Contracting Over Common Property: Cost-Share Contracts for Predator Control

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Abstract

Predator control cost-share contracts among livestock producers in North America date back to 1630. A model is developed which provides refutable implications for the structure and distribution of these contracts over time and space. Historical and contemporary state and county level data on sheep producer coyote control generally support the model.

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> When this ranch was opened, I poisoned and trapped the coyotes all out but it was like trying to dig a hole in the sea; they came right back again.
>
> E.P. Hilton, *Southeast of Tucson, AZ* (Young 1978).

Introduction

Livestock owners of the Massachusetts Bay Colony began jointly funding wolf bounties in 1630. Organized predator control funded by livestock owners existed in virtually every colonial settlement by the end of the 1700s, and moved westward with the cattle industry expansion of late 1800s. Many private livestock associations assessed dues to fund predator control, and public livestock assessments were also common. Assessment programs continue to be maintained through both private livestock groups and state and county government in the form of a per-unit tax on an easily monitorable input such as livestock inventories or land acreage.

This paper develops a model of an assessment contract that shows an inherent tradeoff between efficiency gains from internalizing abatement externalities and efficiency losses from misallocation of the assessed input. The model is then extended to examine the determinants of contract value and likelihood of contract formation. These contracts are examined empirically in various contexts. An analysis of contract structure shows how institutions are used to minimize contracting costs and how participation problems are addressed. A cross-county probit analysis is used to explain contract distribution, and the effects of producer heterogeneity on contract formation. These empirical applications provide broad support for the main predictions of the model.

Theory

Consider a set of landowners whose land lies within a predator population's range, and who reduce livestock depredation by lethal predator control. A number of widely cited population biology models hypothesize that wildlife distributes itself to make best use of available resources within its territory (Pulliam and Danielson 1991, Hestbeck 1988, Stenseth 1988), so lethal predator control on one landholding may reduce the predator density on neighboring landholdings as predators move to make use of the newly available food sources. When acting independently, producers do not account for the predator control benefits accrued by neighboring producers, and suboptimal abatement levels result. This problem is analogous to a wide range of common pool resource problems such as surface and ground water use, oil production, and insect pest control.

Sharing abatement costs. Incentives leading to suboptimal abatement may be addressed by implementing an assessment contract. A fee, τ, is collected from each producer per unit of a monitorable productive input such as livestock inventory or acreage. Producers do not pursue abatement directly, but instead each pays τx_i, which then is redistributed to the group in the form of abatement. Contracting costs will initially be ignored. The first-best case in which abatement levels, assessed-input levels, and the assessment τ are jointly chosen for all producers is

$$\begin{aligned} &\max_{\mathbf{a},\mathbf{x},\tau} \sum\nolimits_i R^i(\mathbf{a}, x_i) - (\tau + r) \sum\nolimits_i x_i \\ &\text{subject to} \qquad \tau \sum\nolimits_i x_i - c \sum\nolimits_i a_i = 0 \end{aligned} \tag{1}$$

where $\mathbf{x} = (x_1, x_2 \dots x_n)$ are assessed-input inventories for each producer, $\mathbf{a} = (a_1, a_2 \dots a_n)$ is group abatement on each producer's land, r and c are competitive input prices for x and a. Substituting $c \sum_i a_i$ for $\tau \sum_i x_i$ and solving results in first-order conditions

$$\sum\nolimits_j R^j_{a_i} - c = 0 \qquad \forall\ i \tag{2a}$$

$$R^i_{x_i} - r = 0 \qquad \forall\ i. \tag{2b}$$

Implicit in this result is that τ is set to satisfy (2). Equation 2a implies that abatement will be distributed such that its marginal value is equal across landholdings.

In reality, producers are free to choose levels of x independently.[1] In order to maximize their individual profits subject to the assessment, producers will set x_i such that their marginal gains from x equal their own marginal costs (including τ): $R^i_{x_i} - (r + \tau) = 0$. Compare this first-order condition (which would enter as a constraint in problem (2)) to the first-best condition (2b). Given diminishing marginal productivity of x, less x will be used relative to first-best. It can be shown that efficiency gains are larger when R_{x^i} (value marginal product of x) is inelastic and $\sum_j R^j_{a^i}$ (total value marginal product of a^i) is elastic.

Contract value and implementation. A contract value function is developed below which provides refutable implications regarding the determinants of contract structure, value, and formation. To simplify matters, additional structure is imposed on the group's aggregate revenue function. Let $n\bar{R}\big(1 - \delta(A, \mathbf{z})\big)$ be the after-damage revenues aggregated over all n participants, where $n\bar{R} = \sum_j R^j$ are total potential revenues, $\delta(\cdot) \in [0, 1]$ is the damage function, A is abatement expenditures summed over all participants, and $\mathbf{z}$ is a vector of factors affecting the marginal product of abatement.

The following assumptions are implicit in this structure. Assessed-input inventories are exogenous for each participant, so that producers do not respond to damage or assessments by changing assessed-input inventories.[2] It follows that for a given producer group, the efficient level of abatement can be attained by choosing the optimal assessment level τ. Abatement is assumed lethal to the predator, and reduces the average or expected predator stock on all landholdings. The damage rate δ is identical across all producers, and the marginal product of abatement for a given abatement level is equal across producers, with $\delta^i_{a_j} < 0$ and $\delta^i_{a_i a_j} > 0$, for all i and j. Although δ is assumed identical across producers, inventories of productive inputs need not be identical, so total damage may differ across producers. The marginal product of abatement is hypothesized to increase with increases in

[1] I know of no case in which assessed inputs are limited by a contract.

[2] Assessments (τ) are small compared to the value of the assessed input r, so distortionary effects will be small in this case. All assessments are less than a dollar/head/year for sheep, whereas the market value of sheep in 1997 was \$40 to \$50 per hundredweight for sheep and \$100 per hundredweight for lambs.

four elements of $\mathbf{z}$: the initial (before abatement) predator stock, $\bar{w}$; the proportion of the predator population's territory owned by participants, l; the concentration of participants' land within the predator's territory, z; and the marginal propensity for the predator to impose damage to livestock, δ_w.

Contracting is costly. Three sources of contracting costs and difficulties are considered. First, the costs of assessment collection and abatement distribution increase with group size (Lueck and Yoder 1997, Lueck 1994, Libecap 1989). Second, the likelihood of contract formation depends in part on the skewness across producers of the net gains from a contract. When net benefits of a proposed assessment are highly skewed, more potential participants may opt out, and costly bargaining to redistribute group abatement costs may be exacerbated (Libecap 1989, p. 24). Third, the existing institutional structure within which a contract is developed affects contract costs and structure.

A group chooses abatement levels and a cost-sharing rule to maximize group profits subject to participation constraints and contracting costs. This can be viewed as a two-part problem. First, abatement levels are set (implicitly by setting τ) to satisfy (2a) for every feasible cost-sharing rule $s \in \mathbf{s}$. Associated with each cost-sharing rule is ρ, the correlation between the costs and benefits of a contract among producers.[3] Second, the cost-sharing rule s that provides the highest group profits (through its effect on participation) is chosen. The group selects A and s to solve

$$\max_{A,\mathbf{s}} \Pi^c = n(\rho)\bar{R}(1-\delta(A;\mathbf{z})) - c^c A - f(n(\rho),\rho,\Omega) \tag{3}$$

$$\text{subject to} \qquad \pi_i^c - \pi_i^p \geq 0 \qquad \forall\, i,$$

where Ω describes characteristics of existing institutions that affect contracting costs. Group abatement techniques may differ from those used by independent producers, and economies of scale may affect the marginal cost of abatement. Therefore, group marginal abatement

[3] Although ρ is chosen via the cost sharing rule, ρ is parametric for any given cost-sharing rule.

costs, c^c, may be different from individual marginal abatement costs, c^p.

Predator control provides positive production externalities. Therefore, group abatement demand is larger than the sum of independent abatement demand.[4] Maximization of (3) leads to aggregate abatement levels of A^c, with $A^p < A^c$, where A^p is the sum across producers of expenditures in absence of a contract and A^c are group abatement expenditures.[5] The value of a contract can now be shown as the difference between the total value of production under the optimal contract (subject to participation constraints and contracting costs) and the total value of production under independent action:

$$\begin{aligned} V &= \Pi^c - \Pi^p \qquad (4) \\ &= \big[n(\rho)\bar{R}(1-\delta^c(A^c;\mathbf{z})) - c^c A^c - f(n(\rho),\rho,\Omega)\big] - \big[n(\rho)\bar{R}(1-\delta^p(A^p;\mathbf{z})) - c^p A^p\big], \end{aligned}$$

where $\Pi^p = \sum_{i\in n}\pi_i^p$ is the sum of profits in the absence of a contract. Exogenous variables are $\bar{R}$, z, l, δ_w, $\bar{w}$, c^c, c^p, ρ, and Ω. The comparative statics (omitted) follow from the Envelope Theorem and are the basis the hypotheses listed below.

Voluntary versus mandatory participation. Predator control is a non-excludable good, and a producer may gain from a contract without bearing any costs if the contract is maintained without that producer's participation. If non-participation is highly detrimental to potential contract value, a contract may stipulate mandatory participation and include punishment provisions for nonparticipation.[6] Two forms of mandatory assessments exist: predator control dues required by private producer associations, and public assessments enforced by law.

[4] This assumes that if there are diseconomies of scale in abatement, they are not too large.

[5] If the contract incorporates all producers in the region ($n = N$), then A^c is at first-best levels assuming contracting costs are uncorrelated to abatement expenditures.

[6] Carlson and Wetzstein (1993) and Carlson, Sappie and Hammig (1989) discuss mandatory participation in the context of insect pest control.

Empirical evidence

In summary, The model predicts that the value and likelihood of a predator control contract among livestock producers will increase in response to a(n):

1. *increase in the output price or inventories of the damaged inputs.*
2. *increase in the predator density.*
3. *increase in the marginal propensity of the predator to impose damage.*
4. *decrease in the marginal cost of group abatement techniques.*
5. *increase in aggregate producer landholdings as a proportion of the wildlife territory.*
6. *increase in the spatial concentration of producers within the wildlife's territory*
7. *increase in the correlation between cost shares and contract benefit shares.*
8. *decrease in measurement, collection, and abatement redistribution costs.*
9. *decrease in the cost of enforcing participation.*
10. *Finally, existing institutions will be used in ways to reduce contracting costs.*

These hypotheses will be examined in a number of settings. A discussion of contract structure will be discussed first, because it provides useful background for subsequent sections.

Monitoring costs and the choice of assessed input. The model implies that *ceteris paribus*, the best input on which to base assessments is that which is most closely correlated with the value of damage abatement (hypothesis 7). Public assessments tend to be based on livestock inventories or associated quantities such as wool weight (table 2, page 10). In contrast, private groups such as trapping clubs in Texas and the Cherry County Association of Nebraska virtually always base their assessments on land acreage rather than livestock inventories (McGinley 1997, Savage 1998).

Because both acreage and livestock inventories routinely are collected by tax assessors, that public assessments tend to be based on livestock inventories suggests that livestock inventories are more closely related to contract benefit shares than other monitorable production capital. Private groups do not have access to the private tax information, and producers may be hesitant to share such information. Livestock must be counted by a group representative or employee, both of which are costly options.

Two characteristics of land reduce counting and monitoring costs for private groups: acreage holdings do not change as often as livestock inventories for any given producer, and landholding size is likely to be more difficult to misrepresent to the group than the size of a herd. Assessing acreage reduces contracting costs for private groups without cheap information about participants' livestock inventories. Thus, using land acreage rather than livestock as the basis for an assessment is consistent with hypothesis 8.

The participation problem. Many historical and contemporary examples of both voluntary and mandatory predator control assessments exist. The model provides insight regarding the likelihood of voluntary versus mandatory assessments.

The Texas Wildlife Damage Management Service (TWDMS) subsidizes predator control on private land. The TWDMS sets a subsidized trapper fee, and landowners form "trapping clubs". These clubs range in size, with an approximate average of about 10 landowners per club (Nunley 1998, Savage 1998). Participants benefit from economies of scale, because increasing group size reduces each participants cost of employing the services of the TWDMS; c^c decreases and the value of a contract increases (hypothesis 4).

Aerial hunting has become a common method of predator control in the West (Phillips and Nunley 1995). Using helicopters or airplanes requires large land areas for it to be a low-cost abatement alternative. Except for owners of exceptionally large landholdings, producers must share in the cost of renting aircraft with nearby neighbors. Despite the incentive to underinvest in predator control, groups form in order to take advantage of economies of scale. Thus, voluntary assessments appear often to be driven by reduced group abatement costs relative to independent abatement costs (hypothesis 4).

When economies of scale in abatement are weak, the effects of shirking and non-participation may be significant enough for a group to induce participation by other means. After funding its local wolf bounty program through voluntary contributions from its members for 8 years (from 1904 to 1912), the Piceance Creek Stock Growers Association of Rio Blanco County, Colorado developed by-laws stipulating that cattlemen who did not pay their wolf dues could not participate in spring and fall roundups:

> Members of this association refused to aid those cattlemen in arrears with wolf assessments in any cooperative help with their roundups, whereby aid from the whole cattlemen's group was of great import in such stock gathering. This meant, therefore, that whosoever reneged on the payment of his wolf bounty fee must singly round up his own cattle, do his own branding, and run his own chuck wagon — work of no small magnitude for a single individual where many square miles of cattle range riding was involved (Young 1944, p. 364).

Excludable membership benefits — economies of scale in roundups — are made contingent on contributions to group predator control, thus providing a means of reducing the costs of promoting participation by using existing cooperative institutions (hypothesis 9). Even today, a number of sheep producer associations in western states add surcharges to their membership dues for predator control.

Wolves and cattle, coyotes and sheep. Cattle production increased dramatically in the West during the latter half of the 1800s. "What eventually intensified the wolf problem in the West ... , more than any other factor, was the building up of [the] cattle industry...(Young 1944, p.377)." Indeed, most predator control livestock assessments in the West during the late 1800s were instituted by cattle producers during the industry expansion of that period (Young 1944, Brown 1983) (hypothesis 1).

By 1915 gray wolves were limited mainly to the rocky mountain states and northern Minnesota, Wisconsin, and Michigan (Young 1944, p. 58). Wolf populations dwindled in the rocky mountains during the period after 1915 (Brown 1983). Coyote populations, on the other hand, have generally not declined. Since the early 1900s sheep producers, not cattle producers, have been most active in contracting over predator control (Young 1978, Feldman 1996). A primary reason for this switch from cattle producer activity to sheep producer activity is simple: wolves have the ability to kill cattle, but coyote depredation on cattle is uncommon and limited to the occasional calf (Eadie 1954). As wolf populations diminished, the marginal value of predator control to cattle producers decreased (hypotheses 2 and 3). Thus, as the model predicts, cattle producers now have less incentive to form contracts over

Table 1: Coyote harvest in the *Predator Free Zone*, Texas.

year	1950	1960	1970	1980	1990	1994
coyotes killed	0	118	420	637	2,168	2,594

predator control. In contrast, sheep producers still actively cooperate in predator control today because coyotes remain.[7]

Coyote density, sheep concentration, institutional heredity. Despite a long history of predator control in Texas and a declining sheep and goat industry, a referendum was held in 1992 by the Texas Sheep and Goat Raisers' Association (TS&GRA) to impose assessments on sheep and goats to fund predator control.[8] The referendum was based on the Texas Commodity Referendum Law of 1969, and was modeled after a beef cattle assessment that had recently been implemented (though not for predator control). These factors — the referendum law and the successful implementation of previous referenda — most likely reduced the costs of implementing the predator control referendum (hypothesis 8).

Another factor promoting the predator control referendum is that the coyote population in the major sheep producing region of the state, the Edwards Plateau, has been increasing. By 1950, predator control efforts had eliminated coyotes and wolves from the plateau, and with the help of a drought, producers managed to keep the plateau a "coyote-free zone" for most of the 1950s (Nunley 1995). Table 1 shows that the number of coyotes killed in the coyote-free zone of the 1950's has increased dramatically over time (Nunley 1995). Predator control efforts may have increased over these years, but the increase in the number of coyotes killed suggests (though it does not imply) that the population of coyotes has increased substantially. The model predicts that the value of a contract and the likelihood of

[7] In the forested northern regions of the great lakes states where little livestock production occurs (Dale 1960), the wolf and coyote were seen to be competing with game hunters — market hunters beginning in about 1860, and later sport hunters. These groups, not livestock producers, were the dominant forces behind organized predator control in these regions (Thiel 1993). This is consistent with the model as well.

[8] The TS&GRA delineated four districts based in part on livestock densities. A vote to implement a livestock assessment was based on total vote in the district, rather than at the county level, as is the case in several other states. Approximately 75% of producers in each district voted in support of the assessment. Of 254 counties, 111 are in one of the three assessment districts. (McSwain 1996).

Table 2: Assessment programs in western states.

state	# of counties	petition requirements	industry	based on	units
CO	5 of 63	51% needed to change	Sheep/cattle	livestock	head
ID	All	Mandatory	Sheep	wool	Lbs.
MT	52 of 56	51% to initiate/change	Sheep or cattle	livestock	head
NE	None	67% to initiate/change.	Sheep/cattle	livestock	head
NV	All	Mandatory	Sheep	livestock	head
SD	All	Mandatory	Sheep & cattle	livestock	head
TX	111 of 254	by referendum	Sheep	sheep	head
UT	All	Mandatory	Sheep, cattle, turkey	wool[sheep] (others)	Lbs. (head)
WY	All	Elected reps. request changes	Sheep/cattle	livestock	head

Source: State statutes, conversations with USDAWS regional directors, and Uhden (Uhden 1996). Data applies to 1992 through 1998.

contract formation will increase as predator density increases (hypothesis 2). The formation of a head assessment in 1992 to increase overall predator control efforts is consistent with the model. Also, the Texas sheep and goat industry is geographically concentrated, with 85% of production taking place in 10% of the counties. This means that the effects of abatement on the land of one producer are likely to affect neighboring producers more, and a coalition among sheep and goat producers more likely than if their landholdings were more diffuse (hypothesis 6).

County assessment programs. Predator control livestock assessments are codified in the statutes of nine western states (table 2). These statutes either require an assessment in all counties, or allow counties the option to implement one. Of the nine states with county assessment programs, three states — Colorado, Montana, and Texas — allow non-participation *and* have some counties that do impose head assessments and some that do not.

The distribution of active assessment programs across counties within these three states is explained using a probit regression. For Montana and Colorado, each county may be seen as one observation of the choice to impose an assessment. The Texas program is divided

Table 3: Probit Regression for county predator control head assessments.

-2 LOG L=271.0;	Dependent Variable:			obs
χ^2=241.1 (p=0.0000)	assessment=1			168
correctly predicted: 83.1%	no assessment=0			204
Variable	marginal	Z-stat	P-value	mean
Constant	-0.3466	-2.89	0.004	
Sheep per pasture acre	2.7700	2.07	0.039	0.0196
Cattle per pasture acre	-0.2257	-1.56	0.119	0.2687
Pasture, prop'n of county	0.2753	1.67	0.094	0.4132
CV*, sheep inventories	-0.1143	-2.55	0.011	1.5025
CV, farmsize	-5.E-06	-0.55	0.584	3635.7
Avg. sheep farm size	4.E-05	2.23	0.026	2026.9
Human population density	-0.2596	-0.86	0.390	0.1033
sheep farms÷human pop.	62.741	3.11	0.002	0.0044
sheep farms÷county acreage	8851.0	2.99	0.003	4.E-05
Montana Dummy	0.4262	2.39	0.017	0.1505
Colorado Dummy	-0.7813	-3.86	0.000	0.1667

*CV stands for coefficient of variation. Data: U.S. Census Bureau and Census of Agriculture, 1992. San Juan county, CO is excluded due to incomplete data.

into four districts, but to the extent that districts are delineated as if to maximize contract value and the likelihood of passing the referendum, individual county data will provide useful information. Furthermore, counties may vote to be included in a district on any election year (biennial). Therefore, Texas counties are also treated as individual observations.

The probit regression results generally support the predictions of the model (table 3). A high sheep density per pasture acre leads to a higher probability of a sheep assessment program (hypothesis 2). Controlling for cattle density, a large percentage of county land devoted to grazing leads to a higher probability of sheep assessments (hypothesis 6).[9]

If the distribution of abatement benefits perfectly coincides with producer inventory shares (and hence cost-shares), then an increase in the variance of sheep inventories should not effect the likelihood of assessment implementation. Heterogeneity over other margins that leads to a skewed net benefit distribution may reduce the likelihood of assessment

[9]This is consistent with Pridgen (1980) and Rook and Carlson (1985), who found that cotton farmers are more likely to join a pest management group if a large proportion of the farmer's land is planted in cotton.

implementation. With this in mind, note that the coefficients on *CV, farmsize* and *CV, sheep inventories* are both negative, the latter being significantly different from zero. Both types of heterogeneity leads to reductions in the likelihood of contract formation (hypothesis 6). A positive effect of livestock inventory heterogeneity on the likelihood of contract formation may represent a comparative advantage of public livestock assessments relative to private assessments, which are commonly based on acreage.

Finally, As sheep farmers and sheep farming become a relatively more prominent industry in a region, sheep-specific assessments will become more likely (hypotheses 4 and 5). This is consistent with the positive coefficients on *sheep farms* ÷ *county acreage* and *sheep farms* ÷ *human pop[ulation]*.

Conclusion

This paper develops a model of a cost-share contract in which a per unit assessment is placed on a productive input, the revenues from which are used for group-funded predator control on participants' land. The model implies a tradeoff between efficiency gains from internalizing abatement externalities and losses from private reductions of the assessed input. The model is extended to provide refutable hypotheses regarding contract structure, value, and likelihood of implementation. Econometric and anecdotal evidence generally supports the model. The model may be adapted to provide insight into the potential value of assessment programs for a wide range of common property or public goods such as groundwater and pest management. It also provides an empirically useful framework for understanding the distribution and incidence of cooperative resource use.

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