1989

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Abstract

This paper explores an incentive-based management system to induce federal grazing permittees to choose sustained cattle stocking strategies which accommodate government-set wild horse numbers and nongrazing uses. Particular attention is paid to constraints imposed by federal grazing statutes. The proposed system employs increased livestock grazing fees to induce permittees to provide increased vegetation for consumption by wild horses and nongrazing uses. The negative impact of increased fees on permittee wealth is counterbalanced with compensatory transfer payments. Taken together, grazing fees and compensation payments induce multiple-use compliance by permittee-stewards and keep their discounted livestock profits intact at some predetermined level.

SYMBOLS

F_t = perennial vegetation density in t (state variable, lbs. d.m./acre)

S_t = cattle stocking rate in t (control variable, head/acre)

H_t = wild horse population grazing the permittee's allotment in t (exogenous variable, head/acre)

$Cn_{s,t}$ = vegetation consumption rate of livestock in t (lbs. d.m./head/t)

$Cn_{h,t}$ = vegetation consumption rate of wild horses in t (lbs. d.m./head/t)

W_t = livestock productivity in t (lbs./head/t)

G_t = vegetation growth rate in t (lbs. d.m./acre/t).

$\dot{F}$ = rate of net change in the forage stock in t (eq. of motion, lbs. d.m./acre/t)

r = exogenous, market-determined, periodic, real interest rate

p_w = beef price (\$/lb.)

g_f = grazing fee (\$/head/t)

c = sum of incidental and opportunity costs of holding livestock on range (\$/head/t)

p_f = compensation for leaving vegetation ungrazed by livestock (\$/lb. d.m./t)

p_h = compensation for wild horse grazing on permittee's allotment (\$/lb. d.m.)

One of the most controversial environmental issues facing federal rangeland managers is how to alleviate the grazing pressure exerted by domestic livestock and overpopulated wild horses and burros on deteriorating public ranges [13]. Rancher efforts to relieve the competitive grazing pressure for their livestock by rounding up and slaughtering wild horses and burros resulted in the passage of the Wild Free-Roaming Horses and Burros Act[2] of 1971 (WFRHBA). The WFRHBA protects these animals from "...capture, branding, harassment, or death...",[3] and directs public managers to "manage wild free-roaming horses and burros in a manner that is designed to achieve and maintain a thriving natural ecological balance on the public lands".[4] Under legal protection, the wild horse population increased from 17,000 in 1971 to 54,030 in 1978--about 23,000 in excess of the level that the Bureau of Land Management (BLM) determined to constitute an ecological balance [13].

The WFRHBA authorizes the BLM to remove excess animals from rangeland by rounding them up for private adoption, or for destruction if no adoption demand exists or they are old, sick, or lame.[5] However, about 7,000 excess horses are backed up on rangeland for two major reasons [13]. First, roundups have been impeded by judicial actions brought by animal rights activists [1],[2],[13]. Second, the BLM has not found an easy or inexpensive way to dispose of unclaimed captured horses. The BLM has refused to destroy them because of potentially large public opposition. Moreover, reduction by adoption has been slowed by animal rights activists recent success in convincing a federal district court to order the Secretary of the Interior (Secretary) to withhold title from adopters who intend to exploit them for slaughter or as bucking stock in rodeos [13]. Finally, Congress has refused to authorize the Secretary to sell horses outright after roundup. Hence, unclaimed captured horses (currently numbering about 8,670 [13]) must be held in federal pens at great public expense.[6]

After taking the teeth out of the roundup/adoption policy, federal courts have directed the BLM to investigate policy alternatives for relieving the competitive grazing pressure on public rangeland in Environmental Impact Statements [2]. Any such policy must satisfy three major statutory mandates.

First, the Federal Land Policy and Management Act[7] of 1976 (FLPMA) requires the BLM to allocate public rangeland vegetation to multiple uses at high-level sustained yields.[8] The multiple-use requirement has been interpreted by federal courts to imply that a wild-horse policy can give neither livestock nor wild horses an exalted status over the other [1]. Hence, the two grazers must be made to coexist unless grazing permittees elect voluntarily for nonuse of their allotments. Moreover, the multiple-use mandate requires that a wild-horse policy allocate vegetation to nongrazing multiple uses competing for forage such as the protection of ecosystems (plant, fish, and wildlife) and environmental quality [14].

Second, the Public Rangeland Improvement Act[9] of 1978 (PRIA) directs the BLM to implement the Experimental Stewardship Program[10]

(ESP). The intent of the ESP is to discover whether allowing qualified federal grazing permittees to actively direct decisionmaking (i.e., to determine livestock numbers and seasons of use) can improve public rangeland conditions [11].

Third, public grazing statutes require policy "...to prevent economic disruption and harm to the western livestock industry...."[11]

In many ways, these statutory restrictions on grazing policy are similar to the political constraints imposed in designing pollution reduction policies. In the pollution reduction arena, issues have traditionally revolved around realigning traditional use patterns to effect environmental quality improvement without unduly and adversely affecting original users, often those with historical rights. Recently, emphasis has also been placed on incentive-based mechanisms, such as charges- and rights- based systems, rather than systems which allocate by fiat (e.g., standards) [4],[5].[12] A natural concern is thus whether an incentive-based system is a feasible means of handling the conflicts between wild horse advocates and traditional livestock operators on public lands. This paper explores such a system with particular attention to the constraints imposed by federal grazing statutes.

An incentive-based wild-horse policy satisfies the above FLPMA and PRIA requirements by persuading permittee-stewards to voluntarily decrease livestock when increased forage is needed for the sustenance of wild horses and nongrazing competing uses. The mechanism proposed in this paper is a counterbalancing incentive system which relies on increased grazing fees per animal to discourage stocking when necessary. Compensatory transfer payments are included to satisfy the statutory mandate of preventing economic disruption to the western livestock industry. Ranchers who acquire grazing permits at a value that have capitalized the net benefits from past low grazing fees stand to suffer large financial losses if grazing fees are significantly increased [3],[9]. Hence, the system fixes compensatory payments at levels counterbalancing permittee financial losses from increased grazing fees (when needed to induce multiple-use compliance).

The paper is organized as follows. The first section develops the analytical grazing model underpinning the wild-horse counterbalancing incentive system. The second section derives the system. The last section discusses how the system may be useful in practical application.

THE GRAZING MODEL

Suppose that the permittee is assessed a public grazing fee each time period t for each animal stocked, g_f (\$/hd/t). Suppose also that the permittee receives compensations each period for every pound of forage consumed by wild horses, p_h (\$/lb dm), and every pound of forage left ungrazed on the allotment, p_f (\$/lb dm); and that the wild horse population grazing the permittee's allotment each period, H_t, is an exogenous policy variable controlled by the BLM consistently with the WFRHBA. Suppose finally that the permittee's assumed objective is to select the cattle stocking strategy which results in a present-value maximizing allocation of range vegetation among livestock grazing, wild-horse grazing, and nongrazing multiple uses over the term of an n-year permit, subject to biological constraints on plant and animal productivity.

The analytical formulation of this problem is

$$(1) \quad \max_{S_t} \; {}_0\int^n \; e^{-rt}\{[p_w W_t(F) - (g_f+c)]S_t + p_h Cn_{h,t}(F_t)H_t + p_f F_t \} \, dt \; ,$$

subject to S_t, F_t, H_t, p_w, $c \geq 0$, and

$$(2) \quad F_{t=0} = F_0, \quad F_{t=n} = F_n,$$

$$(3) \quad S^L = 0 \leq S \leq S^U,$$

$$(4) \quad W_t(F_t) = m \; Cn_{s,t}(F_t)$$

$$(5) \quad \dot{F}_t = G_t(F_t) - Cn_{s,t}(F_t)S_t - Cn_{h,t}(F_t)H_t \; ,$$

where, F_t is the perennial vegetation density in t (state variable, lbs. d.m./acre), S_t is the cattle stocking rate in t (control variable, head/acre), r is an exogenous market-determined periodic real interest rate, p_w is the beef price ($/lb), W_t is animal productivity in t (lbs./head/t), c is the sum of incidental and opportunity costs of holding livestock on range ($/head/t), $Cn_{h,t}$ is the wild horse forage consumption rate (lb dm/head/t), S^L (S^U) is the minimum (maximum) stocking rate in t (head/acre), $Cn_{s,t}(F_t)$ is the livestock forage consumption rate (lb dm/head/t), $\dot{F}$ is the rate of net change in the forage stock in t (eq. of motion, lbs dm/acre/t), and G_t is the vegetation growth rate (lb dm/head/t). Time subscripts are dropped below where no ambiguity exists.

The first term in the integrand of equation 1, $[p_w W_t(F_t) - (g_f+c)] S_t$, measures periodic weight-gain profits from grazing livestock. The second term, $p_h Cn_{h,t}(F_t)H_t$, measures the periodic compensation the permittee receives for the forage consumed by wild horses. Finally, the third term, $p_f F_t$, measures the periodic compensation the permittee receives for ungrazed vegetation left to supply nongrazing uses.

Equations 4 and 5 comprise the ecological component of the grazing model and rely on assumptions prevalent in the grazing ecology literature [15],[16]. Equation 4 assumes that livestock productivity per head is monotonically and linearly related to the rate of forage consumption per head. Equation 5 assumes that the net change in the forage stock in a period is forage growth less total consumption by livestock and wild horses during the period. Forage dynamics are assumed to remain stationary through time.

Forage growth, G(F), is assumed to be adequately described by a pure compensation logistic model

(6) $G(F) = aF - bF^2$

Forage consumption per head by livestock is assumed to follow a "type 2" saturation functional response [10]

(7) $Cn_s(F) = c^x F/(F + K)$

where consumption is related solely to the forage stock in t by a saturation function, increasing at a decreasing rate for lower stocks and reaching a plateau at higher stocks. The parameter c^x is the maximum (satiation) consumption rate per animal. The parameter K is inversely related to foraging efficiency since it represents the forage level at which consumption is half of satiation.

Forage consumption per head by wild horses is assumed to follow a "type 1" linear functional response [10]

$$(8)\quad Cn_h(F) = qF \ ,$$

where q is a grazing efficiency coefficient. Given the above functional responses for G(F) and $Cn_s(F)$, a linear vegetation consumption response for horses is necessary for the optimization problem to generate a unique steady state forage solution for a given combination of g_f, p_f, and p_h. With uniqueness, the model can generate the combination of incentives needed to induce the permittee to sustain a particular steady state forage level satisfying multiple use. Alternatively, a saturation functional response for horses would result in the possibility of multiple steady state forage solutions associated with a given combination of g_f and p_f. The inaccuracy of approximating a saturation functional response with a linear response can be mitigated by choosing a value for the linear grazing efficiency coefficient q such that the two responses are approximately equal in the neighborhood of the target steady state solution.

The linearity of periodic weight-gain profits in S_t results from two assumptions. The first is that the permittee faces a perfectly elastic demand curve for livestock output. The second is that livestock numbers can be costlessly adjusted within a period. The addition of adjustment costs renders the problem, already complicated by the predator-prey dynamics of eq. 5, analytically intractable. The costless adjustment formulation is a useful approximation to the more realistic, yet intractable, costly adjustment formulation. Both formulations can be expected to call for the same type of stocking adjustments to achieve economically optimal sustained forage levels. The difference is that the costless stocking adjustment occurs as rapidly as possible, while costly stocking adjustment occurs more gradually. Hence, the grazing model presented in this paper can speak to the direction of stocking adjustments a permittee-steward can be induced to make to supply nongrazing forage uses; but overestimates the rate at which they occur.

The Solution

The solution to the problem posed in equations 1-8 is found by defining the present-value Hamiltonian (\$/acre/t)

(9) $$H^{pv} = \sigma_t S + e^{-rt}[p_h Cn_h(F)H + p_f F] + \lambda_t^{pv}[G(F) - Cn_h(F)H],$$

where σ_t, the switching function, is given by

(10) $$\sigma_t = e^{-rt}[p_w W(F) - (g_f + c)] - \lambda_t^{pv} Cn_s(F)$$

and λ_t^{pv} (\$/lb. forage consumed) is the costate variable measuring the marginal present value of the forage stock in t, and thus the opportunity cost of consuming forage presently by marginally increasing the density of grazers.

This is a most rapid approach problem (MRAP) which utilizes a bang-bang livestock control sequence from equation 11 below to drive forage to the optimal (singular) solution F^* as rapidly as possible [18]

$$(11) \quad S = \begin{cases} S^U & \text{if } \sigma > 0 \quad (F > F^*) \\ S^* & \text{if } \sigma = 0 \quad (F = F^*) \\ S^L & \text{if } \sigma < 0 \quad (F < F^*), \end{cases}$$

where S^* is the (constant) livestock control which keeps $F = F^*$ so long as $0 < S^* < S^U$. Since forage dynamics are assumed to be stationary and parameters are assumed to be constant through time, the singular solution holds for each grazing season in the n-year horizon of the problem.

The Pontryagin necessary conditions stipulate that the solution functions S, λ and F satisfy

$$(12) \quad \sigma_t = 0, \text{ which yields}$$

$$(13) \quad \lambda^{pv} = e^{-rt}[p_w W(F) - (g_f + c)]/Cn_s(F)$$

$$(14) \quad -\dot{\lambda} = e^{-rt}p_w W'(F)S + e^{-rt}[p_h Cn'(F)H] + e^{-rt}p_f$$
$$\lambda^{pv}[G'(F) - Cn_s'(F)S - Cn_h'(F)H]$$

$$(15) \quad S|_{\dot{F}=0} = [G(F) - Cn_h(F)H]/Cn_s(F).$$

To maximize discounted net returns from grazing, the permittee must balance the opportunity cost of stocking the marginal animal (LHS of equation 13) against the present value of the marginal gain (RHS). Equation 14 requires that the marginal present value of the forage stock (LHS) depreciate at the sum of the rates at which the forage stock contributes to immediate discounted revenues through livestock grazing (first term RHS), wild horse grazing (second term), nongrazing uses (third) and the value of forage stock accumulation (last term). Equation 15 is the forage isocline derived by setting the equation of motion (equation 5) equal to zero. It requires that the singular forage solution be drawn from stocks equilibrating the ecological component of the grazing model.

Routine computation reduces equations 13-15 to

$$(16)\quad G'(F^*) - Cn_h'(F^*)H = r - \frac{[G(F^*) - Cn_h(F^*)H](g_f+c)Cn_s'(F^*)}{Cn_s(F^*)[p_wW(F^*) - (g_f+c)]} \frac{p_f + p_hCn_h'(F^*)H}{[p_wW(F^*) - (g_f+c)]/Cn_s(F^*)}$$

Equation 14 desribes a unique singular forage path F^* which must be "tracked" by stocking $S^* = [G(F^*)-Cn_h(F^*)H]/Cn_s(F^*)$ livestock whenever $\sigma(t) = 0$. The equation represents a type of "modified golden-rule equilibrium" prevalent in renewable resource models, wherein the basic marginal-productivity (or golden) rule governing equilibrium--that the marginal productivity of the renewable resource stock equal the discount rate--is modified by stock dependent terms. In equation 16, the golden-rule forage stock F^{gr} satisfies $G'(F^{gr}) = r$. The second LHS term and the second and third RHS terms are the stock dependent terms modifying F^{gr} as described below.

The second LHS term represents the negative impact of wild horse grazing on the marginal productivity of forage in livestock production, and hence acts to decrease the steady state forage level, F^*.

The second RHS term is a nonnegative "marginal livestock effect" which captures the dependence of livestock forage consumption on the forage stock. The marginal livestock effect is zero when livestock consumption does not depend on the forage stock, $Cn_s'(F) = 0$; grazing costs per animal are zero, $g_f = c = 0$; and/or wild horses consume the entire sustained forage yield each period, $G(F^*) = Cn_h(F^*)H$. A marginal livestock effect greater than zero reduces the impact of the discount rate, and thus acts to increase the steady-state forage stock. The effect is weak when livestock consumption depends on forage stocks but grazing efficiency is very high. Livestock easily find food even at relatively low forage levels, hence, investing in high forage densities by decreasing livestock densities is not profitable. The singular forage density is at (or close to) F^{gr} (assuming momentarily that $p_f = p_h = 0$). On the other hand, the effect becomes stronger as livestock grazing efficiency decreases since grazers benefit from higher forage densities. Hence, investing in forage densities higher than F^{gr} by decreasing stocking densities becomes increasingly profitable.

The third RHS term measures the ratio of the return per pound of forage left on range to provide nongrazing services and wild horse grazing to the return per pound of forage consumed in livestock production. Hence, the term reduces the impact of the discount rate and adjusts the optimal sustained forage stock upward as the relative profitability of supplying nongrazing services and wild horse grazing increases.

Substituting equations 6, 7, and 8 for $G(F)$, $Cn_s(F)$, and $Cn_h(F)$, respectively into equation 16, results in a quadratic equation in F

$$(17) \quad F^2 + \frac{[(a-r-qH)P + bK(g_f+c) + c^x(p_f+p_hqH)]}{2bP} F + \frac{rK(g_f+c)}{2bP} = 0$$

where $P = p_w mc^x - (g_f+c)$. The positive root, given by the quadratic formula, gives the singular forage solution as a function of the fixed parameters of the grazing model

$$(18) \quad F^* = F^*\{p_w, c, r, a, b, c^x, K, m, q, p_f, g_f, p_h, H\}$$

The singular forage solution, F^*, is the standing stock remaining each period after the associated sustained yield, $G(F^*)$, is grazed by a present-value maximizing level of livestock and an exogenously determined wild horse population. Hence, it is the magnitude available to supply nongrazing uses when the grazing system is in bioeconomic equilibrium.

THE COUNTERBALANCING INCENTIVE SYSTEM

The counterbalancing incentive system generates prices designed to induce the permittee-steward to select a cattle stocking strategy accomplishing two purposes. First, the strategy sustains a standing vegetation level satisfying nongrazing uses. Second, the sustained yield generated by the sustained vegetation level satisfies the periodic grazing needs of a present-value maximizing level of livestock and an exogenously determined wild horse population. The incentives are formulated so that the permittee realizes a steady-state wealth position consistent with some specified prior level, for example, that under current grazing fees and no compensation for wild horses or sustained forage.

The offsetting mechanism requires the construction of "iso-supply" and "iso-PV" (present value) functions. The iso-supply function gives the combinations of p_f-g_f which induce the permittee to sustain the vegetation level satisfying multiple-use, F^{mu}. Target forage level F^{mu} can be selected optimally by incorporating demand-side analyses of multiple-use benefits. However, this paper assumes that it is an exogenous variable since the FLPMA requires it to be determined by public rangeland managers.[13] The wild horse population grazing the permittee's allotment is also assumed to be determined by public rangeland managers consistently with the WFRHBA. The wild horse compensation rate, p_h, is arbitrarily set by the government. The iso-PV function is composed of the p_f-g_f combinations which hold the present value of livestock profits constant at a given level. The offsetting price incentives are given by two equations yielding the combination of p_f-g_f at the intersection of the two functions.

The Iso-supply Function

Equation 18 can be inverted into an iso-supply function by fixing a particular forage solution F^{mu} and solving for p_f as a function of variable g_f

$$(19) \quad p_f(g_f | F^* = F^{mu}) \quad = \quad a_1 + b_1 g_f$$

where

$$a_1 = -p_w m(a-2bF^{mu}-r) + (c/c^x)[(a-2bF^{mu}-r) - (k/F^{mu})(r+bF^{mu})] + (q/c^x)[p_w mc^x - c - c^x p_h]$$

$$b_1 = 1/c^x \; [(a-2bF^{mu}-r) - (k/F^{mu})(r+bF^{mu}) - qH].$$

The iso-supply function can be shown to be inversely related to the grazing fee g_f for all positive levels of forage and wild horses. An inverse relationship implies that the steady-state supply is sustained at a given forage level (and not increased) only if increases in p_f or g_f are met by decreases in the other. Increasing the wild horse population on the permittee's grazing allotment can be shown to: (1) shift the intercept of the iso-supply curve upward (downward) when the net return for diverting a pound of forage to livestock production, $(p_w mc^x - c)/c^x$, is greater (less) than the compensation for diverting the pound to wild horse grazing, p_h; and (2) give the iso-supply curve a steeper negative slope (see Figure 1).

The Iso-PV Curve

Suppose that the permittee's steady-state wealth position under the counterbalancing incentives system is to be held constant at the steady-state level consistent with stewardship under a fixed status quo grazing fee, $g_f = g_f^{sq}$; no compensation for forage supporting nongrazing uses, $p_f = 0$; and a wild horse population of zero, i.e.

$$(20) \quad PV(S^{mu},F^{mu},H|p_f,g_f,p_h) = PV(S^*,F^*|g_f=g_f^{sq},p_f=0,H=0) ,$$

which is equal to

$$(21) \quad DF_t\{[p_wW(F^{mu}) - (g_f+c)]S^{mu} + p_fF^{mu} + p_hqF^{mu}H\} =$$

$$DF_t\{[p_wW(F^*) - (g_f^{sq}+c)]S^*\}$$

where DF_t is the relevant discount factor. The iso-PV (present value) curve is derived by solving equation 21 for p_f in terms of variable g_f:

$$(22) \quad p_f(g_f|dPV=0) = a_2 + b_2g_f$$

where

$$a_2 = [p_wW(F^*)-(g_f^{sq}+c)][S^*/F^{mu}] - [p_wW(F^{mu})-c][S^{mu}/F^{mu}] - p_hqH$$

$$b2 = S^{mu}/F^{mu}$$

The tradeoff between p_f and g_f in the iso-PV function is positive since

$p_f'(g_f) = S^{mu}/F^{mu} > 0$. Hence, for steady-state profits to remain constant, increases in p_f or g_f must be met by increases in the other. Increasing the wild horse population on the permittee's grazing allotment shifts the intercept of the iso-PV curve down while leaving the slope unchanged (See Figure 2).

Offsetting Incentives

The intersection of the iso-supply and iso-PV curves gives the counterbalancing combination (cc) of incentives (p_f^{cc}, g_f^{cc}) which results in the supply of range vegetation satisfying multiple-use and keeps the permittee's steady-state wealth intact. The two formulas calculating the counterbalancing combination are

$$(23) \qquad g_f^{cc} = \frac{a_2 - a_1}{b_1 - b_2}$$

$$(24) \qquad p_f^{cc} = a_1 + \frac{b_1(a_2 - a_1)}{b_1 - b_2}$$

where a_1, b_1, a_2, and b_2 are defined after equations 19 and 22. Figure 3 shows the counterbalancing combinations associated with two wild horse populations, H^1 and H^2, and an arbitrarily set wild horse compensation, p_h. As the population increases from H^1 to H^2, the counterbalancing grazing fee, g_f^{cc}, increases while the forage compensation, p_f^{cc}, may increase or decrease depending on the slope of the iso-supply curve associated with H^2.

The counterbalancing combination ensures that the sum of the total discounted forage and wild horse compensations (TC_f and TC_h, respectively) equals the difference between discounted profits earned under the status quo, DP^{sq}, and those earned under the fee system without compensation, DP^{cc}, i.e.,

(25) $$TC_f + TC_h = DP^{sq} - DP^{cc}$$

where DF_t is the relevant discount factor, ar

(26) $$TC_f = DF_t[p_f{}^{cc}F^{mu}]$$

(27) $$TC_h = DF_t[p_h qF^{mu}H]$$

(28) $$DP^{sq} = DF_t\{[p_w W(F^*) - (g_f{}^{sq}+c)]S^*\}$$

(29) $$DP^{cc} = DF_t\{[p_w W(F^{mu}) - (g_f{}^{cc}+c)]S^{mu}\}$$

Note that if the government sets p_h at a relatively high level, the intersection of the curves in Figure 3 may occur at a negative level of p_f. In this case the forage compensation payment becomes a tax in order to maintain the balance dictated by equation 25.

Illustration

The counterbalancing incentive system is illustrated numerically with an application to a "typical" stocker operation on public rangeland. This exercize is not intended to be an empirical analysis since the allotment specific data required to estimate the physical relationships in the system are not generally available. However, previous grazing research [15],[16] has hypothesized reasonable parameter values which this paper adopts solely to illustrate how the system would work if implemented and the required date were collected. The standard values are recorded in Table I along with footnotes detailing the sources and reasoning behind the choices.

The status quo is assumed to be permittee stewardship (i.e., the permittee is free to optimize eq. 1); a wild horse population of zero, the current grazing fee of \$.045/animal/day (\$1.35 AUM); and no compensation for ungrazed forage, $p_f = 0$. The optimal sustained vegetation stock and stocking rate in status quo are calculated to be $F^* = 2150.2$ lbs. d.m/acre and $S^* = .3126$ head/acre. Discounting the flow of net benefits over a single 150 day grazing season (and assuming that the grazing system is in equilibrium the entire season) results in a present value of livestock production of \$17.138/acre.

The government has typically sought to control livestock stocking rates to achieve forage levels maximizing sustained vegetation yield, F^{msy} [12]. Hence, it is assumed that $F^{mu} = F^{msy}$, which is calculated to be 2230.5 lbs. d.m./acre. The cattle stocking rate which sustains F^{msy} through time is $S^{msy} = .31298$. The wild horse compensation rate is arbitrarily set at $p_h = \$.005$/lb/day.

Table II shows counterbalancing grazing fees and forage compensations calculated for wild horse populations ranging from 0 to .5 head/acre. The table also shows that each combination results in the *status quo* present value, \$17.138/acre. Table III demonstrates that the total discounted compensation earmarked for the permittee over the course of a 150 day season equals the difference between discounted grazing profits earned under the *status quo*, and those earned under the fee system without compensation. Total compensation ranges from \$1.15/acre when the wild horse population is zero to \$9.95/acre when the population is .5 head/acre.

DISCUSSION

To summarize, the public rangeland manager determines the wild horse population grazing the permittee's allotment and the sustained vegetation level satisfying nongrazing uses. The manager then calculates a counterbalancing combination of grazing fee and compensatory forage payment associated with an arbitrarily set compensatory wild horse payment. The counterbalancing incentives: (1) induce the permittee-steward to voluntarily select a sustained cattle stocking rate accommodating wild horse grazing and nongrazing uses; and (2) keep the permittee's discounted livestock profits intact at a predetermined level. When underlying circumstances change (e.g., underlying biological or economic parameters change), the open-loop structure of the underlying grazing model requires the range manager to recalculate the grazing fee and compensation.

The sizable amount of allotment-specific information required by the counterbalancing incentives system thwarts its practical application. However, limited application may be practical if the government uses the theoretical economic and ecological relationships set out in the analytical model as a basis for iterating toward a combination of grazing fee and compensation that induces the desired cattle stocking response. In this way, the permittee (who has more of the required information than the government) reveals his valuation of the opportunity costs of converting forage to various levels of nonlivestock use.

Limited application of the system requires that the compensatory payments be financed. One possibility is for the government to redirect grazing fee revenues back to permittees or to use general tax revenues. Another possibility is to assess a fee for nonlivestock services to specific beneficiary groups whenever they can be identified. Some beneficiary groups are readily identified by their rent seeking activities (i.e., lobbying and judicial activities) to promote their interests.

The major argument against assessing beneficiary groups a nonlivestock use fee is that it is opposed to the interpretation that nonlivestock users give the public trust doctrine; namely that they are entitled to enjoy nongrazing uses of public rangeland without cost. The major argument for assessing a nonlivestock fee is that beneficiary groups are forced to face a portion of the social costs generated by the uses they promote (e.g., the huge opportunity and incidental costs of capturing and holding excess wild horses). Hence, they are induced to be more economical in their requests. Moreover, donating members of these groups may also benefit as donations finance conservation directly through nonlivestock fees, instead of indirectly through expensive lobbying and judicial activities. Finally, assessing nonlivestock fees to these groups seems symmetrically equitable in light of the grazing fees assessed specifically to ranchers.

CONCLUDING COMMENTS

The Federal Land Policy and Managment Act (FLPMA) requires the Bureau of Land Management (BLM) to allocate public rangeland vegetation to multiple uses at high-level sustained yields. The BLM's attempts to satisfy the FLPMA are made difficult by the special protection given wild horses under the Wild Free-Roaming Horses and Burros Act (WFRHBA) and successful judicial actions brought by animal rights activists groups. Under WFRHBA protection, wild horse numbers on public ranges have increased many fold and are consistently beyond levels that the BLM determines to constitute an ecological balance. Judicial decisions have exacerbated the overpopulation problem by severely limiting the measures the BLM can take to remove excess horses. Currently, the only alternative seems to be capturing excess horses and holding them in federal pens at great public expense. Hence, large numbers of excess horses remain to exert grazing pressure on deteriorating public ranges to the detriment of livestock and nongrazing uses.

This paper proposed an incentive system to induce federal grazing permittees to choose sustained cattle stocking strategies which accommodate government-set wild horse numbers and nongrazing uses. The use of an incentive system to solve the wild horse problem is compatible with the BLM's mandate under the Public Rangeland Improvement Act to explore innovative grazing management systems which might provide incentives to improve range conditions. In a nutshell, the incentive system uses a stick incentive in the form of increased livestock grazing fees to induce permittees to provide increased vegetation for consumption by wild horses and nongrazing uses. The negative impact of increased fees on permittee wealth is counterbalanced with a carrot in the form of compensatory transfer payments. Taken together, grazing fees and compensation payments induce multiple-use compliance by permittee-stewards and keep their discounted livestock profits intact at some predetermined level.

Practical application of the counterbalacing incentive system is hampered by the sizable amount of allotment-specific biological and economic information required to compute the offsetting incentives. However, limited application may be practical if the government uses the theoretical economic and ecological relationships set out in the analytical model as a basis for iterating toward a combination of grazing fee and compensation that induces the desired cattle stocking response.

Footnotes

1. Footnote to title

2. 16 U.S.C.A. secs. 1331-1340 (1971).

3. 16 U.S.C.A. sec. 1331 (1971).

4. 16 U.S.C.A. sec. 1333(a) (1971).

5. 16 U.S.C.A. sec. 1333(b)(2)(B) (1971).

6. Each horse costs taxpayers approximately $165 to capture and $2.25/day to sustain in captivity. The program has cost $92 million since 1980 [13].

7. 43 U.S.C. sec. 1701 (1982).

8. 43 U.S.C. sec. 1732(a) (1982).

9. 43 U.S.C. sec. 1901 (1982).

10. 43 U.S.C. sec. 1908(a) (1982).

11. 43 U.S.C. sec. 1901(a)(5) (1982).

12. President-elect Bush emphasized incentive-based environmental management when discussing his choice for Secretary of the Interior with the national press in Dec. 1988.

13. 43 U.S.C. sec. 315b (1982).

Table I

Parameter Values Used in Illustration

Symbol	Meaning	Units	Value
a^{a}	max. relative growth rate	day^{-1}	0.0042
b^{a}	plant growth parameter	$(\text{lbs. d.m./acre})^{-1}\text{day}^{-1}$	9.41E-07
$c^{x\,b}$	max. livestock consumption rate	lbs. d.m./head/day	15
m^{b}	livestock feed conversion	---	0.05
K^{c}	livestock grazing efficiency	lbs. d.m./acre	5
q^{d}	wild horse grazing efficiency	lbs. d.m./head/day	.0055
$p_w^{\ e}$	beef price	$/lb.	0.7628
c^{f}	average cost	$/head/day	0.156
$g_f^{\ c\,g}$	livestock grazing fee	$/head/day	0.045
r^{h}	real daily rate of interest	---	0.000154

[a] a and b are assumed to be about 5 % of those values characterizing perennial grassland of high productivity [16]. This reflects the relatively poorer quality of public grassland cited by Congress in the PRIA.

[b] A 500-600 lb. steer placed on the range is assumed to gain 3/4 lbs. per day by consuming a maximum of 15 lbs. d.m. per day (consultation with range specialists).

[c] No information was found to help select a value for K. Hence, K was selected so that the optimal stocking rate, S^*, equals the average rate on western rangeland (0.3126 head/acre) reported in [21].

[d] q was chosen so that a linear wild horse forage consumption response is approximately equal to a saturation response in the neighborhood of the multiple-use forage level, $F^{mu} = 2230.5$. The saturation response is $Cn_h = c_h^x FH/(F+K_h)$. The Stockman's Handbook [7] reports that an 882 pound mature horse at rest (maintenance) will consume $c_h^x = 13.9$ lbs. of feed/day. For lack of better information, it is assumed that wild horses are equally efficient grazers as livestock, i.e., $K_h = 5$. Total consumption rates for increasing wild horse populations are:

H	Linear response	Saturation response
.05	.613	.688
.25	3.067	3.441
.50	6.134	6.881

[e] p_w is the average of feeder steer prices for July and August 1987 (when steers are assumed to come off the range) [20].

[f] c is taken from an article in the Drovers Journal 12-17-87, where a permit holder in Montana kept a tally of man hours invested in the permit over a four-year period. Valuing each hour at $5, the total ran to about $4.68/AUM, or $0.156/head/day.

[g] The grazing fee has been fixed at $1.35/AUM ($0.045/head/day) for the last two years.

[h] r is the daily interest rate on AAA corporate bonds for June 1987 less the percentage change in price from June 1986-87 [6].

Table II

Counterbalancing Payments Associated With Varying Wild Horse Populations

Wild Horses	g_f^{cc}	p_f^{cc}	Present Value[a]
hd/ac	\$/hd/t	\$/lb/t	\$/ac
0	.07025	3.47E-6	17.14
.05	.10772	7.36E-6	17.14
.1	.13786	1.02E-6	17.14
.15	.16263	1.23E-6	17.14
.2	.18335	1.38E-5	17.14
.25	.20094	1.49E-5	17.14
.3	.21606	1.57E-5	17.14
.35	.22919	1.62E-5	17.14
.4	.24071	1.64E-5	17.14
.45	.25089	1.64E-5	17.14
.5	.25995	1.63E-5	17.14

[a] p_h arbitrarily set at \$0.005/lb/day.

Table III

Total Discounted Compensation[a]

Wild Horses hd/ac	$TC_f + TC_h$ \$/ac	$DP^{sq} - DP^{cc}$ \$/ac
0	1.4191	1.4191
.05	2.8875	2.8875
.1	4.2861	4.2861
.15	5.4357	5.4357
.2	6.3973	6.3973
.25	7.2135	7.2135
.3	7.9151	7.9151
.35	8.5245	8.5245
.4	9.0588	9.0588
.45	9.5312	9.5312
.5	9.9517	9.9517

[a] See equations 25-29.

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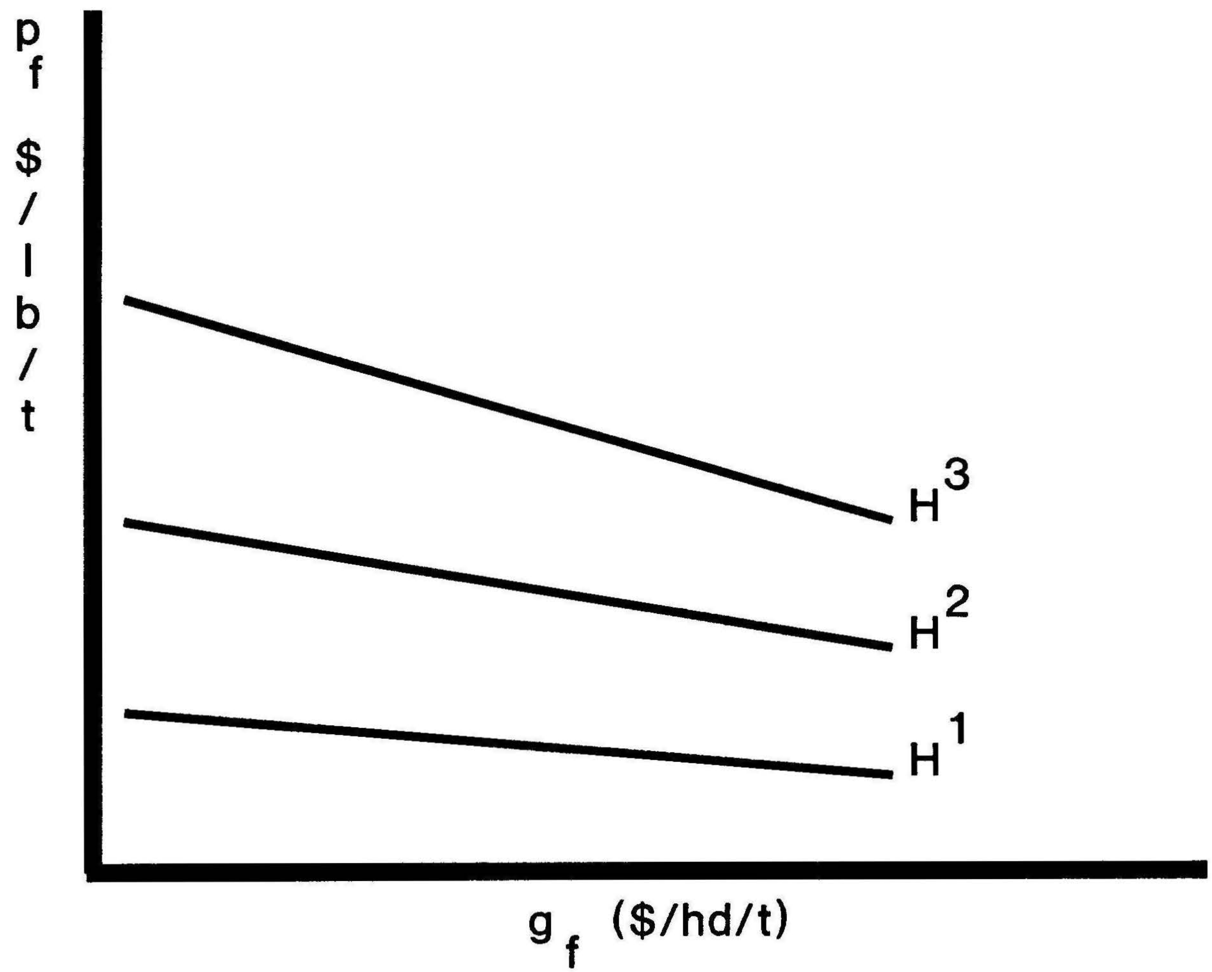
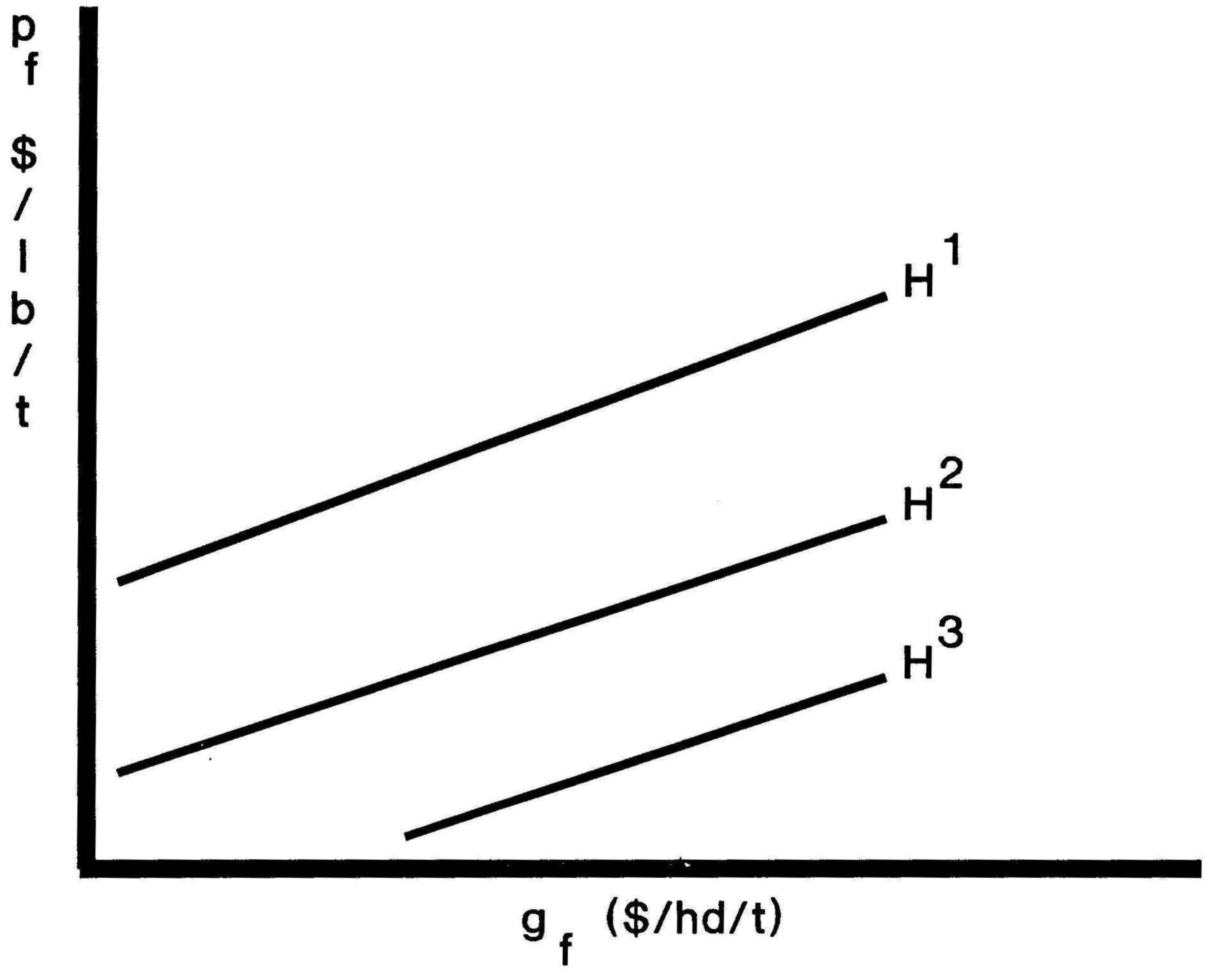
Figure 1: Iso-supply curves associated with increasing wild horse populations, $H^1 < H^2 < H^3$



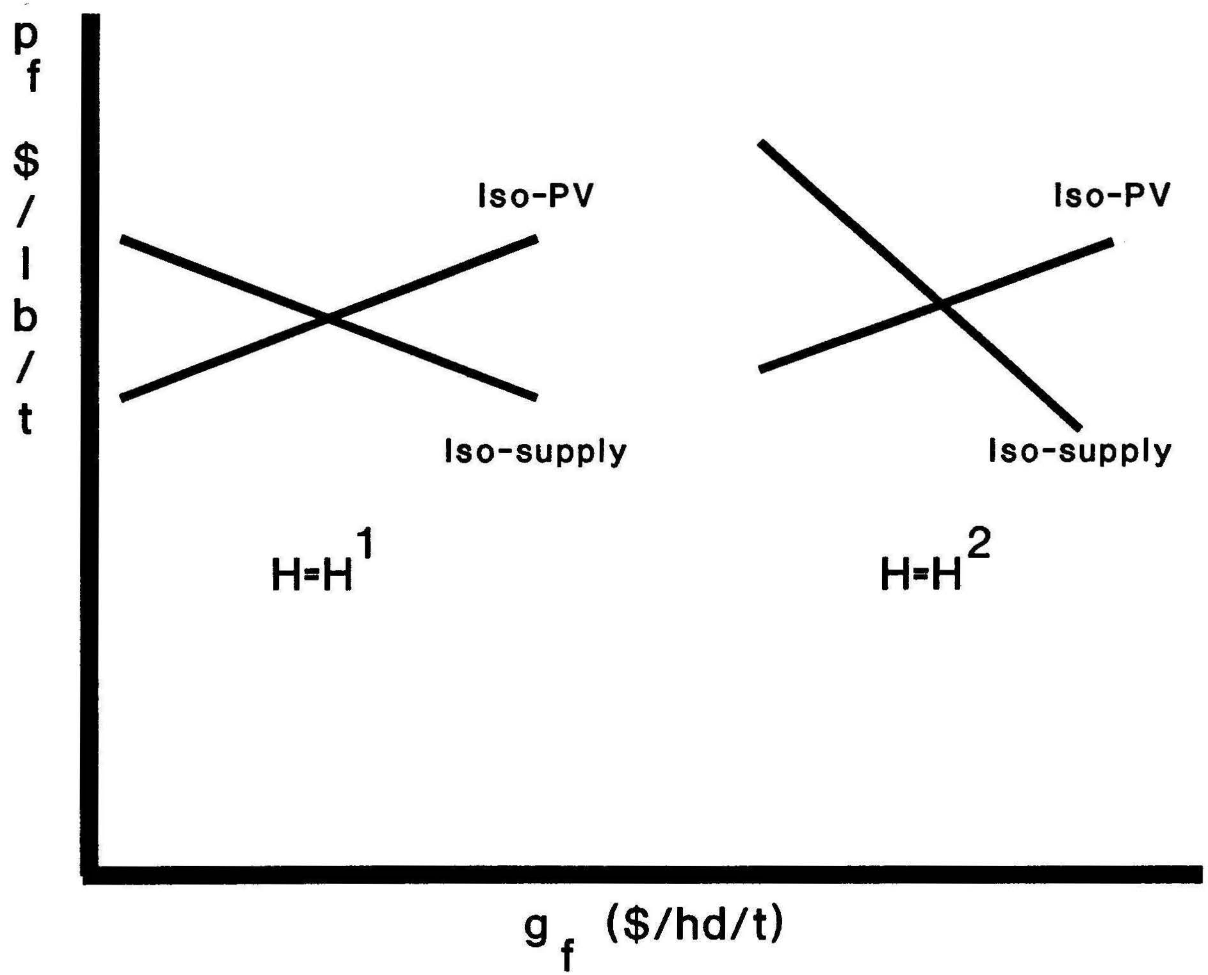
p_f
$/lb/t
H^3
H^2
H^1
g_f ($/hd/t)

Figure 2: Iso-PV curves associated with increasing wild horse populations, $H^1 < H^2 < H^3$



p_f
\$/lb/t
H^1
H^2
H^3
g_f (\$/hd/t)

Figure 3: Counterbalancing incentives associated with increasing wild horse populations, $H^1 < H^2$



p f
$ / l b / t
Iso-PV
Iso-supply
H=H 1
Iso-PV
Iso-supply
H=H 2
g f ($/hd/t)