i \in I}\left(\bar{W}_n - W_c\right) \leq 0. \tag{26}$$

For any allotment that is actively grazed,

$$\min_{i \in I} W_c \geq 0. \tag{27}$$

$$\Rightarrow p_g \leq \min_{i \in I}\left\{v(s^2(a), x^2(a), a, i) / [r \cdot s^2(a)]\right\}.$$