Abstract

Yoder, Jonathan Keith. Wildlife on Private Land: Contracting over Wildlife-Inflicted Property Damage and Abatement. (Under the direction of Gerald Carlson.)

In its search for sustenance and cover, wildlife imposes costs on agricultural property owners. A mosaic of private and public contractual arrangements has evolved to address this problem, with private agricultural organizations, county commissions, wildlife agencies and state and federal departments of agriculture all involved.

A set of prevalent contractual arrangements over wildlife damage is formally examined in this dissertation, including abatement labor sharing, abatement cost sharing, and damage sharing contracts. Wildlife is modeled as a public and potentially common-property good that is affected by and destructive to private agricultural inputs. Independent production choices that affect the wildlife stock may impose externalities on neighboring landowners or other interested parties. Contracts develop to account for these externalities, and contract structure is dependent on the costs associated with potential contract mechanisms. A fundamental problem of contracting over wildlife damage is that abatement labor effort is difficult to monitor by participants. Contract structures reflect this difficulty.

Two of the theoretical models form the basis for empirical examinations. First, livestock producers in many western states maintain cost-share programs for predator control. A contract value function is developed for a prevalent cost-sharing rule, and the model is used to explain the observed structure and incidence of these pro-

grams across counties and states. Second, landowner incentives to alter crop choice in the face of deer-inflicted crop damage are examined. A multicrop econometric model allowing for differential damage rates across crops is estimated using data from Wisconsin. The model provides implications about the effects of changes in certain wildlife agency policy instruments.

This dissertation expands the existing economic literature on wildlife damage, as well as the literature on joint production of private and public goods, the economics of pest and wildlife management, and the empirical literature on contracting over common-property and public goods. Private landowners provide much of the land on which wildlife resides, and their incentives are important in the calculus of wildlife management. This dissertation hopefully will provide a framework useful to wildlife managers for understanding the impacts on and the reactions of private landowners to wildlife damage policy.

Wildlife on Private Land: Contracting Over Wildlife-Inflicted Property Damage and Abatement

by

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Biography

The Author was born in Goshen Indiana on January 1, 1966. He lived in Moshi, Tanzania from age 7 to 12, and graduated from R. Nelson Snider High School, Fort Wayne Indiana in 1984. He received a Bachelor of Arts from Indiana University in 1989, with a double major in Biology and Journalism and a certificate in African Studies, and studied in Nepal during the Fall of 1988 through San Francisco State University. He worked as a research assistant at the Florida Museum of Natural History at the University of Florida, Gainesville until 1991, and received a Master of Science in Applied Economics from Montana State University in 1994. While working toward a doctorate in economics at North Carolina State University, the author held research and teaching assistantships through the Department of Agricultural and Resource Economics and the Department of Economics. The author is married to Holly Ann White and has two children, Ian and Kathryn.

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CHAPTER 1

Introduction

As soon as domestic livestock were brought by settlers to the New World, the wolf began taking its toll. Almost immediately, settlers instituted organized predator control to deal with the problem of livestock losses to wolves. As early as 1630, the Massachusetts Bay Colony passed laws offering bounties on wolves, funded by assessments on livestock owners. In the 1640s, Rhode Island paid hired hunters by the day to kill wolves, and New Plymouth Colony towns were required under penalty of fine to maintain wolf traps. In 1717 Barnstable County (Cape Cod) planned to erect a six-foot fence in order to keep wolves off of the cape, but the plan failed because of opposition from townships on the other side of the proposed fence site.

Organized wolf control efforts continued to grow throughout the next century, and by the end of the 1700s, wolf bounties were offered in virtually every colonial settlement. In the latter half of the 1800s, wolf populations in the East were diminishing, but organized predator control in the form of bounties, hired hunters, livestock assessments and private cooperation moved westward with the expansion of the livestock industry. County and state governments as well as private livestock associations were all actively involved in predator control, and by the 1950s, the wolf population in the lower 48 states was reduced to a few hundred (McIntyre 1995, Young 1944).

Wolves are now protected by state and federal laws, but are still a concern of livestock producers. Ubiquitous wolf bounties have effectively vanished, replaced by public agencies utilizing a host of lethal and non-lethal damage abatement techniques. Wildlife departments regulate killing and harassing wolves, but in many cases provide

support for livestock producers to help reduce wolf-inflicted property damage. For example, Minnesota state statutes provide for funds to hire certified predator control agents to kill wolves found to be damaging livestock. Since 1987 the private environmental group Defenders of Wildlife has compensated ranchers for livestock losses inflicted by wolves reintroduced into the Yellowstone National Park area. Defenders of Wildlife also provide funds to livestock producers for wolf damage abatement.

The evolution of the relationship between livestock owners, the wolf, and more recently, environmentalists in North America illustrates many of the private and public institutional responses that have evolved throughout the world to deal with wildlife-inflicted property damage. Prior to the mid 1900s, wolves were viewed as common pests by virtually everyone, and cooperative private and public programs evolved to eradicate them. Like wolf bounties, bounties on a wide range of species were common until the middle of this century, but have virtually disappeared. Western livestock producers formed "wolf clubs" to share abatement labor, much like farmers in other regions share labor in "rabbit drives" to drive rabbits off their land, and catfish farmers in Mississippi share the responsibility to harass local cormorant roosts to reduce depredation. Abatement cost sharing arrangements like those used by livestock associations and departments of agriculture for predator control today are used to address damage by a variety of species, such as dingo predation on Australian sheep,

blackbirds predation on North Dakota sunflower fields, and crop losses from grazing deer.[1]

When species are highly valued by some subset of society, as with the wolf in the latter part of this century, interested groups other than those suffering damage are often involved in damage abatement programs. Many wildlife agencies are active in damage abatement programs for game species, addressing problems such as geese in Wisconsin grain fields, elephants in Kenyan villages, and the threat of brucellosis transmission from bison to livestock on the fringes of Yellowstone National Park. Abatement methods that are lethal or harmful to highly valued wildlife are often limited by law, and relatively benign abatement methods are often promoted by wildlife agencies. Finally, just as Defenders of Wildlife compensates for wolf damage to livestock producers, a number of state wildlife agencies in the United States compensate property owners for damage inflicted by species such as black bear, deer, mountain lion, moose, and elk. As the with the Defenders of Wildlife, these compensation programs are usually accompanied by a damage abatement program of some form.

The remainder of this chapter provides a discussion of various wildlife damage abatement techniques used in various contexts. Institutional responses in the form of private and public contracting are then discussed, including input sharing arrange-

[1] The longest continuous fence in the world — over 3,300 miles long — is maintained in southwest Australia by three states and private ranchers solely to separate dingos from sheep.

ments among private agricultural producers and damage abatement and compensation programs maintained by departments of agriculture and wildlife agencies.

Wildlife territories usually encompass numerous landholdings, effectively making them a common pool resource much like oil reservoirs, river fisheries, groundwater, and pests such as insects and weeds, and disease. For example, oil production by one firm impacts potential oil recovery, recovery costs, and production capacity of other firms producing from the same reservoir (Libecap and Wiggins 1985, Weaver 1986). Innumerable forms of "pests" such as various troublesome insects, weeds, and transmittable diseases are not confined to individual property boundaries, and damage abatement efforts by one property owner that affect the geographic distribution of the pest may affect his neighbors' welfare (Tullock 1970, Carlson 1975, Carlson and DeBord 1976, Regev, Gutierrez, and Feder 1976, Rook and Carlson 1985, Clark and Carlson 1990, Carlson and Wetzstein 1993). When these external effects are not accounted for, misallocation of productive resources occurs and economic inefficiency results. When this inefficiency is large enough, contractual arrangements may evolve to correct them.

This rationale for contracting over wildlife damage is developed further in the first part of chapter 2. The second part of chapter 2 comprises a set of formal models representing prevalent cooperative/contractual arrangements, including labor-sharing, abatement cost-sharing, and damage sharing contracts, as well as an analysis of the choice between bounty and wage payments mechanisms for predator control.

The structure of each these contracts is defined in part by difficulties associated with monitoring abatement labor effort. There is increasing interest in the wildlife management literature about the motivation and incentive effects of various damage control policies carried out by many wildlife agencies (Wagner, Schmidt, and Conover 1997, for example). The models in chapter 2 provide a first attempt at formally modeling the incentive effects of some of these policy mechanisms in an economic framework.

Chapter 3 builds on the model of a cost-share contract developed in section 2.2.2, and applies it to an examination of the structure and distribution of livestock assessments for control of livestock predator populations in the United States. This model implies that the value of a contract over predator control is a function of various factors, including the value and spatial concentration of livestock production in a region, the predator density, the proportion of the predator's territory used for livestock production, the marginal cost of independent abatement effort and the marginal cost of cooperative abatement effort. The model also implies that the structure of contracts will reflect the relative costs of contracting, and that existing institutions will be used in cases where they reduce contracting costs. State and county level data, as well as anecdotal evidence provide broad support for the main predictions of the model.

Chapter 4 examines the incentives of agricultural producers to change production practices in response to wildlife damage, as well as the incentive effects of compensation and abatement programs maintained by some wildlife agencies for some species.

An acreage allocation model is developed and applied to crop choice in the face of deer-inflicted crop damage in Wisconsin. Acreage and damage equations are estimated for four crops with high damage rates: feed grain, alfalfa, soybeans, and sweet corn. Of the four crops, sweet corn suffers the highest damage rates on average, and the econometric estimates suggest that crop producers respond to high sweet corn damage rates by reducing acreage to sweet corn. Damage rates, in turn, are positively related to deer density. This is consistent with received population biology theory and existing empirical studies of deer damage to crops. Simulated acreage responses to changes in compensation are derived and discussed. Chapter 5 includes a summary and discussion of potential extensions of the research presented in this dissertation.

1.1 Wildlife damage and abatement

Wywialowski (1994) provides a survey-based overview of the percentage of producers claiming to have suffered wildlife damage in 1989. Table 1.1 shows that hoofed mammals cause damage to field crop producers more than any other wildlife group. Deer account for virtually all of the damage in this category in the East, but in the western states elk and pronghorn antelope impose costs as well. Rodents are most commonly cited by fruit, nut, or vegetable producers and owners of stored commodities, and carnivores impose losses on livestock producers more than any other group. Just over

26 percent of livestock producers on the west coast and in the Intermountain West claimed to have suffered losses from carnivores, and 46.5 and 48.6 percent of crop producers in the Midwest and Great Lakes regions respectively claimed to have suffered crop losses from hoofed mammals (table 1.2). The median reported damage per farm was $450, for livestock, $300 for field crops, $200 for fruit and nuts, and $100 for stored commodities. Nationwide, 55% of producers reported some wildlife damage, and total estimated damage for the U.S. in 1989 based on the median of producer losses is $461 million. Because the responses were highly skewed, with many small damage estimates and fewer large estimates, an estimate for total 1989 losses based on the mean reported loss is $1.26 billion (Wywialowski 1994).

These losses are small relative to total agricultural production in the United States (1994 cash receipts for farming alone totaled $188 billion, and total production expenses totaling $167 billion (U.S. Department of Agriculture 1996b), but the costs of wildlife to landowners are significant for two reasons. First, costs imposed by wildlife provide an incentive for landowners to reduce the quantity and quality of wildlife habitat on their land, and to expend resources on damage abatement — both of which can have significant effects on wildlife populations. Because private agricultural land provides a majority of wildlife habitat throughout most of the world, these private incentives are important elements in wildlife management whether the species is highly valued or viewed universally as a pest. Second, wildlife damage is often unevenly distributed, affecting some producers severely (Sterner 1994, Wywialowski

Table 1.1: Percent of producers reporting damage, by wildlife group.

Wildlife group	Livestock & Poultry	Field Crops	Fruits & Nuts	Stored Commodities
Hoofed mammals	2.0	34.4	16.6	1.1
Carnivores	15.6	2.2	2.3	0.3
Rodents/rabbits	2.2	19.3	20.4	19.0
Birds	2.0	8.7	16.6	2.0
Omnivores	2.4	9.7	10.5	3.8
All*	20.4	47.3	45.5	22.8

*Respondents could report ≤ 5 species, so columns do not sum to "all". Source: adapted from Wywialowski 1994.

Table 1.2: Percent of producers reporting damage, by region.

	Livestock & Poultry	Field Crops	Fruits & Nuts**	Stored Commodities
West Coast	30.4	43.6	54.9	22.4
Intermountain West	31.3	48.1	36	21.2
Northern Great Plains	26.6	37.3	36	14
Southern Great Plains	19.8	37.9	36	21.6
Texas	28.5	25.8	49.3	34.6
Southeast	22.9	39.5	45.3	27.7
Midwest	15.2	57.1	40.8	21.3
Great Lakes	10.4	58.1	40.8	19.3
Northeast	16	53.6	40.8	27.7
Nationwide	20.4	47.3	45.5	22.8

*Respondents could report ≤ 5 species so columns do not sum to "all". **Source data were presented on different geographic units. Source: adapted from Wywialowski, 1994.

Table 1.3: Examples of damage control methods.

Resource management	**Animal husbandry:** night penning, change time of breeding, change class of livestock. **Crops:** change planting and/or harvesting time, plant damage resistant varieties, change crop.
Physical separation	Fencing, sheathing, tree protectors, wire grids, netting, storage containers, guard dogs.
Wildlife management	**Habitat management:** modify surrounding vegetation, eliminate standing water, roost thinning, beaver dam removal. **Alternative foods:** plant lure crops, grain piles. **Frightening devices:** propane exploders, pyrotechnics, lights, scarecrows, harassment. **Kill or relocate:** traps, snares, denning, shooting (aerial, spotlighting, tracking), egg/nest destruction **chemical repellents and toxicants**.

Source: adapted from U.S. Department of Agriculture (1994) table 2-4, p. 2-24.

1994). Wildlife damage has led to large private and public expenditures on abatement, as well as significant changes in production practices (Young 1978, U.S. Department of Agriculture 1994, Mott, Glahn, Smith, Reinhold, Bruce, and Sloan in press).

For descriptive purposes, wildlife damage control methods can be placed into three categories: *resource management* (changing the use of productive inputs), *physical separation* of the resource from the wildlife, and *wildlife management* (U.S. Department of Agriculture 1994, table 2-4). Table 1.3 provides some illustrations of each of these types. Resource management for reducing crop damage might include changing planting or harvesting schedules to account for foraging patterns of wildlife, planting different crops, or planting damage resistant varieties of crops as is common in addressing insect pest problems. Resource management for livestock might include

changing the class of livestock, night penning, changing the time of breeding, or periodically moving or herding the livestock are methods often used.

Physical separation of the resource from the wildlife generally involves some form of fencing or other barrier. Separation methods include the use of tree-protectors, netting, storage containers, or guard animals such as dogs.

Wildlife management entails altering the behavior or distribution of the wildlife by other means. This can include changing the vegetation, water availability, or other land characteristics surrounding the area of agricultural production such as a crop field or pasture in order to reduce wildlife proximity to the resource. Planting low-cost lure crops or providing easily accessible low-cost livestock may draw wildlife away from high-value crops or livestock. Frightening devices such as scarecrows, propane exploders, lights, and other devices act to keep wildlife away from productive inputs, and trapping and relocation is another method of dispersing wildlife from an area. Finally, killing wildlife in order to reduce damage is performed through hunting, trapping, den and nest destruction, and poisoning.

1.2 Wildlife damage institutions

Many contractual forms have developed to address wildlife damage. Parties to these contracts may include individual landowners and firms, the private animal damage

control industry, private agricultural groups, county agencies and commissions, and wildlife agencies and departments of agriculture at both the state and federal level.

1.2.1 Private contracting

Most written examples of private cooperation in wildlife damage control have to do with reducing property damage of pests.[2] In particular, there is a rich history of private cooperation and public programs for predator control that dates back to the earliest years of the settlement of the new world.

Perhaps most notable is the impressive growth and scale of predator control efforts in the livestock industry of the Great Plains and Rocky Mountain region from about 1870, when early livestock associations began to form. According to Young (1944), the primary motivation for forming these associations was to cooperate in roundups and to reduce theft by humans and wolves. Many of these associations assessed dues on members per head of livestock to be used to pay bounties on predators or to pay hired hunters. In some cases those who weren't up to date on their "wolf dues" were prohibited by association bylaws from participating in spring and fall roundups or other association functions (Table 1.4).

Even today, with widespread public funding for predator control, some sheep producer associations assess themselves dues to be applied to local predator control, and wolf clubs — groups of livestock producers in a county or localized area — cooperate

[2]The term *pest* is used here to describe animals that hold a net negative value to an individual.

Table 1.4: Examples of private cooperation in predator control.

ST	Year	Group	Description
OR	1843	Willamette Valley Wolf Organization	A committee formed to collect mandatory dues from members of the Willamette Valley Citizens Association to be paid to members of the Association as bounty on wolf kills (McIntyre 1995, p.79).
CO	1870	Bent-Prowers County Cattle and Horse Growers Association	Wolf bounty raised by stock head assessment. Maverick (unbranded) cattle branded with the association brand and proceeds went to bounty fund. Any stockman presenting a wolf killed on his own range for bounty was required to join the association before bounty payment would be made (Young 1944, p. 362).
OK	circa 1880	Cherokee Strip Cattle Association	Organized a "Wolf Rodeo" in Oklahoma and paid bounties for wolves killed. 600 participants circled an area and converged, killing 26 wolves (McIntyre 1995, p.90).
WY	1894	Little Missouri Stockgrowers	Supplemented county bounties (Young 1944).
CO	early 1900s	North Park	Good trappers were paid up to $200/month plus board in addition to $50 per adult and $20 per whelp wolf by individual stockmen (Young 1944, p.364).
CO	1904	Piceance Creek Stock Growers Association	Bounty payments were raised on a voluntary basis until 1912. New by-laws were drawn to make assessments mandatory, stipulating that non-paying cattlemen could not participate in the spring and fall roundups (Young 1944, pp. 363-364).
MT	1916	Montana Stockgrowers Association	Members paid head tax on livestock to be used for predator control (Fischer 1995).
TX	1920s-pres.	Wolf Clubs	Groups of sheep and goat producers voluntarily assessed themselves money to pay for a government trapper for their area (McSwain 1998, Savage 1998).
WI	1950s	Chippewa County Hunting Club	Paid bounties from club funds for wolves (Thiel 1993, p.93).
NE	1992-pres.	Cherry County Association	Cattle producers jointly pay for predator control. Individual assessments based on acreage. Currently over 100,000 acres and 12 landowners involved. The county government is not involved (McGinley 1997).

in predator control on their lands. Another example of private cooperation include Mississippi catfish farmers sharing responsibility for harassing cormorant roosts in an attempt to relocate entire flocks rather than independently chasing the birds locally from pond to pond.[3]

All of the above examples of private contracting refer to a group of individuals acting jointly to address a common damage problem. A different case of private collective action is embodied by a privately funded program developed by the Defenders of Wildlife, a private environmental group, to compensate ranchers for livestock losses suffered from wolves reintroduced into Yellowstone. Between August 1987 and April 1998 Defenders had paid almost $60,000 to 58 ranchers for 78 cattle and 192 sheep kills. In addition to the Wolf Compensation Trust, the Defender's Wolf Habitat Fund offers $5,000 to landowners who allow wolves to raise pups on their land (Defenders of Wildlife 1998), and another program provides financial support for damage abatement methods.

1.2.2 Public agricultural agencies and commissions

Public predator control programs evolved along with private cooperation early in the history of the white settlement of North America (table 1.5). These often came in the form of taxes or assessments on livestock to pay for bounties on predators, and later to pay the wages of hired hunters. By the end of the 18th century wolf

[3]Phil Mastrangelo, USDAWS, personal communication, May, 1997. See also Glahn and Stickley (1995).

Table 1.5: Colonial examples of public predator control.

State	Year	Group	Description
MA	1630	Massachusetts Bay Colony	Assessed a head tax on swine and goats to pay bounties on wolves (McIntyre 1995, p.30).
RI	1658, 1662	Newport Island	Wolf drives were organized to rid the island of wolves. Also, in 1647 Newport passed an order that no deer should be killed for two months in attempts to reduce wolf depredation on livestock (Young 1944).
RI	1640	Providence	Head tax assessed on livestock owners to pay for hired wolf hunters and bounties (McIntyre 1995, p.36).
MA	1717	Barnstable County (Cape Cod)	Planned to build a 6-foot fence slightly NW of what is now Cape Cod Canal in order to keep wolves out. The plan failed apparently because of opposition from townships on the other side of the proposed fence (McIntyre 1995, p.40).

bounties were offered in virtually all colonial settlements (Young 1944), and by the end of the 19th century county and state predator control and bounty programs had become commonplace. In 1915 the federal government began appropriating money for predator control (Cadieux 1983, Young 1978).

Today, many such assessments on livestock producers exist, particularly in western states. Some of these come in the form of surcharges on range improvement funds, or in the form of assessments per head of livestock, and are collected and used at either the state or county level. In some cases, livestock producers within a given county may vote whether or not to impose a head assessment on themselves to pay

Table 1.6: Predator control funding in western states.

	Type of funding				
	State General funds	Statewide livestock assessment	County general funds	County livestock assessment	Private association assessments
AZ	♦		♦		♦
CA	♦		♦		
CO				♦	
ID		♦	♦	♦	
KS					
MT		♦		♦	♦
NE			♦		♦
NM	♦		♦		♦
NV		♦		♦	♦
ND			♦		
OK	♦		♦		♦
OR	♦		♦		♦
SD		♦		♦	
TX				♦	
UT	♦	♦			
WA					
WY	♦			♦	

for predator control in that county. These programs are the subject of chapter 3 of this dissertation, and are summarized in table 1.6 for western states.

In addition to these relatively small-scale public wildlife damage programs, participation of departments of agriculture at both the state and national level and county government has a long history and takes various forms. State game agencies, and for some species the U.S. Fish and Wildlife Service, have jurisdiction over wildlife management in the United States, but the USDA, state departments of agriculture,

and some county governments have histories of involvement in wildlife damage management that in many cases predates the existence of regulatory wildlife agencies.

The federal government became involved in wildlife damage management in 1915 when the Department of Agriculture Bureau of Biological Survey hired professional hunters for predator control (Feldman 1996). Today, it is active primarily through the USDA's Animal and Plant Health Inspection Service Wildlife Services (USDAWS), which provides a broad set of services and has cooperative programs in approximately 38 states (O'Toole 1996).[4] USDAWS now addresses damage problems associated with a much broader set of wildlife species, although it tends to be less involved in dealing with game and endangered species, which are under the jurisdiction of state and federal wildlife agencies (Fagerstone and Clay 1997). To the extent that USDAWS deals with damage inflicted by these strictly regulated species, they generally do so under the oversight of a wildlife agency.

USDAWS provides personnel support and approximately 50% cost share support to individuals, private organizations, and other public agencies. The distribution of funding provides an illustration of the degree of involvement by various agencies and groups. In 1994, 45% of USDAWS expenditures were in cooperation with state agencies, 20% with county agencies, 20% with private organizations, 12% with other federal agencies (table 1.7). Expenditures in cooperation with other categories includ-

[4]The name and agency affiliation of the federal wildlife damage control program has changed numerous times since its inception in 1915. Prior to its recent name change, it was called the USDA Animal Damage Control Program. In 1986 the program was transferred from the US Fish and Wildlife Service to the USDA (U.S. Department of Agriculture 1994).

ing individuals and cities account for less than 2% each of USDAWS expenditures in 1994.

Despite little direct cooperation between the USDAWS and private individuals, the process of addressing wildlife damage on private property clearly begins with the property owner. For a given damage incident on private land, the property owner may contact any one of the organizations or agencies listed above, who may in turn utilize the USDAWS services.[5] Approximately 72% of the USDAWS expenditures in 1992 were for protection of livestock, and nearly 98% of the livestock expenditures were in western states (O'Toole 1996).

1.2.3 Wildlife agencies

Nearly all wildlife species that hold significant value over some margin are regulated by public agencies.[6] Restrictions on killing or harassing wildlife in the act of damaging private property are often reduced, particularly in cases where damage has the potential to be large or the value of individuals of the species is low. A most obvious case is imminent threat to human life or health. For example, all state game agencies allow killing bear out of season or without a permit if a threat to personal safety exists. In the case of deer damage to crops, game agencies often allow landowners to shoot deer out of season, but often only by special permit. Killing or trapping

[5] Martin Mendoza, USDA Wildlife Services. Telephone conversation, May 1997.

[6] For economic analyses of wildlife law and regulatory structure see Lueck (1989) and Lueck and Yoder (1997).

Table 1.7: Damage control expenditures, by USDAWS cooperator group, 1994.

		Source							
Region	Protecting:	USDA	State	County	Org.	Indiv.	Oth. Fed.	Other	Total
	Livestock	380,998	89,862	784	503	427	5,072	2,015	479,661
East	Crops	982,007	535,148	5,781	1,976	4,440	10,841	6,557	1,546,750
	All	4,362,340	1,427,211	157,757	298,543	24,327	507,218	252,351	7,029,747
	Livestock	9,668,407	4,641,193	2,409,827	2,714,147	44,056	81,199	137,889	19,696,718
West	Crops	1,567,771	496,469	264,607	155,480	10,259	8,757	26,095	2,529,438
	All	15,031,566	6,904,491	3,681,533	3,461,595	90,939	767,357	369,404	30,306,885
	Livestock	10,050,140	4,731,055	2,410,611	2,714,650	44,483	86,271	139,904	20,177,114
U.S.	Crops	2,562,409	1,031,617	270,388	186,257	14,699	19,598	32,652	4,117,620
	All	19,554,101	8,651,345	3,839,290	3,804,011	118,580	2,216,261	621,755	38,805,343

State includes primarily Ag. Departments in the west and game departments in the east. **County** funding is mainly from county predator control programs. **Org.**(Organizations) are generally private organizations, and in the west are mostly livestock associations. **oth. Fed.**(Other Federal) represents federal agencies like the FWS, NFS, the NP, and BLM. **Other** includes categories such as "fur sales" from agency abatement, "city", and other minor categories.

coyotes threatening livestock is usually unrestricted even in those states that actively regulate hunting and trapping coyotes.

Most state wildlife agencies have some form of program to address wildlife damage to agricultural property. These programs can be grouped into three categories: landowner rights for actions against problem wildlife, agency abatement support, and compensation. Tables 1.8 and 1.9 provide an overview of these policies for the 50 states.[7] Blank spaces indicate that either state statutes or written agency policy did not apply to column description for that state, or there was no mention of the column topic in any of the sources. The data in these tables were spot checked with various agency personnel during the course of this research.

The first two columns of table 1.8 entitled *No permit required for protected species* provide information about protected species that landowners may destroy without prior agency permission (Musgrave and Stein (1993) and state statutes). In general, those species that can do a lot of damage in a short amount of time are widely represented; livestock predators, for example. Also note that valuable big game species such as deer and elk are absent from this list (with the exception of Vermont). When laws specify which type of agricultural resource can be legally defended by non-permit taking, it tends to be livestock and field crops.

[7]Data for these tables were taken from state fish and game regulations, Musgrave and Stein (1993) and Wildlife Management Institute (1997).

Table 1.8: State damage policies, part 1

ST	No permit required for protected species		Out-of-season depredation permits			Statutory agency regulatory authority		Statutory liability	
	species	to defend	issued for	to defend	carcass owner	damage mngmt	damage agents	species	property
AL	CY	any	game	crops		Yes	Yes		
AK	pred	any	pred, BV	any	D	Yes	No		
AZ	pred	lvstck	game	crops	D	Yes	Yes		
AR						Yes	Yes		
CA			DR,EK,BV	any	LL	Yes	No		
CO	BR,ML	lvstck	any	any	D	Yes	No	pred	any
CT			any	any	LL	Yes	Yes		
DE						Yes	Yes		
FL			DR,BR	crops		Yes	Yes		
GA			BR	bhive		Yes	Yes		
HA						Yes	Yes		
ID	BR,ML,WF	lvstck	any	any	D	Yes	No		
IL			pred,furb	any	D	Yes	Yes		
IN			any	any		Yes	No		
IA	FH		any		LL	Yes	No		
KS						Yes	Yes		
KY						Yes	Yes		
LA	BV	any	any	any		Yes	Yes		
ME	any	lvstck,crop	BR	bhive	D	Yes	Yes		
MD	various	any				Yes	Yes		
MA	any	not grass				Yes	Yes		
MI			DR,TE			Yes	Yes		
MN			various	any	D	Yes	Yes		
MS						Yes	Yes		
MO	most	any	DR,TK,BR			Yes	Yes		

SPECIES: AN=antelope, BC=bobcat, BR=bear, BV=beaver, CY=coyote, DR=deer, EK=elk, FH=hatchery fish, FX=fox, GB=game birds, ML=mountain lion, MS=moose, NN=non-native species, PH=pheasant TE=threatended or endangered, TK=turkey, WF=wolf, game=unspecified game, bgame=big game, pred=unspecified predators, various=large specific list of various game and/or predators. **RESOURCE DAMAGED:** any=unspecified property or wildlife, lvstck=livestock, bhive=beehive. **OWNERSHIP:** D=Department, L=landowner, LL=landowner, limited use. **ABATEMENT SUPPORT:** C=consulting, L=abatement labor, K=abatement capital.

Table 1.8: Continued from previous page

ST	No permit required for protected species		Out-of-season depredation permits			Statutory agency regulatory authority		Statutory liability	
	species	to defend	issued for	to defend	carcass owner	damage mngmt	damage agents	species	property
MT	pred	lvstck	BV	any		Yes	No		
NE	pred	lvstck			D	Yes	No		
NV			furb	any		No	No	EK, NN	crops
NH	any	any			D	Yes	Yes		
NJ						Yes	Yes		
NM	any	lvstck	BV,TE,game			Yes	No		
NY			various	crops,lvstck	D	Yes	Yes		
NC						Yes	Yes		
ND	pred, furb	any	BR,ML	any	LL	Yes	No		
OH			any	any	D	Yes	Yes		
OK						Yes	No		
OR						Yes	Yes		
PA			DR	any	LL	Yes	Yes		
RI	furb	any	deer	crops	D	Yes	Yes		
SC	BC	any	any	any	D	Yes	No		
SD			any	any		Yes	Yes		
TN						Yes	Yes		
TX			any	any	LL	Yes	No		
UT			BV			Yes	No		
VT	DR,BR	crops			LL	Yes	Yes		
VA	FX	lvstck	various	any	L	Yes	Yes		
WA	any	any				Yes	Yes		
WV			DR,BR			No	Yes		
WI			DR,BR,WF			Yes	Yes		
WY	pred	lvstck			LL	Yes	No	bgame,WF	any

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Permits for taking protected species during closed season are widely used to stop damage (columns 3-5 of table 1.8, *out-of-season depredation permits.* Sources: Musgrave and Stein (1993) and state statutes). These permits are primarily issued for game species in protection of high value commodities. When landowners retain ownership of the carcass, there are usually legal limits on its use. For example, a deer shot with a depredation permit might by law only be used by the landowners immediate family.

State wildlife agencies have various degrees of regulatory authority over damage abatement activity performed by the private sector and other public agencies. Columns 6 under the heading *Statutory agency reg'tory authority* shows that all but two wildlife agencies have at least some authority over wildlife damage management, broadly defined. Column 7 shows that wildlife agencies have authority to regulate professional wildlife damage control agents in all but 16 states. Of these 16, 13 are western states (Wildlife Management Institute 1997).

Although state wildlife agencies hold regulatory control over most wildlife and are actively involved in wildlife damage control on private land, the courts have not found them liable for such damage (Lund 1980, Favre 1983, Carlman 1994).[8] However, statutes of some states impose liability for specific species and resources (last two columns of table 1.8). That agencies are in general not held liable for damage begs

[8]The exception to this general common law result is that on two occasions state game regulations disallowing landowners to kill wildlife in the act of causing damage were found to be an invalid regulatory taking (Thompson 1992).

for a motive for the use of agency resources to address damage problems. This is a central question addressed in this dissertation.

Table 1.9 is a continuation of the previous table, but it focuses on agency abatement and compensation programs. Most state wildlife agencies are explicitly authorized by state statute to provide abatement support in the form of consulting, abatement labor, and/or abatement capital. Most wildlife agencies cooperate with the USDAWS. Wildlife agencies are the regulatory authority over wildlife, but in many cases, the USDAWS performs much of the damage control work. In some cases, particularly with big game species, USDAWS activity is monitored by state wildlife agencies (Fagerstone and Clay 1997). In other cases such as with coyote control in many western states, wildlife agencies participate little or not at all. There are still some bounties codified in state statutes, but these appear rarely to be implemented.[9] Finally, some wildlife departments organize special depredation hunts out of season in order to address specific damage problems by game animals such as deer.

Compensation programs tend to be reserved for valuable game animals (last two columns of table 1.9). Certain requirements are usually placed on landowners, such as having to follow abatement recommendations of the wildlife agency and allowing hunters to hunt on the land on which damage is occurring. In at least a couple of cases, compensation is reduced by income received from hunter access fees charged.

[9]Personal communication with Hank Uhden, Wyoming Department of Agriculture, September 1998. As will be discussed later, bounties on wildlife were very common in the U.S. until the mid-1900s.

Table 1.9: State damage policies, part 2.

	Abatement program					Compensation			
							contingent on		
ST	organized depredat'n hunts	wildlife dept. bounty	extens'n trapper	author-ized to provide	Coop. with USDA	species	abate-ment	non-posting	access fees
AL	DR,BV	BV	No		Yes				
AK	WF		No	C,L,K	No				
AZ	game	WF	No	C,L	Yes	BV			
AR			No		No				
CA			No		Yes				
CO			No	C,L	Yes	BR,ML,DR,EK,AN	x	x	x
CT			No		No				
DE			No		No				
FL			No		No				
GA			Yes		Yes				
HA			No		Yes				
ID			No	C,L	Yes	DR,BR,EK,MS,AN,ML	x	x	
IL			No	C,L	No				
IN			No	C,L	Yes				
IA			Yes		No				
KS			Yes	C,K	Yes				
KY		BV	No	C,L,K	Yes	CY			
LA			No		Yes				
ME			Yes	C,L,K	Yes				
MD			No		No	BR			
MA			No		No	DR,MS			
MI			No		No				
MN		pred	Yes		Yes	WF,EK			
MS			No		Yes				
MO			Yes	C,L,K	Yes				

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Table 1.9: Continued from previous page.

	Abatement program					Compensation			
							contingent on		
ST	organized depredat'n hunts	wildlife dept. bounty	extens'n trapper	author-ized to provide	coop. with USDA	species	abate-ment	non-posting	access fees
MT			No	C,L	Yes	bgame			
NE			No	C,L	Yes				
NV			No	C,L,K	Yes	DR,EK,AN			
NH			Yes	C,L,K	Yes	game,ML,BR	x	x	
NJ			No		No				
NM			No	C,L,K	Yes				
NY			No		Yes				
NC			No		Yes				
ND			No	C,L,K	No				
OH			No		Yes	CY			
OK			No		Yes				
OR			No		Yes				
PA			No	C,L,K	Yes	BR,CY	x		
RI			No		Yes				
SC	any		Yes		Yes				
SD		furb	Yes	C,L,K	Yes				
TN			No		Yes				
TX			Yes	C	Yes				
UT			No		Yes	DR,EK,BR,ML,PH,AN,MS,BV			
VT			Yes	C,L,K	Yes	BR,DR	x		
VA			No		Yes	BR,DR			
WA	any		No		Yes	DR,EK	x		
WV			No		No	BR			
WI	DR		No	C,L,K	No	DR,BR,WT	x	x	x
WY			No		Yes	bgame, WF			

SPECIES: AN=antelope, BC=bobcat, BR=bear, BV=beaver, CY=coyote, DR=deer, EK=elk, FH=hatchery fish, FX=fox, GB=game birds, ML=mountain lion, MS=moose, NN=non-native species, PH=pheasant TE=threatended or endangered, TK=turkey, WF=wolf, game=unspecified game, bgame=big game, pred=unspecified predators, various=large specific list of various game and/or predators. **RESOURCE DAMAGED:** any=unspecified property or wildlife, bhive=beehive, lvstck=livestock. **OWNERSHIP:** D=Department, L=landowner, LL=landowner, limited use. **ABATEMENT SUPPORT:** C=consulting, L=abatement labor, K=abatement capital.

1.3 Economic literature on wildlife damage

The economic literature on wildlife damage consists primarily of reports on estimates of damage to agriculture for various species, sectors and regions. The majority of research that discusses economic aspects of wildlife damage is not in economic journals, but more often in wildlife management journals, books on wildlife damage not focused on economics per say, and unpublished manuscripts, often by public agencies and universities.

A dissertation by Thomas (1954) and a subsequent paper (Thomas and Pasto 1955) examines the economic relationship among farmers, hunters, and the local business community arising from the existence of a valuable deer population. It is among the first work to examine how wildlife damage to agricultural property enters into the general problem of maximizing the value of a wildlife population (in this case, Pennsylvania deer) in the context of a set of interest groups. Thomas' dissertation also provides an early attempt at constructing field estimates for deer damage to crops in Pennsylvania.

Rollins (1990) and Rollins and Briggs (1996) focus on the issue of moral hazard in the context of a compensation program for waterfowl-inflicted crop damage in Wisconsin. They recognize that providing compensation reduces the incentive for farmers to perform damage abatement, and characterize compensation for wildlife damage to crops as an insurance problem in which a wildlife agency is the principal

trying to maximize risk-averse-hunter welfare subject to a lower bound welfare constraint for farmers (the agents). Farmers privately choose abatement levels that affect the distribution of wildlife and damage, affecting both hunter welfare and compensation levels. They conclude that compensation rates should be linked to observable variables positively correlated with (hidden) abatement activity.

Sulewski (1996) also recognizes that compensation reduces the incentive for landowners to provide damage abatement effort, and critiques a Saskatchewan compensation program for goose damage. Based on a model to explain goose feeding patterns, he develops a set of simulations that suggest that the current (as of 1996) Saskatchewan compensation/abatement program does not link compensation with abatement sufficiently.

M. Bhat, R. Huffaker, and S. Lenhart have written a series of theoretical papers on optimal dynamic control of beaver damage. Huffaker, Bhat, and Lenhart (1992) and Lenhart and Bhat (1992) examine the impact of immigration of beaver populations on optimal trapping rates to reduce timber damage, and show that in this context optimal trapping effort entails leaving more of the local beaver population in place than when there is no threat of immigration of beavers from surrounding areas. Bhat, Huffaker, and Lenhart (1993) examine the common property characteristics of beaver populations that span numerous landholdings, and consider the potential gains from a centralized beaver trapping strategy.

In addition to these, a number of papers have discussed the economics of wildlife damage tangentially. For example, Skonhoft and Solstad (1998) develops a model of wildlife management in the context of a game reserve where poaching by farmers affects the wildlife stock, and damage to crops increases incentives to poach. Lueck (1989) and Lueck and Yoder (1997) develop a contracting model that explains the structure of wildlife law and ownership, and also provides a rationale for private and public contracting over wildlife damage management. Based on a sample of Montana ranch owners, Lueck (1991) finds that property damage by game animals may have a positive impact on the incentives for landowners to lease their land for hunting.

By far the largest literature on the economics of wildlife damage does not come from the published economics literature, but from the wildlife management literature and research out of public agricultural and wildlife agencies, and universities. For example, a series of papers in the Wildlife Society Bulletin (volume 25 number 2) focusing on overabundance of deer included extensive discussion of the economic impact of deer damage. There is also a long history of discussion of the economics of predator control by livestock interests (for example, see Latham (1951) and Wagner (1972)). Many landowner surveys providing estimates of wildlife-inflicted damage have been published as well (McNew and Curtis 1997, Wywialowski 1994, for example).[10]

This dissertation expands the economic literature on wildlife damage in various ways. First, the contract theory literature on wildlife damage is narrow, focusing

[10]U.S. Department of Agriculture (1994) provides an extensive list of damage surveys that produced damage estimates for various crops [tables 3-21 through 3-23.]

solely on abatement-compensation programs. Yet a broad range of contractual arrangements has evolved to address various wildlife damage problems. The models developed in chapter 2 will expand the theoretical literature on contracting over public and common property resources. Thus, it has implications with respect not only to wildlife damage problems, but possibly to other public or common property problems such as insect pest management, groundwater allocation and use, and oil production.

Second, empirical applications of wildlife damage models are virtually non-existent. As noted earlier, this dissertation includes two of them: an examination of the incidence of producer cooperation over predator control in western states (chapter 3), and estimation of a model of crop acreage allocation in response to deer-inflicted crop damage (chapter 4).

Third, this dissertation expands the literature on the management of wildlife on private lands by focusing on incentives to alter land use and production practices in response to damage. This issue is particularly important where private landowners provide much of the habitat for valuable wildlife and when access to private lands for consumptive or non-consumptive use limits the effectiveness of public wildlife management.

CHAPTER 2

Wildlife & Agriculture

2.1 Introduction

The contracts examined in this dissertation can be categorized as sharing labor, sharing capital and third-party labor costs, and sharing damage. These forms of sharing rules are not mutually exclusive, and in some cases such as in the context of wildlife agency abatement and compensation programs, each may be integrated into a working relationship among landowners and/or agencies. In addition, two prevalent contracts in third-party predator control — time-wage payments to hired hunters versus bounty payments are also examined, as well as a prevalent abatement cost sharing arrangement based on producer assessments. Finally, a summary and discussion of each of these contracts is presented. Table 2.1 provides examples of each type of arrangement.

To motivate and provide background for these models, this chapter begins with a model of the relationship between agricultural production and wildlife, a discussion of the benefits from contracting, the relationship between wildlife value and damage abatement methods, and the role of this relationship in shaping contract structure and contracting costs. After the formal models are developed, a discussion of empirical evidence for each model is then provided. The contribution of this chapter is to elucidate the fundamental economic tradeoffs of prevalent wildlife damage contracts.

Consider an agricultural landowner who can allocate his resources to acquire revenues from wildlife services and revenues from a composite agricultural commodity,

Table 2.1: some possible contract mechanisms and examples

Labor sharing	Wolf, rabbit drives, cooperative roost harassment to protect fisheries against waterfowl, game agency personnel and landowner abatement cooperation.
Capital sharing	Share costs of traps and poisons, helicopters and airplanes for aerial hunting.
Damage sharing	Wildlife agency damage compensation programs, Defenders of Wildlife wolf compensation fund.
Third party labor	Livestock head assessments for predator control, hired hunter versus bounty hunter.

sold in separate markets. The wildlife stock enters both revenue functions — it reduces revenues from the agricultural commodity by imposing damage, and it increases revenues from wildlife services. All models in this dissertation are developed in terms of profit maximization, but in most cases the functional forms are general enough that they can also represent utility functions. For example, the gains to a landowner from having wildlife on his land may come in the form of personal appreciation for the animals, rather than any monetary gain. Assuming a profit maximization objective, the landowner's problem is

$$\max_{\mathbf{x}} \pi = R^y(\mathbf{x}, w(\mathbf{x})) + R^w(\mathbf{x}, w(\mathbf{x})) - c(\mathbf{x}), \tag{2.1}$$

where R^y and R^w are revenues from the agricultural commodity and wildlife services, respectively, $c(\mathbf{x})$ are input costs, and $\mathbf{x}$ is a vector of inputs that might include

land and land characteristics, abatement effort and abatement capital, livestock or crop inventories, or any other factor that affects the realized output of the agricultural commodity and wildlife services. Assuming second-order conditions hold for a maximum and the implicit function theorem holds, the optimal levels of $\mathbf{x}$ satisfy

$$(R_x^y + R_w^y w_x) + (R_x^w + R_w^w w_x) - c_x = 0 \qquad \forall\ x \in \mathbf{x}, \tag{2.2}$$

and $R_w^y < 0$, $R_w^w > 0$ (subscripts denote derivatives throughout this dissertation). Choosing input levels often entails balancing the input's impact on the revenues from both y and w.[1] Consider, for example, a landowner producing corn and deer hunting services. If x is planted corn acreage, it will increase the revenue from the composite y ($R_x^y > 0$), but if corn fields are not a preferred hunting or wildlife viewing environment, corn production may lead to a decrease in R^w (the direct effect $R_x^w < 0$). If corn supports larger deer populations because it is a superior source of forage, revenues from y will decrease as more deer feed on the corn, so that $R_w^y w_x < 0$. If hunters' willingness to pay for hunting access is positively related to deer quality and quantity, hunter revenues will increase ($R_w^w w_x > 0$), and offset to some degree the value of the crop losses. The same type of illustration can be developed for the effects of an

[1] In examining illegal poaching on the part of locals residing near a wildlife preserve, (Skonhoft and Solstad 1998) begin with an objective function similar to this.

abatement input such as fencing around crop fields, where separating deer and crops may increase R^y and decrease R^w.[2]

Wildlife damage problems are diverse, and each of the effects in equation 2.2 need not be important for any given case, though all are important for some subset of damage problems. For example, if wildlife holds no positive value over any margin, R^w drops out, but the marginal impact of inputs on the wildlife stock would still be considered in a landowner's objective function. If the choice of an input has negligible effects on the wildlife population itself, all indirect effects $R^y_w w_x$ and $R^w_w w_x$ disappear.

2.1.1 Benefits of contracting over wildlife damage

If the landowner owns the entire wildlife territory, the first-order condition 2.2 is efficient. When the wildlife population spans more than one individual's landholding, independent action leads to inefficient use of those inputs that affect the wildlife stock. To show this, consider two landowners whose land encompasses the wildlife population's entire range. To simplify notation, revenues from the composite agricultural commodity and wildlife services are condensed into one value for each landowner $i = 1, 2$: $R^i = R^{yi} + R^{wi}$. Also assume one input x used by each producer, with $\mathbf{x} = (x^1, x^2)$ now representing the vector of the single input from each landowner, rather than a vector of multiple inputs from a single landowner.[3] The opportunity

[2]Similar tradeoffs are discussed by Harper and Zilberman (1989) in the context of insect pest damage management when some beneficial insects reduce damage through predation of insect pests but are negatively affected by broad-spectrum insecticides.

[3]The following curvature conditions are assumed to hold: $R^i_{x^i} > 0$, $R^i_{x^i x^i} < 0$.

cost of the input, c, is assumed exogenous and equal across landowners. The maximization problem for each landowner acting independently is

$$\max_{x^i} \pi^i = R^i(\mathbf{x}) - cx^i \tag{2.3}$$

and the profit maximizing input level for landowner i taking the other's actions as exogenous satisfies

$$R^i_{x^i} - c = 0 \qquad i = 1, 2. \tag{2.4}$$

Each landowner sets his personal marginal revenue from private input use equal to his marginal cost. In contrast, consider the result when the sum of the profits are jointly maximized:[4]

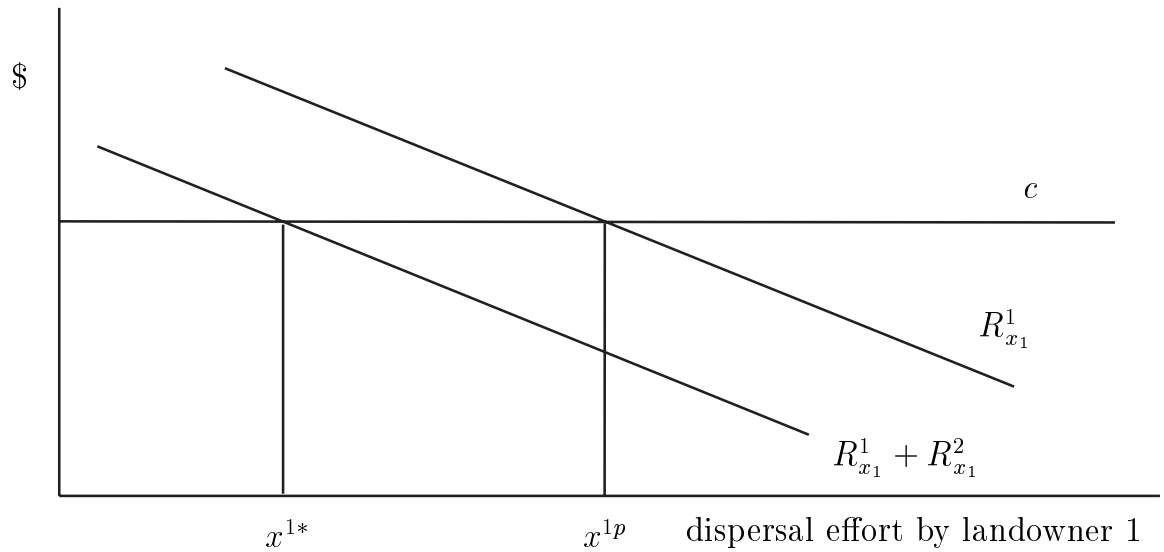
$$\max_{\mathbf{x}} \Pi = R^1(\mathbf{x}) + R^2(\mathbf{x}) - c(x^1 + x^2). \tag{2.5}$$

The first-order conditions are

$$R^1_{x^i} + R^2_{x^i} - c = 0 \qquad i = 1, 2. \tag{2.6}$$

[4]Assume that production technology is separable across landowners so that $R^* = R^{1*} + R^{2*}$ and $\mathbf{x}^* = x^{1*} + x^{2*}$. Also assume a convex joint production set, implying that $R^1_{x^i} + R^2_{x^i} > 0$ and that the Hessian is negative semi-definite to ensure a well defined maximum.

Figure 2.1: Potential benefits from joint wealth maximization.



The difference between equations 2.4 and 2.6 is a standard externality result. When acting independently, landowner 1 does not account for the effects of his actions on landowner 2 (and vice versa), whereas these effects are accounted for when landowners jointly choose input levels. Note that if one person owns the entire territory of the wildlife population, his input decisions are equivalent to the first-best solution because he is bearing all of the costs and benefits of his own decisions.[5]

Figure 2.1 shows this result for $R^2_{x^1} < 0$, which is to say that landowner 1's input use harm's a neighboring landowner. This might occur, for example, if landowner 1 disperses birds onto 2's land that subsequently feed on 2's corn crop. If landowner 1 considers only his own benefits from dispersal, he will expend effort x^{1p}, which

[5]Similarly, Bhat, Huffaker, and Lenhart (1993) develop a dynamic model of beaver trapping that shows that where there are more than one timber owner in the beaver population's territory, trapping costs can be minimized with a centralized, cooperative beaver trapping arrangement. They do not consider the costs of developing and maintaining such an arrangement.

equates his personal marginal benefit equal to his marginal costs of dispersal. In contrast, efficiency requires that the full cost of dispersal is accounted for. Absent transaction costs, the joint wealth of the two landowners will be maximized where the total marginal value of dispersal, $R^1_{x^1} + R^2_{x^1}$, is equal to the marginal cost of dispersal. This results in a lower dispersal rate by landowner 1, x^{1*}.[6]

2.1.2 Wildlife value and abatement methods

Whether input use is too high or too low relative to first-best depends on the value of the wildlife to neighboring landowners and the impact of abatement on the wildlife stock. Although transparent in (2.4) and (2.6), the external effects $R^j_{x^i}$ manifest themselves through their effect on the wildlife stock. Landowner 1's marginal impact on landowner 2 can be characterized as $R^2_{x^1} = R^2_w w^2_{x^1}$, where R^2_w is the marginal impact of wildlife on R^2, and $w^2_{x^1}$ is the marginal impact of 1's input use on the quantity of wildlife affecting landowner 2.

The external effect $R^2_{x^1}$ may be positive or negative, depending on two factors: The net marginal value of the wildlife to landowner 2, R^2_w, and effects of input x^1 on the distribution of wildlife across the two landholdings, $w^2_{x^1}$. Recall that the net marginal value of wildlife is the sum of the marginal impacts on revenues, $R^i_w = R^{yi}_w + R^{wi}_w$, so that if the sum of the marginal impacts is positive the landowner benefits from an

[6]These types of contracts fit into what Olson (1965) called *inclusive clubs*, where in the absence of transaction costs the optimal number of participants in the group (club) is every landowner in wildlife's range. Cornes and Sandler (1986) provides a discussion of clubs and club goods.

increase in wildlife on his land, and if the impact is negative, the wildlife is viewed as a pest.

In this dissertation, the *distribution* of wildlife is defined as the spatial arrangement of individuals within the wildlife population's territory. To understand the distributional effects of changes in x^1 on the wildlife stock on landholding i, define $w^i(\mathbf{x}) = w(\mathbf{x})\theta^i(\mathbf{x})$. The sum of the wildlife stock over all landholdings is w, and θ^i represents the share of the total wildlife stock on landholding i or, equivalently, the probability of a given unit of wildlife being on landholding i. totally differentiating with respect to x^1 shows the impact of a change in x^1 on w^i:

$$\frac{\partial w^i}{\partial x^1} = \frac{\partial w}{\partial x^1}\theta^i + w\frac{\partial \theta^i}{\partial x^1}. \tag{2.7}$$

Equation 2.7 has two elements. The first term on the right is a pure stock effect, and the second term is a pure distributional effect. Abatement affects the stock and its distribution in various ways, depending on the nature of the abatement method.

Consider two fundamental types of damage abatement: lethal techniques and dispersal techniques, which for this discussion are assumed to result in a pure stock effect and a pure distributional effect, respectively.[7] Lethal abatement by landowner 1 will reduce the number of wildlife on his own land by $\frac{\partial w}{\partial x^1}\theta^1$, but will also reduce

[7]Generally, abatement and land-use choices will affect both the carrying capacity of the wildlife's range as a whole, as well as the distribution of the wildlife within the range. As is the case with models of perfect competition and pure monopoly, the polar cases of purely lethal and purely distributional effects on the wildlife stock are unlikely in reality, but are useful analytical tools.

Table 2.2: Qualitative character of external effects.

effect of x^1 on w^2	marginal value of wildlife to 2: positive ($R^2_w > 0$)	marginal value of wildlife to 2: negative ($R^2_w < 0$)
$w^2_{x_1} > 0$	$R^2_{x_1} > 0$ ($x^{1*} > x^{1p}$)	$R^2_{x^1} < 0$ ($x^*_1 < x^{1p}$)
$w^2_{x^1} < 0$	$R^2_{x^1} < 0$ ($x^{1*} < x^{1p}$)	$R^2_{x^1} > 0$ ($x^{1*} > x^{1p}$)

the wildlife population on 2's land by $\frac{\partial w}{\partial x^1}\theta^2$ as the wildlife redistributes itself to best make use of the resources available to it.[8] If the wildlife is a pest to 2, then lethal abatement by landowner 1 will benefit 2 ($R^2_{x^1} > 0$). If the net value of wildlife to 2 is positive, private lethal abatement by 1 imposes costs on 2 ($R^2_{x^1} < 0$).

If on the other hand landowner 1 disperses the wildlife from his land, the effect on the wildlife stock on 2's land is $w\frac{\partial \theta^2}{\partial x^1}$. In contrast to lethal abatement, landowner 2 will benefit from dispersal by landowner 1 if landowner 2 values wildlife on his land, but 2 will suffer if wildlife is but a pest.

Table 2.1.2 provides an overview of these externality results. Input level x^{1*} represents first-best input allocation by landowner 1, and x^{1p} represents private input levels for which the effect on landowner 2 is not accounted for in landowner 1's input

[8]Many population biology models imply that wildlife will distribute itself in equilibrium to make best use of available resources. An example is the *Ideal Free Distribution* (Pulliam and Danielson 1991) which posits that individuals (wildlife) sample a set of potential habitats and settle in the habitat with the highest average "suitability." In economic terms, wildlife will choose the habitat with the highest average product for reproduction/foraging effort. In equilibrium, the wildlife distribution will equate the average product of reproductive or foraging across habitats. This model is exactly analogous to the model of open access developed by Gordon (1954) for humans. More sophisticated population biology models have been developed (e.g. Hestbeck (1988) and Stenseth (1988)), but this suffices to justify the stock effects discussed here.

decisions. As the table shows, private action results in too little (too much) dispersal abatement (lethal abatement) if wildlife is positively valued by 2, and too much (too little) if wildlife is a pest to 2. Efficiency gains may be captured if these resource misallocations can be alleviated through the formation and enforcement of a contract which adjusts resource use, but contracting is costly. These costs are the subject of the next section.

2.1.3 Information, contracting costs, and contract structure

The term *contract* is used here to represent a set of rules among a set of individuals that delineates property rights over a set of resources, and *contracting* represents the process of delineating and enforcing the rules stipulated by the contract (Libecap 1989). For example, a contract may stipulate that participants will each bear some share of the total damage imposed by wildlife to the property of parties to the contract. A specific case of this contractual form is a compensation contract in which wildlife agencies pay landowners for a certain fraction of crop damage imposed by foraging deer. Another form of contract stipulates that participants share the cost of damage abatement, where each landowner's share is based on their share of total inventories of a productive input. A specific case of this contractual form is an assessment on livestock inventories of a group of producers, the proceeds of which are then used for predator control in their region.

Libecap (1989, p. 21) lists five factors that can affect the value of a contract, the likelihood of contract formation, or both:

1. Aggregate gains from the contract.
2. Number of interested parties (see also Lueck 1994).
3. Heterogeneity of interested parties (see also Lueck 1994 and Rook and Carlson 1985).
4. Incomplete and asymmetric information (see also Kennan and Wilson 1993).
5. Skewness of gains of a proposed contract among potential participants.

The issues that will receive the most attention here are the potential aggregate gains, the number of interested parties, asymmetric information, and the skewness of the distribution of gains from the contract.

A maintained hypothesis underlying the following models presented in this chapter is that monitoring damage abatement labor is costly, leading to labor monitoring costs or, when monitoring is prohibitively costly, to resource misallocation over unenforced labor effort. This focus on monitoring costs is justified because most abatement labor is done in the field where monitoring by potential cooperators is difficult simply because of the time and distances associated with carrying out abatement activity.

If the effects of abatement and other production choices on damage levels could be costlessly inferred from damage rates, then a contract using realized damage rates as a contracting mechanism could in principle eliminate the need for monitoring abatement. As with agricultural output in general, however, damage is stochastic (Just and Pope 1978, Pingali and Carlson 1985, Rollins and Briggs 1996).

A common means of introducing stochasticity into a production process is to let $y = \varepsilon f(\mathbf{x})$, where y is realized output and ε is a random variable such that $\varepsilon \sim (1, \sigma^2)$ (Braverman and Stiglitz 1982, Allen and Lueck 1993). An analog for the present problem would be $y = \varepsilon f(\mathbf{x})(1 - \delta(\mathbf{x}))$, where δ is the damage rate as a fraction of total output. An alternative is to let damage be stochastic: $y = f(\mathbf{x})(1 - \varepsilon\delta(\mathbf{x}))$. In the former case, the variance of output increases with output but decreases in damage, and in the latter case the variance of total damage increases with either output or damage. Heteroskedasticity implied by the latter case is likely to be more realistic.

This stochastic nature of damage may limit the usefulness of realized damage as a contracting mechanism. Realized damage rates are used as a contracting mechanism only in the case of the damage-sharing contracts discussed in this chapter. Other contract forms examined here are not based on damage rates, but instead can be seen as attempts to affect abatement levels directly through monitoring or by contracting over the use of other inputs. The relative value of each contract form depends on its ability to balance contracting costs with efficiency losses resulting from moral hazard.

Contract design is assumed in this dissertation to be based on the objective of joint wealth maximization subject to informational constraints that allow hidden private action on the part of participants. Participants are assumed to be risk neutral, and the structure of contracts stem from contracting costs and the effects of private

actions.[9] This approach has been the basis of several recent theoretical/empirical studies, and when tested empirically seem to out-perform principal-agent models based on assumptions of risk aversion (Leffler and Rucker 1991, Allen and Lueck in press).

2.2 Prevalent contracts over wildlife damage

The contractual arrangements examined below are categorized as sharing labor, sharing capital and third-party labor costs, and sharing damage. These forms of sharing rules are not mutually exclusive, and in some cases, as in the context of wildlife agency abatement and compensation programs, each may be integrated into a working relationship among landowners and/or agencies. In addition, two prevalent contracts in third-party predator control — time-wage payments to hired hunters versus bounty payments to anyone with a proof of a kill — are presented, as well as an examination of a prevalent abatement cost sharing arrangement based on producer assessments. Finally, a summary and discussion of these contracts is presented. Empirical evidence for each of these models is discussed in section 2.3.

To date, there have been no formal economic analyses of any of these contractual arrangements except compensation programs, and the model of compensation presented here employs a perspective somewhat different from that used by others. As

[9] Other studies of contracts assuming risk neutrality on the part of all participants include Eswaran and Kotwal (1985), Lazear (1986) Leffler and Rucker (1991), Allen and Lueck (1993), and Allen and Lueck (in press), among others.

such, these analyses are but brief introductions to the fundamentals of these problems, and their primary contribution is as formal descriptions to provide a starting point for further research.

2.2.1 Coordinating labor

Abatement labor effort is difficult to monitor, yet there are examples of landowners voluntarily coordinating abatement labor effort to reduce wildlife damage. *Coordination* refers to changes in techniques, location, and timing of abatement on the part of participants. Participation is voluntary in the sense that there are no formal mechanisms to require participation, or punish non-participation, and no contractual mechanism to alter the effort level of participants.[10] The group size depends on the number of individuals who find it in their interest to participate *given the participation of others* in the group; this is to say that the distribution of participants' costs and benefits from cooperation belongs to the core (Mas-Colell, Whinston, and Green 1995, p.679). Despite the voluntary nature of the contract, monitoring takes place on the part of participants because it provides reassurance that others are holding up their end of the bargain. This type of contract has also been termed an *assurance problem* in the game theory literature (Runge 1981).

Coordinating abatement effort is costly, because some subset of the group must spend time to design the coordinated effort, and because each participant must alter

[10]The impact of long-term relationships among neighboring landowners may be important in this context, however.

the time, place, or abatement technique. A willingness to coordinate abatement effort with others does not imply optimal labor effort on the part of participants, however. One can punch the time clock, so to speak, but still produce very little during the work day. Given the potential gains from coordination, participants may still have an incentive and the opportunity to shirk in terms of the level of effort. Similar concepts of coordination and coordination costs are examined by Becker and Murphy (1992) in the context of gains from specialization and costs of coordinating specialized effort.[11]

Following Lazear (1986, p. 418), let some minimum amount of effort, call it *participation*, be monitorable by other participants, but the actual level of effort is assumed to be unmonitorable and/or unenforceable, so that the problem is to maximize the value of group production subject to private incentives to shirk. The gains come from reorganizing labor, not from altering private labor effort incentives above the level of participation. Consider a set of n identical landowners whose cooperation leads to temporal or spatial coordination of abatement effort which increases their personal marginal product of labor subject to the participation of others in the group. Each participant's problem is to solve

$$\max_{x^i} R^i(x^i; x^j, z, n) - cx^i - \frac{1}{n} f(z, n), \tag{2.8}$$

[11] If participants are able to restrict entry into the group if coordination and monitoring costs became "too high," then this problem becomes even more like Becker and Murphy (1992), where the number of specialized labor participants is a choice variable.

where z coordination effort on the part of participants, R^i is participant i's revenue, x^i is i's effort level, and x^j is the effort level of each of the other participants. $R^i_{x^i}$, R^i_z and R_n are non-negative, and $R^i_{x^i x^i}$, R_{zz} and R_{nn} are non-positive. A competitive wage c is the opportunity cost of time, and $f(\cdot)$ are coordination costs, assumed to be distributed uniformly among participants, with $f_z > 0$, $f_{zz} > 0$, $f_n > 0$ and $f_{nn} > 0$. The first-order condition for this problem is

$$R^i_{x^i}(x^i; x^j, z, n) - c = 0 \tag{2.9}$$

Higher levels of coordination (e.g. more strict timing of abatement effort on the part of all participants) and more participants are assumed to increase the marginal product of labor for each participant so that $R_{xz} > 0$ and $R_{xn} > 0$. This first-order condition is equivalent to equation 2.4, which is suboptimal if $R^j_{x^i} \neq 0$.[12] Equation 2.9 implies labor effort by each participant $x^i = x^i(x^j(z, n), z, n) = x^i(z, n)$. Given abatement effort by participants, and the requirement that each participant is better off participating than not participating, the group maximizes over z. Because producers are identical, the subscripts are dropped, and the problem is

$$\max_z n[R(x, z, n) - cx] - f(z; n) \tag{2.10}$$

subject to

[12] Optimal abatement would account for externalities, so that $R^i_{x^i} + (n-1)R^j_{x^i} - c = 0$, which is equivalent to equation 2.6.

$$IC: \quad x = x(z, n)$$

$$IR: \quad \pi(z, n) \geq \pi^p.$$

The first constraint (IC) is the Incentive Compatibility constraint, (IR) is the Individual Rationality constraint (also known as the participation constraint), and π^p denotes the level profit an individual would receive were he not to participate. Assuming the participation constraint is not binding, optimal coordination is defined by the first-order condition

$$n[R_x x_z + R_z - c x_z] - f_z = 0, \tag{2.11a}$$

which, by first-order condition 2.9 is equal to:

$$n R_z - f_z = 0. \tag{2.11b}$$

This implies a "demand" for coordination $z = z(n)$, which in turn implies the effort function $x = x(z(n), n) = x(n)$. Plugging these into the group's maximization objective function results in a group profit function

$$\Pi^g = n\big[R(x(n), z(n), n) - c x(n)\big] - f(z(n), n). \tag{2.12}$$

The effects of the number of participants on the value of production can be seen via the Envelope Theorem:

$$\frac{\mathrm{d}\Pi^g}{\mathrm{d}n} = R + nR_n - f_n \gtrless 0. \tag{2.13}$$

Because $R_{nn} < 0$ and $f_{nn} > 0$, gains from cooperation will increase at first, and then decrease as coordination and monitoring costs overtake the revenue gains.[13] When the marginal gains from increased participation are high, increases in participation will increase the value of labor coordination. After a certain point, the equivalent of congestion sets in and the value of coordination diminishes.

Assume, in turn, that the marginal product of coordination R_z and the marginal cost of coordination f_z are constant over a range of z. The Envelope Theorem applied to equation 2.12 results in

$$\frac{\mathrm{d}\Pi^g}{\mathrm{d}R_z} = nz \qquad \text{and} \qquad \frac{\mathrm{d}\Pi^g}{\mathrm{d}f_z} = -z. \tag{2.14}$$

Because π^p (independent profit) does not depend on any of these parameters, the change in the value of labor coordination is equal to the change in the value of production as shown in equations 2.13 and 2.14. These Envelope Theorem results

[13] To see that equation 2.13 holds, differentiate equation 2.12, which results in

$$\frac{\mathrm{d}\Pi^g}{\mathrm{d}n} = R + n(R_x - c)x_n + (nR_z - f_z)z_n + nR_n - f_n.$$

Equations 2.11b and 2.9 imply that the terms in brackets equal zero, and the end result is (2.13).

imply that the value of a contract increases with increases in the marginal product of coordination and decreases with increases in the marginal costs of coordination.

Equations 2.11a through 2.14 are derived assuming that the participation constraint is not binding. Recall that the basis for voluntary participation in group abatement effort is one of *assurance*. If non-participation by one individual does not affect the integrity of a contract from which they benefit, then the incentive to participate is diminished because they can receive benefits without expending effort. For very small groups (picture a group of three), the marginal value of an individual is high and non-participation by one individual reduces the value of cooperation among others, possibly so much that cooperation does not occur at all. However, as the group gets larger, non-participation at the margin will not be as detrimental to contract value. Non-participation by one individual may go unnoticed, and so the potential costs to the non-participant of *not* participating are low. All else constant, this effect will tend to keep group sizes relatively small. Additional means of strengthening incentives to participate include imposing mandatory participation with penalties for non-participation, or providing excludable benefits for participants only. These two options may support the relatively weak *assurance* incentive for larger groups.

The analysis thus far has centered on gains from coordination and increasing returns to scale in participation, but the type of abatement used by the group also matters. Consider two separate cases of damage abatement: one in which the group increases lethal abatement which benefits participants and non-participants alike,

and one in which the group increases dispersal effort of the pest from the land of its participants, forcing more wildlife to go elsewhere — in particular onto the land of non-participants. The former contract is likely to suffer more from free-rider problems, because non-participants will gain from others' efforts without bearing the costs. On the other hand, if non-participants stand to be worse off by not participating in an existing contract, they will be more likely to cooperate or attempt to block a contract among others.

It is also possible that with a change in the organization of abatement labor, abatement techniques may change and require different tools. One could easily show, also via the Envelope Theorem, that as the marginal cost of the the group's abatement technique decreases (holding the cost of independent abatement constant), the value of coordinated effort increases.

In summary, various cooperative wildlife damage abatement activities can be viewed as an attempt to capture economies of scale in coordination and labor. A number of implications follow from this model: as the costs of monitoring participation and organizing labor decrease, the value of labor coordination increases (equation 2.14); as the marginal value of coordinating effort increases, the value of a contract increases (equation 2.14). As marginal economies of scale in participation increase, the value of coordination increases. In all cases, as the value of labor coordination increases, the likelihood of this type of cooperative activity increases. As discussed in the previous three paragraphs, the value of cooperation increases as the marginal cost of

abatement techniques used by the group decreases. The type of abatement used by the group affects the incentives of individuals to shirk, and excludable goods may be used to promote participation. These predictions will be discussed in the context of anecdotal evidence in section 2.3.

2.2.2 Sharing abatement costs

The model of labor coordination in the previous section focuses on economies of scale in abatement. Gains are made through coordination of effort over time and space, but the problem of internalizing damage abatement externalities is not addressed through the coordination process. Most damage control contracts do not take the form of effort coordination, but rather can be better explained as an attempt to alter private abatement incentives. When abatement provides positive externalities, the effects of landowner shirking may be reduced if there is some mechanism in place for monitoring landowner abatement effort. One way to do this is to collect money from participants and then redistribute it among participants in the form of third-party abatement labor. Although monitoring monetary contributions to group abatement efforts can reduce shirking, there are two potential sources of inefficiency associated with abatement cost sharing arrangements of this type that are not associated with labor sharing arrangements. First, assessments based on the level of some other productive input may lead to distortions in the use of that input. Second, deadweight

losses from the abatement distribution process will arise through rent-seeking efforts by participating producers.[14]

The most common way in which predator control funds are collected from a group (whether it be all producers in a county or members of a livestock association) is to assess a fee, call it τ, per unit of some monitorable productive input such as livestock inventory or acreage. The funds are then distributed in the form of abatement — almost always lethal abatement such as hunting and trapping. It is necessary to make an explicit distinction between the productive input which is the basis for the assessment, and the abatement input which the assessment is used to purchase. Therefore, for landowner i, let x_i be the productive input with r its competitive wage, and let a_i be the abatement input with c its competitive wage. Revenues are a function of both abatement inputs $\mathbf{a} = (a_1, a_2 \ldots a_n)'$ and productive inputs $\mathbf{x} = (x_1, x_2 \ldots x_n)'$, where abatement affects the distribution of wildlife across landholdings, but productive inputs do not. Abatement is funded entirely by the assessment, so total abatement costs $c \sum_i a_i$ are restricted to equal the total income from the assessment on the productive input: $c \sum_i a_i = \tau \sum_i x_i$.

First, consider the first-best solution in which abatement levels, productive input levels (livestock inventories, for example), and the assessment level τ are jointly chosen for all producers.[15] Note that producers do not pay for abatement directly, but

[14] Rent-seeking issues may play a part in any of the contracts examined in this chapter.

[15] Livestock and other inputs such as standing grain are commonly viewed as outputs. In the context of damage, however, it is helpful to view these inventories as capital inputs subject to damage.

instead each pays τx_i which goes into the predator control fund. To focus on resource allocation, any contracting costs associated with collection and redistribution of funds will initially be ignored. The joint maximization problem is

$$\max_{\mathbf{a},\mathbf{x},\tau} \sum_i R^i(\mathbf{a}, x_i) - (\tau + r) \sum_i x_i \tag{2.15}$$

subject to

$$\tau \sum_{i=1}^{n} x_i - c \sum_{i=1}^{n} a_i = 0 \qquad (\lambda)$$

where λ is the Lagrange multiplier associated with the constraint. The first-order conditions are:[16]

$$a_i : \qquad \sum_j R^j_{a_i} - \lambda c = 0 \qquad \forall\ i \tag{2.16a}$$

$$x_i : R^i_{x_i} - (r + \tau) + \lambda\tau = 0 \qquad \forall\ i \tag{2.16b}$$

$$\tau : -\sum_i x_i + \lambda \sum_i x_i = 0 \tag{2.16c}$$

Equation 2.16c implies that $\lambda = 1$. Substituting 1 in for λ in the remaining first-order conditions in 2.16 imply first-best marginal conditions on x_i and a_i.[17]

[16] The first-order condition with respect to λ returns the constraint

[17] Without the assessment, the problem is

$$\max_{\mathbf{a},\mathbf{x}} = \sum\nolimits_i R^i(\mathbf{a}, x_i) - r \sum\nolimits_i x_i - c \sum\nolimits_i a_i,$$

for which the first-best first-order conditions are $\sum_j R^j_{a_i} - c = 0$ and $R^i_{x_i} - r = 0$.

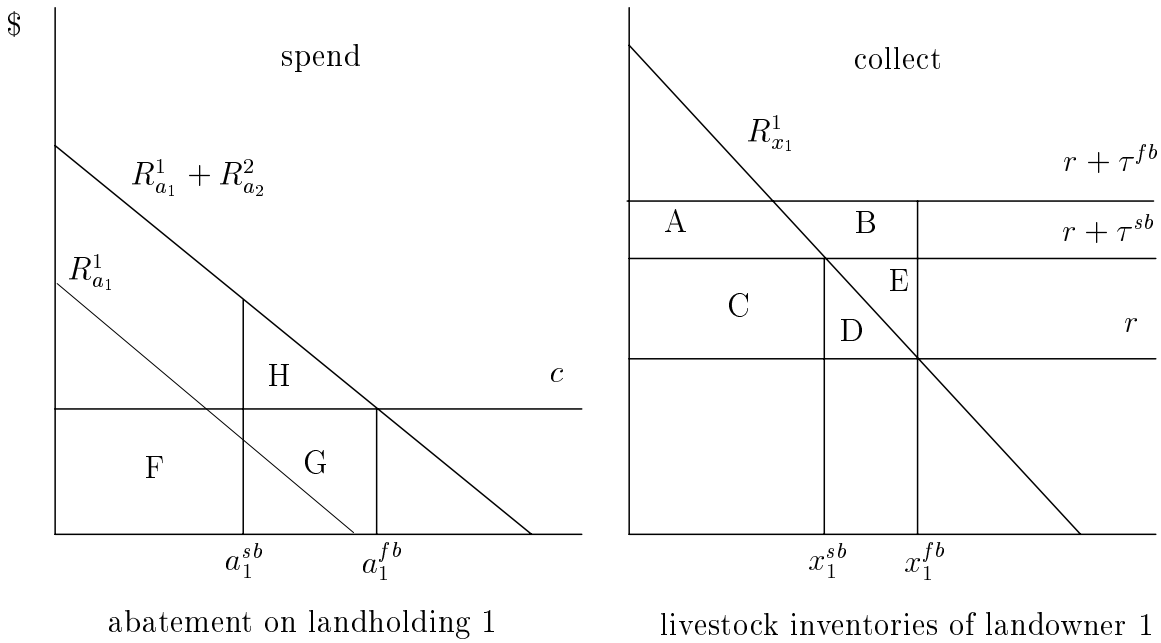
First-order condition 2.16a implies that abatement will be distributed such that the marginal value of abatement is equal across landholdings.

Figure 2.2 provides an illustration of these results for two identical producers. On the left side, $R^1_{a_1}$ is the marginal value of abatement to himself, $R^1_{a_1} + R^2_{a_1}$ is the total marginal benefit of 1's abatement including the marginal value of 1's abatement to 2, and c is the marginal cost of abatement. On the right side, R_{x_1} is the marginal value of the assessed input x, and r is its marginal cost. Acting independently, landowner 1 would produce abatement effort where $R^1_{a_1}$ equals c in the left graph (This is not labeled, but it would be to the left of a_1^{sb}). The first-best level of abatement a_1^{fb} is where $R^1_{a_1} + R^2_{a_1} = c$. If landowners 1 and 2 each are each assessed τ, the total assessment would be $\tau(x_1 + x_2)$, which would then be used to pay for abatement. In the first best case where producers choose x to maximize joint profits, x_1^{fb} would be chosen for landowner 1 to satisfy the first-best marginal conditions for x. The first-best assessment τ would be that which set (A+B+C+D+E) in the right frame equal to (F+G) in the left frame, leading to first-best allocation of both x and a.

In reality, landowners do not jointly maximize their profits, as is assumed above, and a potential problem with these assessments is that producers are generally free to choose levels of x independently.[18] In order to maximize their individual profits subject to the assessment, landowners will set x_i such that their marginal gains from

[18] I know of no case in which the levels of the productive inputs used by participants are somehow limited through the abatement cost-sharing agreement.

Figure 2.2: Per unit input assessment.



x equal their own marginal costs (including τ):

$$R^i_{x_i} - (r + \tau) = 0. \tag{2.17}$$

Comparing (2.17) with the first-best solution $R^i_{x_i} - r = 0$, immediately it can be seen that in order for this equality to hold, less of x will be used given the standard assumption of diminishing marginal productivity of x.[19] Adding equation 2.17 as a constraint to problem 2.15 (one for each landowner), and assuming a well-defined

[19]The first-best solution is (2.16b) with $\lambda = 1$, which is required by (2.16c).

maximum, first-order-conditions for a_i and τ become:[20]

$$a_i : \qquad \sum_j R^j_{a_i} - \lambda c + \lambda_i R^i_{x_i a_i} = 0 \tag{2.18a}$$

$$\tau : -\sum_i x_i + \lambda \sum_i x_i - \sum_i \lambda_i = 0 \tag{2.18b}$$

where λ is again the multiplier on the budget constraint and λ_i is the Lagrange multiplier for the incentive compatibility constraint for landowner i (equation 2.17).[21] Because $R^i_{x_i}$ is too high relative to first-best, an increase in $R^i_{x_i}$ would lead to a decrease in the value of the objective function. This in turn implies that $\lambda_i < 0$. for all i. [22] If both constraints are binding, equation 2.18b implies that $\lambda = 1 + \frac{\sum_i \lambda_i}{\sum_i x_i} < 1$. This in conjunction with equation 2.18a implies that abatement levels will be below first-best levels.[23]

Figure 2.2 provides a graphical illustration of this result for landowner 1's inputs allocation, assuming linear marginal products, identical producers, and technical independence of x and a (i.e. $R_{ax} = 0$). Producer 1 chooses x to maximize his personal profit subject to the optimal assessment, implying that he will set $R_{x_1} = r + \tau$ (the incentive compatibility constraint). There is now an opportunity cost for the assessment in the form of the reduction in x_1, which is now set at x_1^{sb}. The equilibrium

[20] For a discussion of the limitations of this "first-order condition approach", see Laffont (1990).

[21] Again, first-order conditions with respect to λ and λ_i return the constraints.

[22] Recall that in the context of the Lagrangian method, $\frac{dv}{dc} = \lambda$, where v is the value of the objective function, c is the value of the constraint, and λ is the Lagrange multiplier (Dixit 1990).

[23] This assumes that abatement and productive inputs are technical complements, as would be the case for a common functional form such as $R = py(x)(1 - \delta(a))$, where $R_{xa} = -py_x\delta_a > 0$.

assessment given the incentive compatibility constraint is therefore lower; $\tau^{sb} < \tau^{fb}$. Because both τ and x_1 are lower than first-best, so are the total funds available for use on abatement. In this case, the budget constraint implies that (C) on the right equals (F) on the left, and abatement allocated to producer 1 is $a_1^{sb} < a_1^{fb}$.

The welfare implications of the misallocation of x_i can be shown in both figure 2.2 and mathematically through the budget constraint. First, note that the misallocation in productive inputs x_i is driven by the assessment rate itself which, after rearranging the budget constraint, is $\tau = (c \sum_i a_i)(\sum_i x_i)^{-1}$. As the sum of productive inputs gets large relative to the total cost of abatement, the assessment is small and its effect on producers' chosen levels of x will be small. The deadweight loss resulting from misallocation of x is represented in figure 2.2 by (D+H). By rotating R_{x_i} (the value of the marginal product (VMP) of x) around the point where $r = R_{x_1}$ making it more inelastic, τ^{sb} will increase, abatement levels will increase, and the deadweight loss will diminish. When x is perfectly inelastic, the deadweight loss is non-existent. In contrast, as the VMP of abatement $R_{a_1^1} + R_{a_1}^2$ becomes more inelastic, deadweight losses become larger.

Two additional implications of this model should be mentioned. First, if the marginal size of the externality ($R_{a_1}^2$ in figure 2.2) is relatively small, the VMP curve for abatement is relatively inelastic, and the demand curve for x is relatively elastic, it is possible for an assessment to make participants worse off than with no assessment. Second, it may be also be possible, particularly in the circumstances described before,

that *even with homogeneous producers*, private abatement may be used to supplement an assessment.

In addition to the inefficiencies that result from misallocation of the assessed input, there are also costs associated with collecting and redistributing abatement funds, costs of contracting with third-party abatement labor, and the potential for the distribution of assessment costs to differ substantially from the distribution of assessment benefits. If a subset of landowners can potentially have a large negative impact on contract value by not participating, it may *a priori* be in the interest of the group to impose mandatory participation. These final points are the focus of chapter 3.

There may be other reasons for producers to expend private abatement effort to supplement group abatement. For example, when a producer finds a predator in the process of harassing livestock, it may be more expeditious to address problem on his own rather than to rely on predator control agents hired by the group. Furthermore, despite attempts by the group administrators to distribute abatement optimally, rent-seeking forces and heterogeneous bargaining power within the group may in reality lead to distribution problems. Although the model abstracts from this possibility, suboptimal abatement may induce some landowners to supplement group abatement.[24] Finally, when group predator control is limited to certain forms

[24]Rook and Carlson (1985) discuss this issue, but they assume that group abatement is distributed uniformly among participants.

of abatement such as aerial hunting, it may be in the interest of a producer to expend private effort performing other abatement alternatives.

In summary, efficient allocations of both the assessed input and the abatement input follow from joint maximization over both inputs, or joint maximization over abatement when productive input levels are fixed (equations 2.16). However, when the assessed input is variable and not subject to contract restrictions, producers will respond by reducing inventories of the assessed input, leading in turn to suboptimal assessment rates and abatement expenditures (equations 2.18). This inefficiency is exacerbated when the productive input demand is elastic relative to abatement demand. Assessments are costly to implement, and the value of an assessment program also depends on the costs of collection and abatement distribution. Further, the distribution of costs relative to the distribution of benefits from the contract will affect the number of participants and therefore the value of an assessment contract.

2.2.3 Third party labor: hired hunter versus Bounty hunter

This section takes a cost-sharing arrangement among a set of individuals suffering wildlife damage as given and examines the tradeoff between hiring a third-party hunter and paying bounties for predator control. The defining difference between these two payment schemes is that the bounty hunter is paid for exchanging the remains of an animal for a bounty payment, whereas the hired hunter is paid a salary

which is not contingent directly or solely on the number of animals killed. The problem of choosing between a bounty system and a hired-hunter system is similar in some ways to the choice between paying labor by the piece or by salary (Lazear 1986). Bounty payments do not compensate the bounty hunter for an individual predator's propensity to inflict damage, and inefficiencies may result under certain circumstances. The imposition of selection rules on bounty payments has historically lead to widespread fraud. This element of the problem is examined as well.

Abatement effort consists of two tasks: "search" or "selection" efforts to select those animals with the higher propensity to damage, and "kill" effort. For concreteness, the problem will be discussed in terms of lethal abatement. Further, contracting costs related to employer group dynamics will be ignored, so the problem reduces to a bilateral contract between the employer, which pays the bounty or the wage, and the employee, which is either a bounty hunter or a hired hunter.

The revenue function for the employer is $R(s, w(k))$, where s is selection effort, k is kill effort, and w is the predator stock. Assume that s is a non-essential input and that selection increases the marginal value of a reduction in the wildlife stock, implying $R_{ws} = R_{sw} < 0$. Concavity requires $R_{ss} < 0$, $R_w w_{kk} < 0$, and $R_{ss} \cdot R_w w_{kk} - (R_{ws} w_k)^2 < 0$.

Hired hunter

The hired hunter allocates his time efficiently across selection and kill effort subject to monitoring by the employer, and is indifferent between the two tasks. Monitoring the number of kills may be easier than monitoring selection effort; here it will be assumed that the employer can costlessly verify a kill for both the hired hunter and the bounty hunter. Let the employer maximize over kill effort and selection effort subject to marginal monitoring costs m^s. For example, for every hour of effort put forth by the hired hunter, the employer may have to spend some fraction of that time verifying that the hired hunter is working the desired location. The employer's problem for employing a hired hunter is:

$$\max_{k,s} \pi^h = R(s, w(k)) - c(s + k) - m^s s, \tag{2.19}$$

where c is the wage per unit time of the hired hunter equal to the perfectly competitive labor market wage. The first-order conditions are

$$R_w w_k - c = 0 \tag{2.20a}$$

$$R_s - (c + m^s) = 0, \tag{2.20b}$$

which imply that the optimal allocation of search and kill effort equate the marginal gain of each input to its marginal cost, including the wage rate and monitoring cost.

Bounty hunter

Because bounty hunters are compensated for k but not s, income maximizing bounty hunters will spend no effort selecting those individuals in a wildlife population that impose higher damage, but rather will go for the easiest kills first. It will be assumed at first that proving a kill in order to receive a bounty is costless for both parties. For the following discussion it is necessary to explicitly distinguish between the wildlife stock remaining after abatement and the wildlife taken through abatement. Let the after-abatement wildlife stock be $w = \bar{w} - \acute{w}$, where $\bar{w}$ is the beginning (predetermined) wildlife stock and $\acute{w}$ is the number of animals killed. The number of animals killed is a function of kill effort k: $\acute{w} = \acute{w}(k)$.[25] It follows that the change in the wildlife stock with respect to lethal abatement is the negative of the change in the number of kills with respect to a change in lethal abatement effort: $w_k = (\bar{w} - \acute{w})_k = -\acute{w}_k < 0$. In choosing abatement levels, the bounty hunter solves the following problem:

$$\max_k b\acute{w}(k) - ck, \tag{2.21}$$

[25] In general, k *does not* equal the number of animals killed. The only instance in which $\acute{w} = k$ is when the hunter kills one animal per unit of effort, say one animal per day, if k were measured in days.

where b is the bounty received for each animal killed, and c is the hunter's opportunity cost of labor. The first-order condition for this problem is

$$b\acute{w}_k - c = 0. \tag{2.22}$$

Assuming diminishing returns to hunting, this implies a supply function for bounty hunting $k = k(b, c)$ which is increasing in b and decreasing in c.

For an individual to hunt in return for a bounty, his total income from bounty hunting must be at least as large as his opportunity cost. Assuming his next best alternative is working in the competitive labor market, participation requires $b\acute{w}(k) - ck \geq 0$. The employer's problem is to set a bounty b that maximizes his profits, while accounting for the participation and incentive requirements of the bounty hunter. The employer's problem is

$$\max_b R(0, w(k)) - b\acute{w}(k) \tag{2.23}$$

$$\text{subject to}$$

$$IR: \quad b\acute{w}(k) - ck \geq 0$$

$$IC: \quad k = k(b, c)$$

where the zero in the revenue function indicates no selection effort by the bounty hunter ($s = 0$). The first constraint is the participation (individual rationality) con-

straint and the second is the incentive compatibility constraint.[26] Given that the individual rationality constraint holds with equality and assuming the first-order conditions are satisfied with equality, plugging the constraints directly into the employer's problem (equation 2.23) results in

$$R(0, w(k(b))) - ck(b), \tag{2.24}$$

for which the first-order condition with respect to b (after factoring out k_b) is

$$R_w w_k - c = 0. \tag{2.25}$$

This result is identical to the employer's first-order condition for k with the hired hunter (equation 2.20a), except that before he was choosing k directly. Here k is chosen indirectly through his choice of b. Together, the first-order conditions of the employer (equation 2.25) and the bounty hunter (equation 2.22) define the equilibrium bounty. These two first-order conditions together imply

$$\begin{aligned} b\acute{w}_k &= R_w w_k \\ -bw_k &= R_w w_k \\ b &= -R_w, \end{aligned} \tag{2.26}$$

[26]See Laffont (1990, chapter 11) for a discussion of potential difficulties with this approach.

which is to say that the bounty payment is equal to the value of reducing the wildlife stock by one unit. Also note that by replacing b in the bounty hunter's participation constraint with R_w (the maximum the landowner is willing to pay for a kill), there may be no bounty payment suitable to both parties. In particular, any $-R_w^0(s=0)$ not big enough to satisfy the participation constraint

$$-R_w^0 \acute{w}(k^b) - ck^b \geq 0, \tag{2.27}$$

will not support an equilibrium bounty payment.

These results have implications with respect to the size of the bounty payment, the importance of selection effort in reducing damage, and the value of a bounty system. By definition, increases in selection effort will increase the marginal product of the kill. When there is large variation in the propensity to damage property within the wildlife stock, in particular when a very small fraction of the predator population has a large propensity for damage, selection effort becomes more important in reducing damage (R_{ws} becomes big). The marginal value of an indiscriminate kill $-R_w(s=0)$ will be small, and the optimal bounty will be relatively small. When each member of the wildlife population being killed for bounty has the same propensity for damage, then selection effort is of little value and the bounty will be relatively high.

Totally differentiating along an isorevenue curve will provide some insight into the efficiency losses associated with a bounty contract. Recall that total revenues may

include income from the wildlife itself and income from other agricultural production: $R = R^w + R^y$. Suppose further that income from the wildlife stock is not affected by s.[27] Totally differentiating an arbitrary profit level $\bar{R} \equiv R^w(w(k)) + R^y(s, w(k))$ with respect to s and k and rearranging leads to

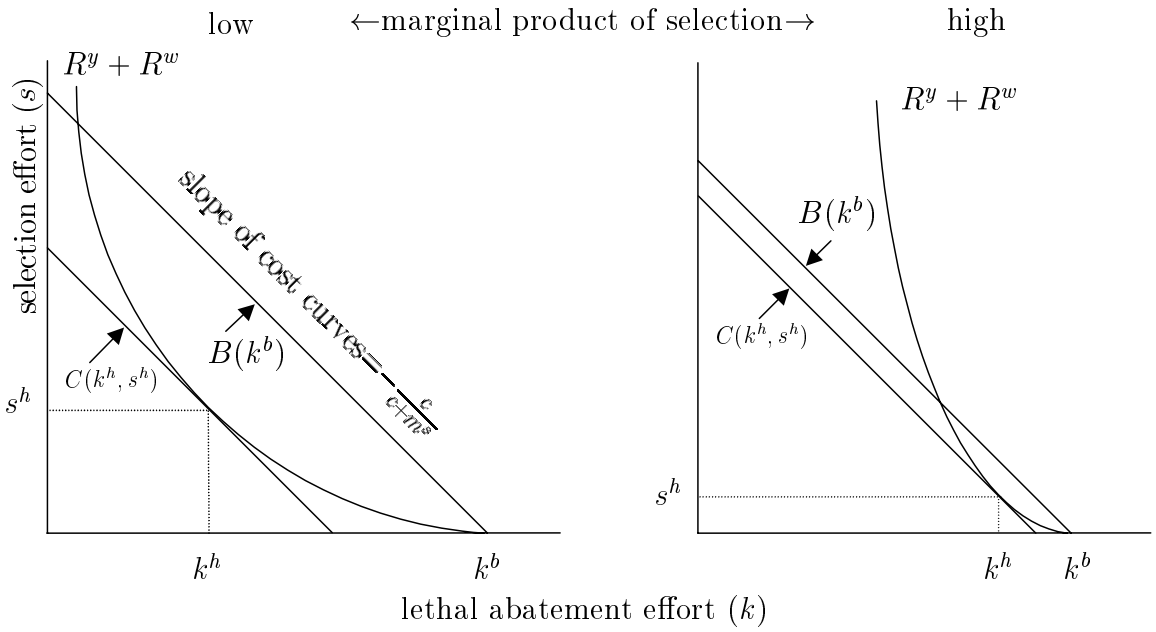
$$\frac{\mathrm{d}s}{\mathrm{d}k} = -\frac{(R^w_w + R^y_w)w_k}{R^y_s}. \tag{2.28}$$

Equation 2.28 corresponds to the slope of the isorevenue curve $\bar{R}$, and shows that the isorevenue curve becomes flatter with increases in the net marginal value of wildlife $R^w_w + R^y_w$, the marginal product of kill effort w_k, and with decreases in the marginal product of selection R^y_s.

Figure 2.3 illustrates the problem. The left side of figure 2.3 shows a steep isorevenue curve, which could correspond to a situation in which the marginal product of selection effort is high. The right side shows a case in which the marginal product of selection is low. The cost of reaching this isorevenue curve with the hired hunter is $C = (c + m^s)s + ck$, and the slope of this cost line is $-\frac{c}{c+m^s}$, which becomes flatter as m^s becomes large. Because the bounty hunter is not compensated for selection of high-damage wildlife, his effort will be expended entirely on the kill by selecting the easiest prey first regardless of its relative propensity to damage property. This leads to a corner solution at k^b. $B\left(k^b\right)$ in the figure represents the cost of reaching

[27] This is equivalent to assuming that consumers of wildlife or wildlife services are indifferent between the individual animals that impose the most damage relative to those that do not.

Figure 2.3: Comparison of labor effort, hired hunter versus bounty hunter.



the isorevenue curve using a bounty hunter at relative prices for the hired hunter and $s = 0$, and the vertical difference between C and B is proportional to the difference in the cost of reaching that isorevenue curve.[28]

An interior solution for the hired hunter requires $|\frac{ds}{dk}| < \frac{c}{c+m^s}$. On the other hand, if $|\frac{ds}{dk}| \geq \frac{c}{c+m^s}$, the marginal gains from selection effort will be outweighed by the marginal gains from indiscriminate killing at every point along the isorevenue curve, leading to a corner solution at $k = k^b$, and the equilibrium behavior by the hired hunter will be identical to that of the bounty hunter. However, as the isorevenue curve becomes flatter, the hired hunter will (subject to adequate monitoring) allocate his efforts such that the marginal rate of substitution between selection and kill effort

[28]Specifically, the intercept of C is $C/(c+m^s)$ and the difference in the costs is $1/(c+m^s)(C-B)$.

is equal to the slope of the isocost curve, reducing the cost of abatement to $C(k^h, s^h)$. A comparison of the left and right sides of figure 2.3 shows that the smaller in absolute value is $\frac{ds}{dk}$, the flatter is the isorevenue curve and the larger are the efficiency losses from a bounty system relative to a hired hunter (holding monitoring costs constant).

Equation 2.28 and figure 2.3 together show that the value of a bounty system decreases as the marginal productivity of selection effort increases, as the net marginal value of wildlife increases, and as the marginal productivity of killing effort decreases. The value of contracting with a hired hunter decreases as monitoring costs increase.[29]

Bounties with selection rules and the potential for fraud

The incentive problems that result from rewarding the kill but not the selection of particular animals have often led to the imposition rules specifying which animals are eligible for bounties. One virtually universal rule is that bounties tend to be species-specific, and different species tend to carry different bounties. Another is that bounty payments are limited to animals killed only within a specified region, such as on the land of the producers paying the bounty (for private bounties), or within the county or state (for public bounty payments). The imposition of these selection rules moves the bounty system closer to a hired hunter system in that monitoring for selection is

[29] Another factor that will not be discussed here is the impact on pelt prices for bounty hunting. When bounty hunters are allowed to keep pelts to sell after receiving the bounty, bounty hunters will provide more effort when pelts are highest in value, which may not be when the effort is needed most. Further, if bounty payments are seasonal, they may lead to inefficient harvest when furs not at their prime (Latham 1951, p. 67). Generally, hired hunters do not retain ownership of the pelts.

required. However, the incentive for fraud is stronger with the bounty system because of the stronger incentive structure.

Suppose the wildlife population is made up of two subpopulations, distinguished by a high propensity to damage, $\bar{R}_w$ and a low propensity to damage $\underline{R}_w$, so that $-\bar{R}_w > -\underline{R}_w$ for any and all levels of w.[30] If the bounty-hunter's participation constraint is satisfied for each subpopulation, equilibrium bounties $\bar{b}$ and $\underline{b}$ will be offered (equation 2.26). If animals from different subpopulations are costlessly distinguishable, bounty payments will only be paid for the wildlife subpopulation for which it is intended. However, when they are not easily distinguishable, bounty hunters, unlike hired hunters, have an incentive to kill animals from the $\underline{b}$ subpopulation and sell them at $\bar{b}$. This is the basis for the widespread fraud that has pervaded bounty systems throughout its history.

In such situations, costs are incurred by employers to reduce fraud. Furthermore, as more low R_w animals are used to receive bounty payments, the average R_w associated with the animals receiving bounties will decline, and equilibrium bounties will be bid down, possibly to zero, because the marginal value of an animal carcass in terms of damage reduction for the employers declines.

Suppose for example that a county has an established bounty $\bar{b}$ based on $\bar{R}_w$, the marginal damage propensity of the wildlife *living in the county*, w^1. The other

[30]The subpopulations could be two different species, the same species with two different types of individuals, or the same species in two different areas, with $\bar{R}_w$ the local subpopulation and $\underline{R}_w$ a more distant subpopulation (the next county over, perhaps), changes in which may affect local damage through cross-county wildlife distribution effects.

subpopulation of this species, w^2, lives in county 2 across a river that does not offer a bounty ($\underline{b} = 0$). The river completely separates the wildlife populations and transporting goods from one side of the river to the other is costly. Suppose a bridge is built over the river, reducing transportation costs enough to make importation of predator carcasses profitable for bounty hunters, so hunters begin to import carcasses. A bounty hunter's maximization problem is then to spend k^1 units of effort killing in county 1 and k^2 units of effort in county 2 to maximize

$$\max_{k^1,k^2} \bar{b}(w^1(k^1) + w^2(k^2)) - c(k^1 + k^2) - tk^2 \tag{2.29}$$

where t are marginal transportation costs across the river from county 2 to county 1. An implication of the first-order conditions for this problem is $w^1_{k^1} = w^2_{k^2} - t$. If county 1 adjusts the bounty so it is equal, say, to the average marginal propensity to damage of the wildlife brought for bounties, this value will decline as a higher proportion of county 2 wildlife ($R^2_w = 0$) are brought in. If county 2 is a relatively cheap source of wildlife for bounties (including transportation costs), the bounty offered by county 1 will become low and ineffective for reducing the local wildlife population. If, on the other hand, county 1 is a relatively low-cost method for hunters of receiving a bounty, then fraud will be less of a problem.[31]

[31] For example, fewer look-alike animals will be brought for bounty if the look-alike species is more difficult to kill and bring in.

The transportation costs t can represent any of a number of factors that affect the costs of bringing the *wrong* animal in for bounty, including the costs of raising the wildlife in captivity specifically for bounties, and the expected costs of being caught collecting bounties fraudulently. The latter would be endogenously determined by monitoring effort by county 1, but would depend on things such as the difficulty of distinguishing between species or in-county and out-of-county animals.

In summary, equation 2.28 and figure 2.3 show that the value of a bounty system decreases as the marginal productivity of selection effort increases, as the net marginal value of wildlife increases, and as the marginal productivity of killing effort decreases. The value of contracting with a hired hunter decreases as monitoring costs increase. Finally, as the costs of differentiating between bountied and non-bountied animals increases, or the ease with which hunters can substitute the bountied species with other species increases, the value of a bounty system decreases.

2.2.4 Sharing capital

The costs of damage abatement capital also may be shared among individuals and groups to address damage problems. Livestock producers buy and share traps and airplanes for predator control, and wildlife agencies subsidize fencing to reduce crop damage by deer and other ungulates. A model is developed here to examine capital as a shared, monitorable abatement input. It is shown that sharing the cost of monitorable inputs can alleviate incentive problems when abatement labor is costly

to monitor. The use of one monitorable input to compensate for private hidden action over another input has been examined in various contexts, such as imposition of capital restrictions to control fisheries harvest (Johnson and Libecap 1982), and contractually linking cropshare arrangements with output marketing, tenant credit, and consumption goods (Braverman and Stiglitz 1982).

A general case

Consider two landowners, 1 and 2, each of which provides abatement labor l and abatement capital k such as a fence on his own land (k is defined differently here than in section 2.2.3, where it refers to lethal abatement). Assume that monitoring the usage of the abatement capital by one landowner is costless for the other, but that monitoring labor effort is prohibitively costly at any level. The landowners will jointly pay for the optimal level of capital and distribute it to each landholding subject to (optimal) contracted levels, but abatement labor effort will be set by each individual at non-cooperative levels. As usual, assume that both abatement inputs by each individual may impose external effects on the other's production, so that the revenue function of landowner i is $R^i(\mathbf{l}, \mathbf{k})$, where $\mathbf{l} = (l^1, l^2)$ and $\mathbf{k} = (k^1, k^2)$

Acting independently, each landowner maximizes profits taking the other's actions as given. Landowner i's problem is

$$R^i(\mathbf{l}, \mathbf{k}) - c^l l^i - c^k k^i \tag{2.30}$$

for which the first order conditions are

$$R^i_{l^i} - c^l = 0 \tag{2.31a}$$

$$R^i_{k^i} - c^k = 0. \tag{2.31b}$$

Because each does not consider his effects on the other's revenue function, this outcome is inefficient for producers as a group (see section 2.1.1 for a more complete discussion).

Landowners can increase aggregate wealth by contracting over abatement capital subject to independent labor effort by each. The landowners maximize aggregate profit by jointly choosing capital subject to equation 2.31a, which acts as an individual rationality constraint for joint maximization. Assuming the participation constraints are non-binding, the joint maximization problem is:[32]

$$\max_{\mathbf{k}} \sum_{i=1}^{2} R^i(\mathbf{k};\mathbf{l}) - c^k \sum_{i=1}^{2} k^i \tag{2.32}$$

subject to

$$IC: \quad R^i_{l^i} - c^l = 0 \quad (\lambda_i) \quad i = 1, 2,$$

[32] Although this approach describes how abatement capital will be distributed among landowners, the distribution of the shared costs of abatement capital is transparent here. It is only assumed that the distribution is such that the cost-sharing rule satisfies the participation constraint of each participant.

where the Lagrange multipliers λ_i are associated with the incentive compatibility constraints for each landowner. The first-order conditions are

$$R^1_{k^i} + R^2_{k^i} - c^k + \lambda_i R^i_{l^i k^i} = 0 \quad i = 1, 2 \tag{2.33}$$

in addition to the constraint. Equation 2.33 implies that optimal capital use will differ from first-best if the labor constraint is binding (if $\lambda_i \neq 0$, or alternatively if there are no externalities associated with l^i) and if labor and capital are not technically independent.

Note that the first-best levels of l^1 satisfy $R^1_{l^1} + R^2_{l^1} - c = 0$. If $R^2_{l^1} < 0$ (l^1 imposes a negative externality), then based on the constrained maximization problem 2.32, l^1 will be too high relative to first-best and a decrease in l^1 will increase the value of the joint objective function. This implies that the $\lambda_1 < 0$.[33] Alternatively, if $R^2_{l^1} > 0$ (l^1 provides a positive externality), then $\lambda_1 > 0$. The same holds for λ_2 and the external effects of l^2.

Consider the case where capital and labor are technical complements, such that $R^i_{l^i k^i} > 0$. First-order condition 2.33 implies that if abatement labor imposes negative external effects ($\lambda_i < 0$), contracted levels of capital will be below first-best. The reason for this is that as capital use is reduced, the marginal product of abatement labor is reduced, which leads to lower abatement labor effort. If abatement labor

[33]Recall again that in the context of the Lagrangian method, $\frac{dv}{dc} = \lambda$, where v is the value of the objective function, c is the value of the constraint, and λ is the Lagrange multiplier (Dixit 1990)

provides positive externalities, (2.33) implies that capital use will be above first-best to compensate for the misallocation of labor. If capital and labor are technical substitutes $R^i_{l^i k^i} < 0$, the results will be just the opposite: capital levels will be set higher in order to reduce abatement labor effort if negative externalities follow from labor abatement, and capital levels will be set lower if positive externalities follow from abatement labor.

In summary, landowners have an incentive to contract over monitorable inputs, even if other inputs are not monitorable and subject to misallocation in response to private incentives. If the inputs are technically independent, allocations of the perfectly monitorable input will be set at first-best levels. If the monitored and unmonitored inputs are technical substitutes or complements, then additional gains can be made by accounting for the capital input's effect on labor effort.

Abatement subsidies

Many wildlife agencies provide abatement support for landowners, in the form of consultation services, agency personnel abatement labor support, and cost-sharing for abatement capital such as fences. These programs can be viewed as special cases of the general model developed directly above.

Suppose two landowners own parts of the wildlife territory, one of whom specializes in farming crops and one specializes in fee hunting or some other form of wildlife services. Assume that lethal abatement labor l carried out by the farmer is not fea-

sibly monitored, but a non-lethal abatement alternative k in the form of standing physical capital or agency abatement carried out on the landowners property, is perfectly monitored by both parties. Suppose that in the absence of a contract over damage abatement with the farmer, the wildlife manager maximizes revenue, taking the farmer's abatement effort as given, so that his problem is $\max_w R(w;l)$, with $R_l < 0$ and $R_w > 0$. Note in particular that abatement capital is assumed not to affect the wildlife stock.[34] Given that abatement capital will be determined jointly, the farmer solves

$$\max_l R^y(l;k) - c_l l,$$

for which the first-order condition is

$$R_l^y - c_l = 0 \tag{2.34}$$

When entering into a contract with the wildlife manager, the level of k will be explicitly contracted over, but because l is not monitored, first-order condition 2.34 must be included as a constraint on joint wealth maximization. The constrained problem is

$$\max_k = R^y(k,l) + R^w(l) - c_k k \tag{2.35}$$

[34] Actually, $R(w;l)$ in this case would be better thought of as the wildlife manager's direct profit function, but it will be left this way so as not to require additional notation.

subject to

$$R_l^y - c_l = 0 \quad (\lambda)$$

where $R_l^w < 0$, which is to say that lethal farmer abatement reduces the value of the stock for the wildlife manager. The first-order condition is

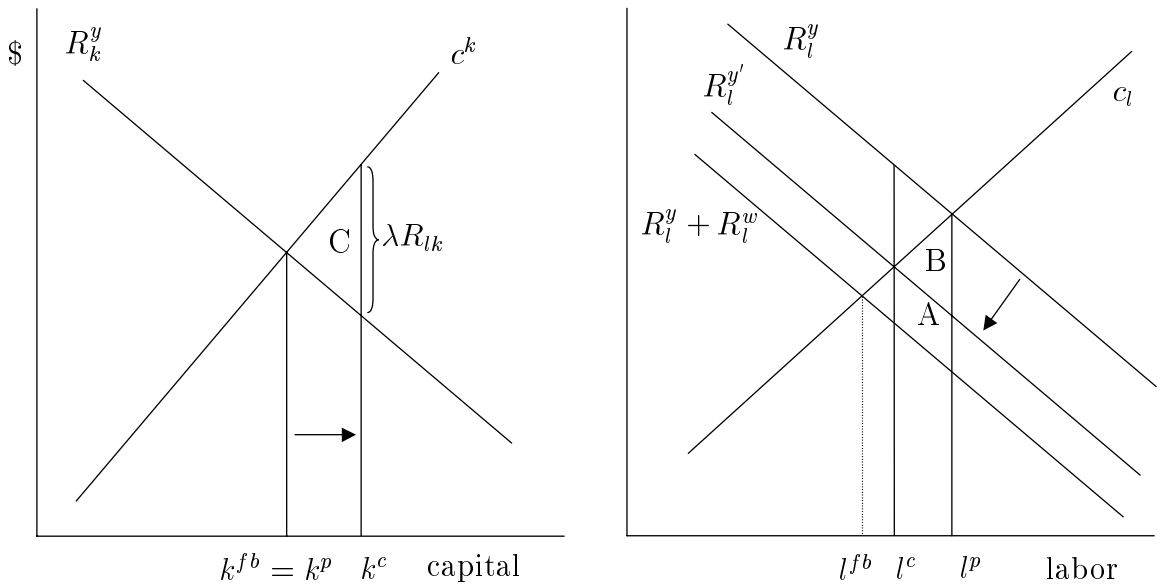
$$R_k^y - c_k + \lambda R_{lk}^y = 0. \tag{2.36}$$

If $R_{lk}^y = 0$ (l and k are technically independent), then equation 2.36 is identical to the farmer's independent result (2.34) because k has no direct affect on the value of the wildlife stock, and there is no incentive basis for a contract. If on the other hand k and l are not technically independent, k becomes an important contracting tool due to the enforceability of its use, even though it is assumed to have no direct effect on the wildlife manager.

Because the farmer utilizes too much lethal abatement, $\lambda < 0$. If l and k were complements ($R_{lk} > 0$), the contract would stipulate a reduction in k relative to first-best levels, which would reduce the marginal product of lethal abatement and reduce lethal abatement itself.[35] If the two inputs are technical substitutes ($R_{lk} < 0$), such

[35]This result is similar to placing legal restrictions on the types of netting and other fishing equipment in order to reduce the impact of excess fishing effort in an open access fishery (Johnson and Libecap 1982).

Figure 2.4: Sharing capital: total capital and labor use.



as shooting and fencing are likely to be, a contract would stipulate a higher level of k than otherwise if l and k were technically independent.

Figure 2.4 illustrates this result. Because k has no direct affect on the wildlife stock, the farmer's independent level of capital use k^p is equal to the first-best level of capital, k^{fb}. Contracting for higher levels of k (the first panel) will shift the marginal product of labor effort on y downward from R_l^y to $R_l^{y'}$, thereby reducing the value of the constraint. The optimal level of k sets the marginal losses from misallocation of capital (λR_{lk}) equal to the marginal gains from a reduction in the farmer's effort l (which equal the marginal reduction in the R_l^y weighted by the change in the marginal value of the constraint). The second-best optimum is reached at k^c and l^c, and the gains relative to independent action are (A+B-C).

A few implications follow from this model. First, the wildlife manager has an incentive to become involved in abatement efforts if it will affect the farmer's abatement effort levels, even if he is not legally bound to do so. As the marginal impact of the farmer's abatement efforts on the wildlife stock increase, the incentive for wildlife manager involvement in abatement increases. The stronger a substitute k is for l, the more valuable k becomes for reducing the farmer's incentives. The higher the marginal cost of k the less valuable will be the use of k as a substitute.[36] An additional implication of this model is that lethal abatement will not in general be zero, even under a contract. Further, when the costs of monitoring abatement capital use are non-zero, the contracted levels of lethal abatement will be higher and contracted use of capital will be lower.[37]

2.2.5 Sharing damage

One response to an open access resource problem is to share output from the use of the resource (Lueck 1994). Such a response to a wildlife damage problem is possible, but is either rare or non-existent. An analogous response, sharing damage itself, is practiced in the form of compensation programs maintained by some wildlife agencies for specific species and agricultural resources. Compensation of this sort amounts to a transfer from the wildlife agency to a landowner for property damage, and the

[36] If k were a complement to l, increases in the marginal cost of k would increase the value of a contract.

[37] This last point draws on (Leffler and Rucker 1991).

defining characteristics of this form of contract are that transfers are tied to damage rates, and they do not exceed the amount of damage sustained by the receiving party.

General model of damage sharing

For modeling purposes, a damage function will be made explicit. Following Lichtenberg and Zilberman (1986), let landowner i's damage be modeled as a fraction δ of potential revenue, where δ is a function of productive inputs of all landowners in the wildlife territory, so that $\delta^i = \delta^i(\mathbf{x})$. After-damage revenue from the composite private agricultural output then becomes $R^i(1 - \delta^i(\mathbf{x}))$. Consider two landowners, with $\mathbf{x} = (x_1, x_2)$ representing abatement inputs of landowners 1 and 2, respectively. Each landowner i chooses x^i to maximize $R^i(1 - \delta^i(x^i; x^j)) - cx^i$ $(j \neq i)$, for which the first-order condition is $-R^i\delta^i_{x^i} - c = 0$. The value $-R^i\delta^i_{x^i}$ is the marginal benefit *to landowner* i of x^i — call it MB^i_i. These independent first-order conditions imply $MB^1_1 = MB^2_2$. This equality follows because it is assumed that the marginal cost of abatement, c, is the same for both producers. The potential (before damage) revenues R^i are assumed exogenous. This last assumption amounts to assuming that producers do not respond to damage by changing productive input use. It is imposed here because issues of altering productive input use in response to damage are addressed elsewhere in the dissertation (section 2.2.2 and chapter 4) and because it reduces notational clutter without sacrificing the central points of this discussion of damage sharing.

Suppose that at the end of the crop-growing season the total damage is pooled and then divided according to the following sharing rule, which is jointly chosen *ex ante*: the proportion of total damage absorbed by landowner 1 is γ, and $(1-\gamma)$ is absorbed by landowner 2. The sharing rule is chosen to maximize joint profits subject to independent, unmonitored abatement labor.

Landowners 1 and 2 select abatement effort independently. Their maximization problems and first-order-conditions subject to the sharing rule γ and $1-\gamma$ are (respectively):

$$\max_{x_1} \; R^1 - \gamma \sum\nolimits_{i=1}^{2} R^i \delta^i(x^1; x^2) - cx^1,$$

$$\text{f.o.c. } 1: \quad -\gamma \sum\nolimits_{i=1}^{2} R^i \delta^i_{x_1} - c = 0; \tag{2.37a}$$

and

$$\max_{x_2} \; R^2 - (1-\gamma) \sum\nolimits_{i=1}^{2} R^i \delta^i(x^2; x^1) - cx^2,$$

$$\text{f.o.c. } 2: \quad -(1-\gamma) \sum\nolimits_{i=1}^{2} R^i \delta^i_{x_2} - c = 0 \tag{2.37b}$$

The left-hand-side of (2.37a) and (2.37b) both equal c. Equating the left-hand-side of these and rearranging leads to

$$\frac{\gamma}{1-\gamma} = \frac{\sum_i R^i \delta^i_{x_2}}{\sum_i R^i \delta^i_{x_1}} \equiv \frac{MB_2^{1+2}}{MB_1^{1+2}}, \tag{2.38}$$

where the middle and right hand side terms are the total marginal benefit of x^2 (MB_2^{1+2}) over the total marginal benefit of x^1 (MB_1^{1+2}).

The first-order conditions 2.37a and 2.37b enter as constraints in the problem of maximizing total wealth (profits), where γ is the choice variable. This maximization problem, assuming the participation constraints are non-binding, is

$$\max_{\gamma, x_1, x_2} \sum_{i=1}^{2} R^i(1 - \delta^i(\mathbf{x})) - c \sum_{i=1}^{2} x_i \tag{2.39}$$

subject to

$$-\gamma \sum_{i=1}^{2} R^i \delta^i_{x_1} - c \qquad (\lambda_1)$$

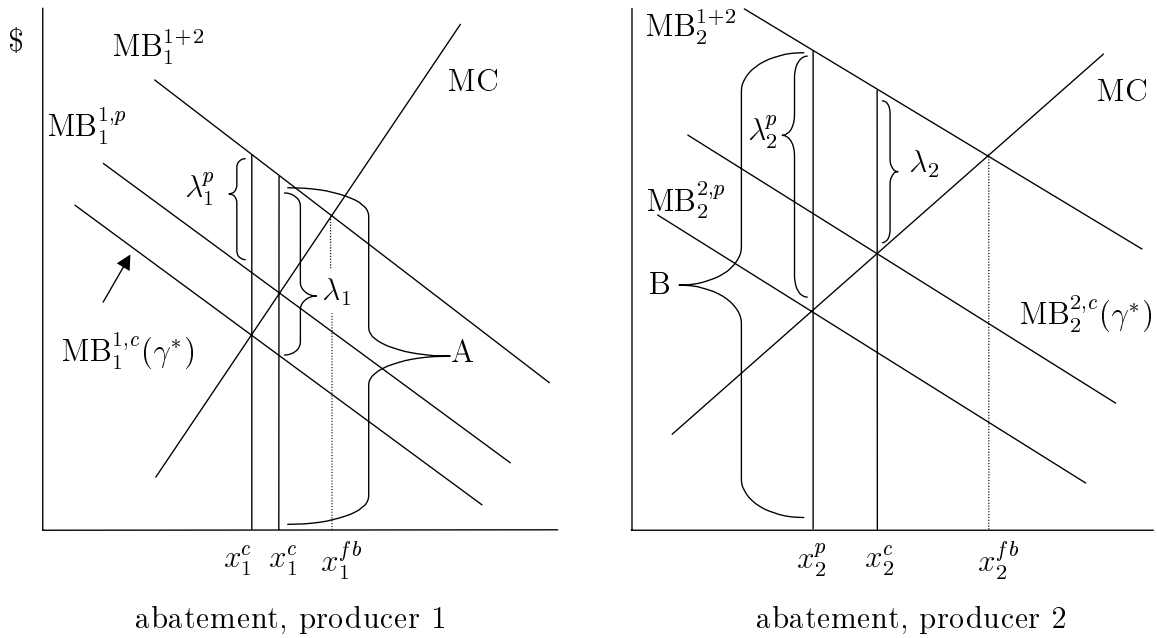
$$-(1-\gamma) \sum_{i=1}^{2} R^i \delta^i_{x_2} - c \qquad (\lambda_2)$$

where λ_1 and λ_2 are associated Lagrange multipliers. The first-order conditions of this problem are

$$MB_i^{1+2} - c + \gamma \left[\lambda_2 \frac{\partial MB_2^{1+2}}{\partial x_i} - \lambda_1 \frac{\partial MB_1^{1+2}}{\partial x_i} \right] = 0 \tag{2.40a}$$

$$\lambda_2 MB_2^{1+2} - \lambda_1 MB_1^{1+2} = 0 \tag{2.40b}$$

Figure 2.5: Optimal damage sharing



in addition to the two constraints. Rearranging first-order condition 2.40b gives $\frac{\lambda_1}{\lambda_2} = \frac{MB_2^{1+2}}{MB_1^{1+2}}$, which with equation 2.38 implies

$$\frac{\gamma}{1-\gamma} = \frac{\lambda_1}{\lambda_2} \tag{2.41}$$

which shows that the ratio of the marginal value of the constraints from the independently chosen abatement levels is equal to the marginal rate of substitution between x_1 and x_2, which is also equal to the ratio of damage shares.

Figure 2.5 illustrates the result. As γ is changed, the effective private value of the marginal product of x_i is being changed for both landowners (from $MB_i^{i,p}$ to $MB_i^{i,c}(\gamma^*)$), and this changes their abatement allocation. Because increasing the

damage share for one reduces that for the other, the effective private marginal product of abatement must increase for one and decrease for the other (in the figure it decreases for 1 and increases for 2). At $\gamma = \gamma*$, $\frac{\lambda_1}{\lambda_2} = \frac{MB_1^{1+2}}{MB_2^{1+2}} = \frac{A}{B}$, which follows from the first-order conditions. Whereas x_i^p are the independent abatement levels, x_i^c are the abatement levels under optimal damage sharing. Under independent action, the value of landowner i's incentive compatibility constraint is λ_i^p.

Consider (2.41) in the context of two identical producers. When acting independently, each producer will suffer the same level of revenue losses, thus each will suffer 50% of total losses. If these two producers were to form a contract to share total damage, the value of their incentive compatibility constraints (λ_1 and λ_2) would be equal to each other, because by assumption they are identical producers. It follows from equation 2.41 that $\gamma = (1 - \gamma) = .5$. Because this is the share of losses that each producer suffered without the contract, an optimal damage sharing contract gains them nothing. Assuming risk neutral producers, this result implies that a damage-sharing contract will be useful only for heterogeneous participants.

Another important factor that will affect the potential value of a contract is the cost of measuring damage. For some resources such as field crops, measuring and verifying damage may not be prohibitively costly. In the case of browsing damage to forests, the true costs may be difficult to verify. Unlike field crops, standing timber is

not harvested each year, and browsing may have effects on growth that are not easily measurable.[38]

Compensation: damage sharing between a farmer and a wildlife manager

Assume two specialized producers: one farmer who produces crops on his own land, and one wildlife manager whose income is derived from a wildlife stock which ranges over the land of the farmer (and possibly elsewhere). All of the physical damage to crops or other property occurs on the farmer's land, and the farmer's abatement method x is lethal to the wildlife stock. Assume that any activity on the farmer's land is perfectly monitorable by the farmer, and existing property rights are such that the wildlife manager is unable to perform abatement himself or directly alter the farmer's abatement levels without the owner's consent. Because the farmer's abatement levels are not monitorable by the wildlife manager, the legal property rights with regards to abatement are irrelevant. This is because even if the wildlife manager had the legal right to prohibit abatement that affects the value of the wildlife stock, it would be unenforceable. Despite these limitations on the wildlife manager, he has the opportunity and the incentive to alter the abatement activities of the landowner indirectly through sharing the damage by compensating the landowner for all or part of the damage imposed by the wildlife stock.

[38]These costs are similar in some respects to the division costs associated with output sharing rules (Lueck 1994, Allen and Lueck 1993).

The sharing rule is chosen to maximize joint profits subject to independent, unmonitored abatement labor by the farmer. The farmer's maximization problem is $\max_x R^y\big(1-(1-\gamma)\delta(x)\big)-cx$, where x is his privately chosen abatement level. The first-order condition for this problem is $-R^y(1-\gamma)\delta_x - c = 0$, which implies abatement effort $x = x(R^y, \gamma, c)$, with $\frac{\mathrm{d}x}{\mathrm{d}\gamma} < 0$ given standard concavity assumptions.[39] Because all of the damage is inflicted upon the farmer's property and the farmer's abatement is detrimental to the wildlife stock, it must be the case that if there is a transfer, it will be from the wildlife manager to the farmer. Therefore, a participation constraint will be required for the wildlife manager. As in section 2.2.4, assume that the wildlife manager simply maximizes revenue, so that his problem is $\max_w R(w;x)$. His participation requires that he be at least as well off with the optimal compensation program as without it. His individual rationality constraint (IR) is $R^w - \gamma R^y\delta(x) - \bar{R}^w \geq 0$, where $\bar{R}^w$ is his optimal level of R^w without a contract. This provides a budget limit for a damage compensation contract. The constrained joint maximization problem, with the compensation rate and abatement rate as choice variables is

$$\max_{\gamma,x} R^w(x) + R^y(1-\delta(x)) - cx \tag{2.42a}$$

subject to

[39] Specifically,

$$\frac{\mathrm{d}x}{\mathrm{d}\gamma} = \frac{R^y\delta_x}{R^y(1-\gamma)\delta_{xx}} < 0,$$

where $\delta_a < 0$ and $\delta_{xx} > 0$ for concavity.

$$-R^y(1-\gamma)\delta_x - c = 0 \quad (\lambda_1) \tag{2.42b}$$

$$R^w(x) - \gamma R^y \delta(x) - \bar{R}^w \geq 0 \quad (\lambda_2). \tag{2.42c}$$

The first-order conditions with respect to γ and x are

$$R^y(\lambda_1 \delta_x - \lambda_2 \delta) = 0$$

or

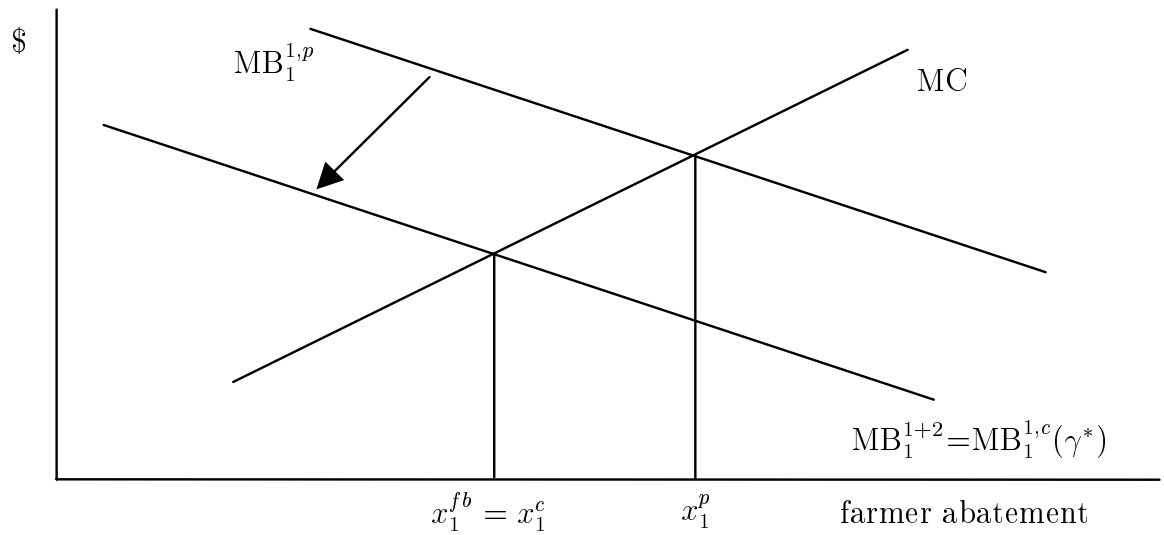
$$\lambda_1 \delta_x - \lambda_2 \delta = 0, \tag{2.43a}$$

and

$$R^w(1+\lambda_2) - R^y \delta_x (1+\gamma\lambda_2) - \lambda_1 R^y (1-\gamma)\delta_{xx} - c = 0. \tag{2.43b}$$

Suppose that the wildlife manager's participation constraint were non-binding, so that $\lambda_2 = 0$. Equation 2.43a implies that the compensation rate would be set so that the landowner's incentive compatibility constraint were non-binding and $\lambda_1 = 0$. Because the farmer's abatement effort (x_1) imposes negative externalities on the wildlife manager, the total marginal benefit will be below the farmer's private marginal benefit ($MB_1^{1+2} < MB_1^{1,p}$). As the compensation to the farmer increases, the farmer's effective marginal benefit curve ($MB_1^{1,c}(\gamma)$) shifts down (figure 2.2.5). The compensation rate that maximizes joint wealth is that which sets the farmer's effective marginal benefit from abatement equal to the total marginal benefit of abatement.

Figure 2.6: Optimal compensation



If the wildlife manager's participation constraint is binding, the actual compensation rate will be such that $MB_1^{1,c}(\gamma^*)$ lies between MB_1^{1+2} and $MB_1^{1,p}$ and the abatement levels will lie between x_1^{fb} and x_1^p.

The model implies that a decrease in the marginal value of wildlife decreases the likelihood that the wildlife manager's participation constraint will be satisfied, and a compensation contract will be less likely. Further, rearranging (2.43a) gives

$$\frac{\lambda_1}{\lambda_2} = \frac{\delta_x}{\delta}. \tag{2.44}$$

The closer the result of independent action is to this result, the less valuable is a compensation program.

Just as compensation reduces the farmer's incentive to carry out abatement or habitat destruction that is detrimental to the wildlife stock, it reduces the farmer's incentive to carry out more benign forms of damage abatement as well. The farmer will not only have less of an incentive to shoot deer, for example; he has less of an incentive to put a fence around his crops as well. Suppose there were two abatement alternatives for the farmer. Following the notation in section 2.2.4, replace x with two forms of abatement: l, which represents lethal abatement, and k, represent abatement that does not affect the wildlife stock, so that $R_l^w < 0$ and $R_k = 0$. The first-order condition for an input x with the farmer acting independently is equation 2.42b; in this case there would be one of these each for l and k, the solutions to which are the input demands $l = l(\gamma)$ and $k = k(\gamma)$. Both of these input demands will be decreasing in γ because as γ increases, the private marginal value of abatement decreases.

Now, let the total cost to the wildlife manager of his compensation program be $\mathcal{C} \equiv \gamma R \delta(l(\gamma), k(\gamma))$. Totally differentiating with respect to γ,

$$d\mathcal{C} = R\left(\delta + \gamma \frac{\partial \delta}{\partial l}\frac{\partial l}{\partial \gamma} + \gamma \frac{\partial \delta}{\partial k}\frac{\partial k}{\partial \gamma}\right) d\gamma. \tag{2.45}$$

Because $\frac{\partial \delta}{\partial l}$ and $\frac{\partial l}{\partial \gamma}$ (and their counterparts for k) are negative, all elements of $d\mathcal{C}$ are positive. Recall that k does not negatively affect the wildlife stock, however. For a given level of γ, reductions in k will raise the compensation payments without benefiting the wildlife manager. This implies that if there are benign abatement

alternatives, compensation programs will become less valuable because reductions in detrimental private abatement will be accompanied by higher damage levels due to reductions in benign private abatement, and thus higher total compensation payments for a given sharing rule.

One way to address the problem of reductions in benign abatement by landowners is to accompany compensation with subsidies to reduce the cost to farmers of benign abatement. To model this problem formally is cumbersome, but intuitively, suppose that the wildlife manager offers a compensation rate γ as well as an offer to pay for some fraction, ρ, of the costs of the benign abatement k, which is monitored by both parties. Thus, the farmer's effective marginal cost of k is $(1-\rho)c^k$, shifting the landowner's demand curve for k out. This offsets the inward shift of the demand curve of k associated with compensation. Furthermore, if l and k are substitutes, reducing the effective marginal price of k in this way will further reduce the demand for l, the input detrimental to the wildlife stock.

In summary, the model of damage sharing and compensation presented here implies that compensation programs will be more valuable when some groups have more private control over damage than others (equation 2.41), when the net gains from wildlife are distributed unevenly, when damage measurement costs are low, and where there are no practical benign abatement substitutes (equation 2.45). When

benign alternatives exist, this model provides an explanation for linked compensation and abatement programs as many agencies with compensation programs do.[40]

2.3 Applications and discussion

Table 2.3 summarizes the contractual models presented in this chapter. This section provides brief discussions of anecdotal evidence relating to each of the models presented above except the cost-sharing model of section 2.2.2. Cost-share contracts will be examined empirically in chapter 3.4.

2.3.1 Labor sharing

Enforcement of a labor contract can be difficult when the labor is being carried out in the field and the product of labor in terms of reduced damage or other indicators is hard to isolate. These difficulties may be enough to confound any enforceable contract over abatement labor. There are, however, cases in which groups of landowners or interested parties share labor to address a common wildlife damage problem. Two

[40]Rollins and Briggs (1996) examine the compensation problem in the context of a principal-agent model, but their approach is somewhat different than that presented here. They treat compensation as an insurance mechanism, the results of which pivot on assumptions of risk aversion on the part of the farmer and wildlife manager. In the model presented here, risk neutrality is assumed, and the final contracted distribution of damage depends on the relative impact of private action on total damage. Rollins and Briggs (1996) treat the wildlife manager as a Stackelberg leader, presenting a contract to which farmers react. In the model presented here, the farmer and the wildlife manager are treated symmetrically in the sense that both participate on equal footing to maximize wealth subject to informational constraints and private action.

Table 2.3: Various Contractual arrangements over wildlife damage

Contract type	maximize	subject to constraints
labor coordination	$\max_z n[R(x,z,n) - cx] - f(z;n)$	$R^i_{x^i} - c = 0$ $\pi(z,n) \geq \pi^p$
cost sharing	$\max_{\mathbf{a},\tau} \sum_i R^i(\mathbf{a}, x_i) - (\tau + r) \sum_i x_i$	$\tau \sum_i x_i - c \sum_i a_i \geq 0,$ $R^i_{x_i} - (r + \tau) = 0$
capital sharing	$\max_{\mathbf{k}} \sum_i R^i(\mathbf{k};\mathbf{l}) - c_k \sum_i k^i$	$R^i_{l^i} - c_l = 0$
[abate. subsidy]	$\max_k R^y(k,l) + R^w(k) - c_k k$	$R^y_l - c_l = 0$
hired hunter	$\max_{k,s} \pi^h = R(s, w(k)) - c(s+k) - m^s s$	$c^h \geq c$
bounty	$\max_b R(0, w(k)) - b\acute{w}(k)$	$b\acute{w}(k) - ck \geq 0,$ $k = k(b,c)$
damage sharing	$\max_\gamma \sum_i R^i(1 - \delta^i(\mathbf{x})) - c \sum_i x_i$	$-\gamma \sum_i R^i \delta^i_{x_1} - c = 0$ $-(1-\gamma) \sum_i R^i \delta^i_{x_2} - c = 0$
[compensation]	$\max_\gamma R^w(x) + R^y(1 - \delta(x)) - c_x$	$-R^y(1-\gamma)\delta_x - c = 0$ $R^w(x) - \gamma R^y \delta(x) - \overline{R^w} = 0$

cases are discussed here: wolf roundups, also known as ring drives, and cooperative roost harassment to reduce waterfowl depredation of commercial fisheries.[41]

A stylized description of a wolf drive is as follows. Participants jointly attempt to reduce the local wolf population by either corralling and disposing of the animals (or dispersing them). These activities tend to be spatially and temporally coordinated, so that participants work in close proximity to each other. The level of cooperation may be highly integrated, where participants form a line or circle an area (on foot, horseback, or otherwise), move in unison, and either disperse or kill the pests as they converge toward the center of the circle (McIntyre 1995). Coordination may be less structured, as when participants agree to provide abatement effort on a given day or time anywhere within the county or local area (Sorensen 1994). There are costs associated with these ring drives. First, they must be advertised, and second, in most cases, they are organized under a leader who coordinates the progress of the participants, up to 600 people in some cases, during the drive (Young 1944, McIntyre 1995).

Ring drives have been used widely in North America for thinning out pest populations in small areas. In addition to the "wolf rodeo" of Oklahoma noted in table 1.4, Young (1944, pp.310-313) reports this type of cooperation in the form of "coyote drives" occurring in the West at the time of his writing; in a number of states

[41] There are also accounts of rabbit drives of a similar nature (Gerald Carlson, personal communication, October 1998). Perhaps the most widely known example of such an event is the Springfield Snake Drive on the "Whacking Day" episode of Matt Groening's popular television cartoon "The Simpsons."

bordering the Mississippi on the East; in the Wabash Valley, Indiana in 1860; and throughout New England including New Hampshire in 1830 and on Portsmouth and Newport Islands in 1658 and 1663. Participants in these events often were members of the same town or county.

In some cases, participation in ring drives was rewarded with excludable byproducts of the hunt, such as a share of the furs collected during the hunt, or the carcasses of game animals killed during the hunt (Young 1944, p.310). These hunts Often ended with a party for all participants, in which game animals taken during the hunt were prepared and eaten. Sorensen (1994) describes an 1849 hunt organized by the Mormons of Utah in which two groups totaling up to 209 hunters competed to reduce predator and other wildlife pest populations. The losing team was to pay for a feast after the hunt.[42]

The model of labor coordination provides some insight into the structure of these arrangements. First, the proximity with which participants work make the costs of monitoring each other's participation low, or even incidental to the activity itself. This would not be the case were the participants working in isolation. There are economies of scale up to a point in the number of participants for an organized roundup of this sort; adding another individual to the human wall is likely to increase the marginal product of each participant's effort more than in less coordinated efforts. Thus, close proximity of participants not only utilizes potential economies of scale, but results in

[42]There is some evidence that the participants were chosen by the church, so participation may not have been voluntary in any real sense.

low monitoring costs for participants. For larger groups, the incentive to participate based solely on the *assurance* mechanism is likely to be weak. The distribution of excludable goods resulting from a hunt to its participants is one way to induce more participation.

Another example of cooperative wildlife damage abatement is cormorant dispersal from Mississippi catfish farms. There are about 100,000 acres of commercial catfish ponds in the Delta region (which itself is about 15,000 km^2) of Mississippi, owned by about 300 farmers. Stickley, Warrick, and Glahn (1992) found at 16 catfish ponds in this region, producers were losing on average $400 per day from cormorant depredation.

Acting independently, catfish farmers would use noise-making devices to scare cormorants off of their ponds. Farmers claim that this method is relatively ineffective, but a sample of them were spending on average $7,400 to scare cormorants off of their ponds (Glahn and Stickley 1995). In response, to this harassment, many birds tend to move locally from pond to pond or from one roost to a nearby roost. However, when all roost sites in the area are harassed simultaneously and systematically (every night for on average 12.6 days) many of the flocks move from the delta region where the catfish are produced to the Mississippi oxbow lakes to feed.[43] Mott, Glahn, Smith, Reinhold, Bruce, and Sloan (in press) found that roost harassment reduced

[43]James Glahn, USDA Mississippi Research Station, personal communication, July 1998. There are also approximately 50 Double-Crested Cormorant nesting sites in the region, 25% of which are occupied at any given time. This type of coordination is similar in some respects to imposing regional uniform planting dates for cotton to control boll weevil populations (Carlson and Wetzstein 1993)

depredation problems in areas where producers were systematically cooperating in roost harassment, and depredation either remained the same or increased in regions of the delta without systematic roost harassment. Although Mississippi catfish growers performed the roost harassment themselves, USDA Wildlife Services (USDAWS) personnel act as coordinators for the producers, and the producers perform the abatement. About 100 of the 300 producers in the region actively participate.

Reductions in catfish losses are accomplished not only by coordinating roost harassment timing among producers, but by adopting a different type of abatement technique than that which is used independently. In addition, the participation of USDAWS acted to reduce the costs to participants of coordinating the project.[44] No catfish grower's association exists in this region, and many of these producers are not on speaking terms. The USDAWS therefore is apparently a crucial liaison for the project which reduced contracting costs among producers, and it appears likely that the cooperative effort would not have materialized without USDA Wildlife Services involvement.[45]

2.3.2 Bounty hunters versus hired hunters

Bounty systems developed in North America almost as soon as did white settlements, and remained the dominant form of predator control system for about 300 years.

[44]In a similar vein, Rook and Carlson (1985) showed that lower insect abatement costs to pest management participants lead to an increased probability that an individual will join.

[45]James Glahn, USDA Mississippi Research Station, personal communication, July 1998

Since around the turn of the 20th century the hired hunter began to replace bounty systems as the dominant form of predator control labor contract. Hired hunters have historically been paid by the day, or week, or month, whereas bounty hunters are paid for delivering a carcass (or parts of one), often contingent (at least officially) on a specific geographic source of the carcass.

The model presented in section 2.2.3 predicts the following: the value of a bounty system increases as the marginal product of selection effort decreases, as the marginal value of the wildlife stock decreases, as the marginal product of kill effort increases, and when the cost of monitoring for potential fraud decreases. The value of a paid hired hunter increases as the costs of monitoring labor effort and allocation decreases. Further, as the marginal cost of non-labor inputs for killing relative to the marginal cost of non-labor inputs for selection increases, the hired-hunter becomes more valuable than the bounty-hunter system.

When the easiest kills do not coincide with the most damaging wildlife, animal selection becomes more important and the bounty system becomes less valuable. In 1916, Wallis Huidekoper, vice president of the American National Live Stock [sic] Association stated

> It is a well-known fact that stock-killing individuals among wolves are only a small proportion of their kind inhabiting an area. Moreover, these stock-killing individuals are the most wary and cunning of their kind in shunning traps and hunters, as nearly all of them are survivors of continued campaigns for their destruction ... A bounty hunter traps in areas where predatory animals are most numerous, regardless of whether they

> interfere with stock or not; and when he has killed the least wary of the animals ... he moves to another locality, leaving the more destructive and wary animals to continue their depredations (McIntyre 1995, p. 175).

Other authors have made this point as well, including Sproat (1943) addressing bounties and coyote depredations and Young (1978, p. 224) mentioning the inadequacy of bounties for reducing predation on national forest summer stock range due to its difficult terrain. Sampson and Bennitt (1948) make a similar point in a study of the Missouri bounty system:

> The bounty system is the cheapest way to assure the destruction of a large number of predators. However, such destruction is indiscriminate and reduces neither the material damage nor the number of complaints.

In most accounts of predator control through bounty systems, particularly public bounty programs, there is little evidence of interaction between those who fund bounties and bounty hunters, other than the disbursement of bounties in exchange for evidence of a kill.[46] Hired hunters, public or private, however, tend to have closer working relationship with livestock producers suffering losses. Today, for example, the USDA Wildlife Services is the primary predator control entity in the United States. its personnel are full time employees, but they deal with coyotes only in response to specific requests for assistance in reducing specific damage problems.

The model predicts that bounty systems result in a larger number of wildlife kills. This is supported by the quote by Sampson and Bennitt (1948) above. Bounty

[46]Some livestock producers did appear to have long-term relationships with hunters whom were paid with a bounty, or a combination of a bounty and a salary (Brown 1983, p. 43-45)

systems will be of less value relative to hunters hired to selectively take animals if the value of the wildlife population for other uses increases. Support for this hypothesis is provided by the effect of in a change in the understanding of predators in the context of game management (Wagner 1972, McIntyre 1995), and is best illustrated by Aldo Leopold's change in perspective on predator control.

In the 1910's and 20's Aldo Leopold, an influential ecologist, wildlife biologist and author of *A Sand County Almanac, and Sketches Here and There* (Leopold 1949a), actively supported the extermination of wolves and other predators of wild game animals to allow for larger game populations (McIntyre 1995, p. 187-192). By the 1940's he had recognized the now widely accepted view that predators provide a valuable balancing and culling influence on game populations and ecosystems. Although he still supported predator control of some form (Leopold 1949b), in 1943 as a professor of game management at the University of Wisconsin Madison, he was a leading proponent of eliminating bounties on wolves in the state (Thiel 1993, p. 99, 107).

As environmental groups and the broader public began supporting this new perspective on predators and interest in predators as valued species grew in the 1970s and 1980s, bounty systems continued to decline in prevalence relative to the number of damage control personnel hired by county, state, and federal agencies. Bounties have been a part of the history of every state, and although some states' statutes allowing bounties still exists for some species, bounty payments are now rarely, if ever, funded (see table 1.9).

Another closely related wildlife damage management phenomenon that may have supported the transition from bounties and toward hired hunters is the increasing use of non-lethal, integrated pest management (IPM) abatement techniques by public predator control agencies, spurred in part by animal rights lawsuits (U.S. Department of Agriculture 1994, p. 1-10). The bounty system is not very adaptable to integrating various lethal and non-lethal abatement techniques, whereas the hired abatement specialist, with weaker incentives for performing any one task, is likely to be much more adaptable to such a setting.[47] Other possible socioeconomic changes that could have supported this transition are increases in real wages and a decline in the number of people who hunt or trap for fun or income.

Fraud has been a ubiquitous problem with bounty systems for the more than three-hundred years they have been used in the U.S.[48] Given the prolificacy and ubiquity of bounty systems until the mid-1900s, it seems unlikely that the decline of bounty systems in the U.S. resulted from fraud becoming significantly easier (more costly to detect) over this time period. As discussed stylistically in section 2.2.3, however, one potential for fraud is for hunters to transport hides for bounty from one region to another to fetch higher bounties. As transportation costs decreased throughout this century, it may have become less costly to perpetrate this type of fraud.[49]

[47] This argument follows Holmstrom and Milgrom (1994)

[48] Bounty fraud has, of course, not been limited to the U.S. (Hamilton 1946).

[49] Just as bounty payments are contingent on the selection of a specific species or location of kill, hired hunters are often given bonuses, or their performance is judged with a heavy weight on the number of kills. As such, there is a continuum between bounties and hired hunter contracts that is only touched on here.

Differences in the potential for fraud across bountied species may help explain which species were bountied and which were not. Latham (1951), for example, recommended the bounty on goshawks in Pennsylvania be discontinued due to the documented difficulty of telling goshawks apart from other "beneficial" species of bird which were often brought in for bounty. Although beyond the scope of this section, such differences may prove to be an important element in explaining the distribution of bounties across species.

2.3.3 Sharing capital

Some implications of the capital sharing model presented section 2.2.4 are that if there are abatement inputs whose use is relatively easy to monitor, these inputs will be the mechanism over which contracts are formed. The stronger a substitute or complement the monitorable input is for unmonitored private abatement effort, the more valuable it becomes for altering labor incentives, and the more valuable a capital sharing arrangement becomes.

Livestock producer associations and other producer-funded predator control programs often purchase abatement capital such as traps, poison livestock collars, helicopters, and airplanes to be used either by individuals hired by the group or by the producers themselves. Jointly purchasing traps and poison collars for group participants increases the marginal product of their private abatement effort, which induces higher effort levels. Because this activity reduces the predator population of the re-

gion, it likely benefits other producers in the region. Thus sharing the cost of this type of abatement capital is consistent with the model.

As table 1.9 shows, wildlife agencies often provide direct support for wildlife damage abatement on private land, despite the fact that they are seldom legally liable for wildlife damage (Lund 1980, Favre 1983, Carlman 1994). Agencies often share the costs of abatement capital, and provide support for landowners in the form of agency personnel abatement effort or consultation services.

The landowner often has options for reducing damage on his land which may affect the wildlife stock to varying degrees. When methods relatively detrimental to the wildlife stock are used by a landowner, the game manager may be able to reduce the incentive to use these types of abatement methods by subsidizing the use of substitute methods. For example, when deer are damaging crops, landowners have the incentive to kill the culprits, as well as to reduce the quantity and quality of deer habitat surrounding their crop fields. Game agencies often provide financial support and labor for putting up fences and performing other forms of abatement likely to be less injurious to deer.

For the following discussion it is important to remember that the term *capital* is used loosely here. The important distinguishing feature of capital in this context is that its use is relatively easy to monitor by both parties to the contract. Once a fence is erected, both parties can see that it is up; that the costs associated with its use are sunk. Because many forms of damage abatement take place on the farmer's

land, abatement labor by agency personnel *on the farmer's land* will be more easily monitored by the farmer than farmer's abatement activity would be monitored by the agency. Thus, the model provides a justification for agency personnel to be involved in damage abatement. To the extent that telephone consultations increase the marginal product of more benign abatement methods, consultation services by the agency are consistent with the model as well.

An argument might be made that the wildlife agency may be involved because of a comparative advantage in wildlife management and damage abatement. This could be one reason for their involvement, but it would also imply that private industry specialists (with no stake in the wildlife itself) would become involved. In fact, there is a growing private wildlife damage abatement industry, but it usually is involved with damage by non-game animals, and is usually highly regulated by wildlife agencies.

The model of abatement sharing also explains the use of hotspot permits and depredation hunts as means of addressing damage problems. A hotspot permit is a permit that allows landowners to kill damaging wildlife out of season, and depredation hunts are hunts organized by wildlife agencies, sometimes out of season, to reduce localized damage problems. The model implies that hunting pressure will be increased above a wildlife manager's independent optimal hunting level to account for damage to the farmer. There is substantial anecdotal evidence that wildlife agencies allow additional hunter harvest in regions of high damage, and in some cases organize out-of-season depredation hunts to reduce problem populations. Hunting may be seen

as a substitute abatement method in which the wildlife manager and/or the farmer himself gain some, but not all, of the potential benefits of the wildlife stock. As with the bounty hunter discussed above, hunters do not necessarily go after the specific individuals within the wildlife population that are doing the damage, so the reduction in damage by a hunter kill is not necessarily as high as if the landowner himself were selecting the animal to kill.

Wildlife agencies restrict killing or harassing game animals, and they spend resources enforcing these regulations. At the same time, landowners often have more legal rights over the wildlife stock than do non-landowners. Further, landowners are often able to kill wildlife when they are inflicting damage, either with a special permit or without one (see table 1.8). Even if the constraint on private farmer abatement were dropped and a first-best contract were possible, private lethal abatement would be used, but at a lower level than the farmer's private optimum. These landowner rights over regulated wildlife therefore can be seen as a legal response to the additional costs that wildlife places on landowners, as well as a response to the fact that it is likely to be more costly to monitor landowner actions over the wildlife stock; they have both a stronger incentive to negatively impact the wildlife stock, and a greater potential to do so than non-landowners.

2.3.4 Compensation

The model of damage sharing and compensation presented in section 2.2.5 implies that compensation programs will be more valuable when some groups have more private control over damage than others (more heterogeneity), when the gains from wildlife are distributed unevenly, when damage measurement costs are low, when there are no practical benign abatement substitutes, or when benign abatement substitutes are easily monitorable by all parties.

The most common form of damage sharing is game agency compensation programs, where the income/damage distribution from wildlife between agricultural producers and wildlife managers is relatively polar; for example, where deer impose significant costs to landowners but the revenues go mostly to wildlife managers. Virtually all compensation programs by wildlife agencies are for game species.[50]

The general model implies that the reason to redistribute damage among producers is to increase (or maybe reduce) the abatement effort of those in the group who have the largest marginal impact on total damage. This is done at the expense of having the opposite effect on the incentives of others in the group. If producers are identical, this type of redistribution is ineffective at altering total damage levels. Compensation programs have been discussed at length among sheep producers, but apparently no such program has ever been implemented that is entirely funded

[50] *Game species* are wildlife species hunted for sport or consumption, and for which these hunting activities are limited and regulated by wildlife agencies. Compensation for coyote damage is in three states provided by the state department of agriculture. This will be discussed below.

by sheep producers (Wagner 1972, p. 46-48). As table 1.8 shows, Kentucky, Ohio, and Pennsylvania have compensation programs for livestock depredation by coyote through their departments of agriculture, but in all cases the programs are based on domestic dog laws and are paid for out of general county or state funds, rather than paid for by producers.[51]

Measurement costs also may have an effect on the usefulness of compensation programs. Many programs specify the types of damage that are eligible for compensation (Wagner, Schmidt, and Conover 1997). For example, most or all programs for damage by ungulates pay for damage to seasonal crops, for which damage to a given crop is relatively easy to calculate.[52] Wisconsin compensates farmers for damage done by goose, deer, or bear damage to Christmas trees and fruit trees, but not for damage to more heterogenous stands. Compensation for damage done by predators is often limited to livestock losses, and bear damage compensation payments are in some cases limited to beehive damage. No programs compensate for bodily injury. As verification of damage becomes more costly, compensation and damage sharing become more difficult and less valuable contractual options.

[51] A theory of risk-pooling and insurance where producers are risk averse could be developed that would imply that such risk-pooling/compensation programs could be useful even with homogeneous producers and stochastic damage, but again, these type of programs are either rare or non-existent. This type of program would not be analogous to Rollins and Briggs (1996), where one group who values wildlife pays another group, both of whom are modeled as risk-averse.

[52] For example, Wisconsin Bureau of Wildlife Management personnel will estimate the average yield on an undamaged acre, the average yield on a damaged acre. the difference between these two is then used as the per-acre yield lost. This is then multiplied by the number of acres damaged.

The model implies that compensation reduces the incentive for landowners to perform abatement, whether it is detrimental to the wildlife stock or not. If benign abatement alternatives exist, the cost of compensation programs alone may become high. This prediction is supported by the fact that of the agencies providing compensation, 80% of them also provided abatement assistance, and 70% of them tied compensation payments to some form of abatement requirements. In some states, compensation is also contingent on allowing hunter access to their land, which reduces the local population while providing hunting benefits to the public. When access fees are charged by landowners, compensation payments are often reduced by the revenues received from charging for access. This is consistent with the model, because receiving access fees provides incentive for landowners to maintain their land for wildlife (Wagner, Schmidt, and Conover 1997).

2.4 Summary

This chapter has developed a model of wildlife in the agricultural production process, provided an economic rationale for contracting over wildlife damage, and formally modeled various contractual arrangements that have developed for addressing the problem of wildlife damage.

Economies of coordination and scale increase the value of landowner labor sharing, but shirking becomes a problem as group size becomes large. With effective collection

mechanisms, cost sharing arrangements can mitigate landowner shirking incentives, but organizational costs, misallocation of inputs upon which assessments are made, and incentive problems with third-party labor reduce the gains from this form of contract.

Two forms of third-party labor have been examined in this chapter: bounty hunter and hired hunter contracts. In cases where selection of specific individuals within the wildlife stock doesn't matter much, bounty systems can reduce contracting costs by reducing (in many cases to zero) third-party abatement labor effort. Where selection within the local wildlife stock is important or where breeding or importing wildlife for bounty payments is a low cost alternative, hired hunters and labor sharing have the upper hand.

Sharing the cost of any easily observable input becomes a valuable alternative when the input acts as a substitute or complement for an input that is difficult to monitor. A specific example of this is provided with a model of abatement subsidies, with fencing and other physical capital as the input over which costs are shared among participants.

Finally, reallocating damage shares among participants is useless with homogeneous producers, or when damage shares under independent action happen to be at their (jointly) optimal levels. However, when a damage transfer can draw the private marginal benefits of an individual's abatement toward the social marginal benefit with minimal distortion of others' abatement, damage sharing becomes a more valuable

alternative. One of these distortions, for example, is when there are two abatement alternatives — one having negative impacts on the wildlife stock, and one benign. Shifting the burden of damage away from the individual doing the abatement (as when agencies provide damage compensation to farmers) provides incentives to reduce levels of both the damaging form of abatement and the benign form. As a result, many agency compensation programs are accompanied by agency abatement programs that support benign forms of abatement.

The following chapters build on two of the models presented here. Chapter 3 takes a livestock producer head-assessment cost-sharing arrangement and hired hunters as given, and examines further the determinants of the value of such a contract, focusing more fully on the impact of the wildlife distribution, livestock producer distribution, and livestock producer heterogeneity on the incidence of county head assessment programs in the western states. Chapter 4 is an empirical examination of the effects of deer damage and compensation on crop acreage allocation in Wisconsin.

CHAPTER 3

Predators & Livestock

3.1 Introduction

> "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).

In 1630, livestock owners of the Massachusetts Bay Colony began sharing the cost of funding bounties on wolves. By the end of the 1700s, privately and publicly organized predator control funded by livestock owners existed in virtually every colonial settlement, and organized predator control developed along with the westward expansion of the cattle industry in the late 1800s. Today, coyotes instead of wolves are the primary source of livestock losses to predators, and western sheep producers instead of cattle producers are most active in cooperative predator control. Livestock producers often have used existing institutions such as private livestock associations and county, state, and national governments as tools to organize predator control efforts.

This chapter draws from the literature on open access and common property resources, and transaction cost theory to develop a model of a type of cost-share contract that is often used to fund predator control. The model is then used to explain the structure and distribution of contemporary cost-share contracts among livestock producers for predator control in the United States.

These cost-share arrangements impose a per-unit assessment on an easily monitorable input such as livestock inventories or land acreage. The revenues are then

used to purchase abatement inputs for the group in order to correct participating producers' private incentive to shirk on predator control labor effort, which is difficult to monitor. The contract benefits include gains in participants' profits from reductions in livestock losses due to increasing predator control above independent levels. The basic structure of this form of contract is developed in section 2.2.2, and is extended in this chapter.

The model developed in this chapter shows that the benefits of a contract depend on various factors, including the spatial distribution of livestock producers within the predator's territory, the proportion of the predator's territory not owned by producers, the marginal value of livestock production, predator densities and their marginal propensity to damage livestock, and the number of participating producers. The model also explains the degree of centralization and the effects of producer heterogeneity in input use on the likelihood of contract formation.

The benefits from contracting over predator control come at a cost. The assessment mechanism may introduce distortions in the use of the assessed input that may reduce the net contract value. Received contract theory and empirical work suggest that contracting costs increase with the number of participants, the degree of heterogeneity among participants, and the extent of private information. Specifically, the costs of monitoring participants' inventories of the assessed input, and the costs associated with redistributing group funds to participants in the form of predator control are two aspects of these contracts that are addressed by the model.

These assessment contracts are examined empirically in various contexts. An analysis of contract structure shows how institutions are used to minimize contracting costs, and how the existence of these institutions affects contract structure. Cross-state and cross-county probit analyses are used to explain contract distribution, geographic scale, and the effects of producer heterogeneity on contract formation. These empirical applications provide broad support for the main predictions of the model.

3.2 Theoretical model

As discussed in section 2.1.1, livestock producers acting independently are assumed to maximize private profits, taking the actions of other producers as given. The model developed below is based on the premise that a contract among producers will stipulate abatement levels that account for predator control externalities subject to participation constraints and contracting costs associated with forming and maintaining a predator control contract.

The following simplifying assumptions will hold. The predator stock is distributed uniformly across its territory and redistributes itself instantaneously (back to uniformity) with a change in the size of the wildlife stock resulting from abatement. Abatement is in the form of predator control lethal to the predator, so given instantaneous redistribution, predator control on landholding i reduces the average or

expected predator stock on all landholdings.[1] The damage rate δ is the same across all producers, and the marginal product of abatement for a given abatement level is the same across producers, with $\delta^i_{a_j} < 0$ and $\delta^i_{a_i a_j} > 0$, for all i and j. Although the damage *rate* is assumed identical across producers, inventories of productive inputs (e.g. livestock or acreage) need not be identical, so that total sustained damage may differ across producers.

Finally, the inventories of the assessed inputs are assumed exogenous. This amounts to assuming that producers do not respond to damage or assessments by changing inventories of the assessed input. This simplifying assumption is made because issues of changing productive input use in response to damage and assessments are addressed elsewhere in the dissertation (sections 2.2.2 and chapter 4), and because it cannot be addressed empirically in this chapter due to data limitations. Most assessments are quite small compared to the value of the livestock being assessed; virtually all assessments are less than a dollar per head for sheep or cattle for a given year. For example, the Texas Sheep and Goat Predator Management Board assesses \$.20 per head of sheep, and in 1997 sheep were fetching \$40-\$50 per hundredweight (lamb prices were roughly \$100 per hundredweight). Cattle assessments tend to be larger per head than sheep assessments, but per pound are smaller. Given the

[1]See the footnote on population biology theory in chapter 2 on page 40 for a justification of the assumption regarding redistribution. Although the assumption of uniformity is certainly unrealistic, it simplifies the following analysis without affecting any of the qualitative implications of the model. Based on simple population biology models and given instantaneous redistribution and lethal abatement, the assumption of a uniform wildlife distribution is the equivalent of assuming uniform habitat within a wildlife's range.

small assessments per head relative to the value of sheep, the distortionary effects on livestock inventories of such assessments are likely to be small.

The efficient level of a producer's abatement accounts for the effects of his abatement on all producers. The necessary conditions for this efficient allocation can be derived by maximizing total group profits by choosing abatement levels of all producers. The first-best problem, assuming no contracting costs is:

$$\max_{\mathbf{a}} \sum_{i=1}^{N} R^i(1 - \delta(\mathbf{a}; \mathbf{z})) - c^c \sum_{i=1}^{N} a_i \tag{3.1}$$

where $\mathbf{a}$ is an N-vector of abatement by N producers, and $\mathbf{z}$ is a vector of parameters affecting the marginal product of abatement, the elements of which will be discussed shortly. The marginal cost of abatement for the abatement technique used by the group is denoted c^c. The first-order conditions for the problem are

$$-R^i \delta_{a_i} - \sum_{j \neq i} R^j \delta_{a_i} - c^c = 0 \qquad \forall i \tag{3.2}$$

Abatement levels that satisfy (3.2) provide the maximum after-damage value of production for the group as a whole, and are economically efficient. The associated abatement effort (input demand) functions are $a_i^* = a_i^*(\mathbf{R}, \mathbf{z}, c^c)$, where $\mathbf{R}$ is an N-vector containing all R^i.

A producer acting independently considers only the impact of his own abatement effort on his private gains from abatement, taking abatement levels of all other producers as given. The independent producer's problem is

$$\max_{a_i} R^i(1 - \delta(a_i; \mathbf{a}_j, \mathbf{z})) - c^p a_i, \tag{3.3}$$

where $\mathbf{a}_j$ is an $(N-1)$-vector with $a_i \notin \mathbf{a}_j$, and c^p is the marginal cost of the abatement technique used when producers are performing abatement independently. The abatement technique used by an independent producer is not necessarily the same as the group abatement technique, and hence its marginal costs may be different. The first-order condition is for (3.3) is

$$-R^i \delta_{a_i} - c^p = 0, \tag{3.4}$$

with private abatement cost c^p and implied abatement effort for each producer $a_i^p = a_i^p(\mathbf{R}, c^p, \mathbf{z})$.

The difference between first-order conditions 3.2 and 3.4 is the marginal external effect of abatement, $-\sum_{j \neq i} R^j \delta_{a_i}$. As the number of producers in the region increases, the aggregate size of this external effect will increase, and first-best abatement levels will increase relative to independent levels.[2] Letting $A^* = A^*(\mathbf{R}, \mathbf{z}, c^c, N)$

[2]To support this claim, let $\bar{R} = (1/N) \sum_i R^i$ be the average R over all producers, the value of which is independent of N. If follows that $\sum_i R^i = N\bar{R}$. Now, including a^c into the first-order condition 3.2 and replacing $\sum_i R^i$ with $\sum_i R^i = N\bar{R}$ leads to the identity $N\bar{R}\delta_{a_i}(\mathbf{a}) - c^c \equiv 0$.

and $A^p(\mathbf{R}, c^p, \mathbf{z}) = \sum_i a_i^p(R, c^p, \mathbf{z})$ be the total abatement effort put forth by producers under first-best and independent action respectively, it follows that $A^* > A^p$ for $N > 1$. This in turn implies that damage rates will be higher when producers act independently relative to first-best: $\delta^p(A^p; \mathbf{z}) > \delta^*(A^*; \mathbf{z})$.

Consider now the specific case of interest. Producers form a contract to assess a fee on the physical inventory of inputs such as livestock or land, and the proceeds are distributed back to producers in the form of predator control by hunters/trappers hired by the group. Recall from section 2.2.2 that placing an assessment on a productive input in order to promote the use of another input (abatement, in this case) provides an incentive for producers to reduce their inventories of the assessed input below efficient levels. This possibility will be avoided here by assuming that inventories of the productive input (as well as output prices and output levels) are exogenous. Given this simplifying assumption, it follows that for a given group of producers, the efficient level of abatement can be attained by choosing the optimal assessment level τ, and redistributing the total assessment back to producers in the form of abatement so that the value of the marginal product of abatement is equal across producers.[3]

Totally differentiating this with respect to N gives

$$\frac{\mathrm{d}a_i}{\mathrm{d}N} = -\frac{\delta_{a_i}}{N\delta_{a_i a_i}} > 0.$$

thus, independent abatement levels decrease relative to first-best as the number of producers increases.

[3]As will be discussed shortly, if some producers do not participate in the contract, abatement levels will not be first-best.

The value of a contract that acts to change abatement levels will increase as the marginal product of abatement increases. The marginal product of abatement depends on factors denoted by the vector $\mathbf{z}$ in equations 3.1 through 3.4. Three factors are hypothesized here to be of particular importance. First, predator control effort has a negative effect on the predator population size, so that $\frac{\partial w}{\partial a} < 0$. Assuming diminishing returns, the marginal impact of predator control on the predator population increases with the size of the predator population, so that $\frac{\partial^2 w}{\partial a \partial \bar{w}} < 0$, where $\bar{w}$ is the initial (before abatement) predator population.

Second, a number of widely cited population biology theories imply that a predator population adjusts to removals in one part of its territory by redistributing itself to make best use of the resources available to it (Pulliam and Danielson 1991). As predators are removed by abatement on producer land, other individuals from the predator population will move onto producer land from land not subject to predator control ("residual land"). Thus, residual land acts as a *source*, and producer land acts as a *sink* for this predator movement. In the case where most land in the predator's territory is subject to predator control, this in-migration from residual land will be small relative to the case where only a small proportion of the land is subject to predator control. Therefore, it is reasonable to assume that the marginal reductions in the predator stock on producer land due to abatement will increase as the proportion of land subject to abatement increases, which is to say that $\frac{\partial^2 w}{\partial a \partial l} < 0$, where l is the proportion of the predators' territory subject to abatement.

Third, various theories in the population biology literature and the literature on spatial statistics recognize that movement is costly, and that as the distance of one habitat to another decreases, the likelihood of wildlife movement between these two habitats increases (Buechner 1987). When producer land is interspersed with residual land, these two types of plots are on average closer, and in-migration rates in response to predator removals on producer land are likely to be higher than when producer land is concentrated in one area of the predators' territory. Alternatively, when producer land is concentrated in one region of the wildlife territory, individual producers are on average closer together and abatement effort an each producer's land will have a larger effect on other producers. For a given l and $\bar{w}$ if z is an index proportional to the concentration or proximity of producers in the predators' territory, then increases in z will be associated with increases in the marginal impact of abatement on the predator population on producer land, and $\frac{\partial^2 w}{\partial a \partial z} < 0$.[4]

These three elements of $\mathbf{z}$ — $\bar{w}$, l, and z — enter the damage function as shift parameters for the marginal product of abatement, through abatement's effect on the wildlife stock. For example, the marginal impact of z on damage is $\frac{\partial \delta}{\partial z} = \frac{\partial \delta}{\partial w}\frac{\partial^2 w}{\partial a \partial z}$. The element $\frac{\partial \delta}{\partial w}$ (δ_w for short) represents a predator's marginal propensity to damage livestock, and also acts as a shift parameter for the marginal product of abatement.

Despite the potential gains from reductions in shirking, to form and maintain a cost-share contract this is costly and these costs affect the value and structure of a

[4]This model does not allow the possibility of eliminating, or "hunting out" an area. A dynamic model would be necessary for a marginal analysis of this issue.

contract and the likelihood of contract formation. Further, distribution of the total net benefits from a contract affects the number of producers who find it in their interest to participate. First, consider the importance of the distribution of the gains from a contract among participants.

Numerous factors have been discussed in the literature as affecting the costs of contracting. Three of these will be examined, which are chosen for discussion based on their relative importance in the context of predator control and the available empirical evidence. First, contracting costs may increase with the number of participants. The costs of assessment collection, group monitoring of producer inventories, and distribution of group-funded abatement will all increase as the number of participants increase. Second, Libecap (1989, p. 24) argues that the likelihood of contract formation depends in part on the skewness of the gains from a contract. The contracting costs associated with this skewness include pressure from participants to redistribute the gains from the contract. Third, the existing institutional structure within which the contract is developed affects both the costs and structure of contracts. For example, existing producer associations, or legal and administrative structures may be used as implementation mechanisms in order to minimize contracting costs.[5]

[5]Other potentially important factors discussed in the literature include imperfect information and information asymmetries (Wiggins and Libecap 1985, Libecap 1989), heterogeneity (Libecap and Wiggins 1984, Lueck 1994), and pricing and division costs (Allen and Lueck 1993). Finally, chapter 2 provides a theoretical basis for producer assessments of this form: monitoring independent abatement effort is prohibitively costly to monitor. By the same token, monitoring third party abatement requires monitoring effort by producers and the group, or it may introduce other distortions.

The cost-sharing rule affects the distribution of net gains from a potential contract, and may influence the number of producers who benefit from a predator control contract. The value of a contract can be written as $V = \Delta R - \Delta C$, where ΔR is the change in total revenues and ΔC is the change in total costs (including contracting costs). Define $s_C^i = \frac{x^i}{\sum_i x^i}$ as landowner i's share of ΔC, where x^i are inventories of the assessed input (as in section 2.2.2) and s_R^i as his share of ΔR. The value of the contract to producer i is then $\Delta\pi^i = s_R^i \Delta R - s_C^i \Delta C$.[6] For a given number of producers N and total contract value V, the number of those who find it in their interest to participate will depend on the relationship between s_R^i and s_C^i. If for example $s_R^i = s_C^i \ \forall \ i$ and $V > 0$, then every producer benefits from participating. On the other hand, if s_R^i is negatively correlated with s_C^i — high revenues to those whose cost shares are low, the distribution of gains may be highly skewed and many potential participants would not benefit (Libecap 1989).

This relationship between costs shares and benefit shares has at least three implications. First, given that a contract stipulates higher abatement expenditures for each participant than would be spent in the absence of a contract, an increase in the number of participants will increase the aggregate after-damage revenue from a contract by decreasing aggregate damage.[7] Unless the contracting costs of increasing

[6] Recall that revenues are not explicitly shared, and differences in revenues and shares s_R^i are incidental, resulting from differences in production practices, surroundings, and other factors that result in producer heterogeneity.

[7] (Mas-Colell, Whinston, and Green 1995, p. 679) show in the context of increasing returns to scale that as the total gains from a contract increase, the core of an economy increases; i.e., there is

group size are too large, there is an *ex ante* incentive for the group to choose a cost-sharing rule that maximizes the correlation between the share of the gains and costs of the contract so as to maximize the number of participants.

Second, as with club goods and heterogeneous participants, it may be optimal for groups to be separated by type (Cornes and Sandler 1986, p. 199), with different predator control and assessment programs for each subgroup. The gains may come in the form of assessments and abatement allocation that better suits each subgroup than a program that covers all subgroups, so that more producers choose to participate. Heterogeneity in producer type can follow from heterogeneity in any of the parameters in the model, such as differences in predator densities across space, the production of different livestock types, and differences in the size of landholdings and the number of producers.

Third, if the cost-sharing arrangement perfectly matches the distribution of gains, then the variance across producers of the input being assessed should not affect the likelihood of contract formation.[8] If livestock is the input being assessed and $s_R^i = \frac{x^i}{\sum_i x^i} = s_C^i$ for all i, then a group of individuals who differ only in their livestock inventories are no less likely to form a head assessment contract than a group with identical within-group inventories.[9] On the other hand, increases in the variance of

more leeway in terms of sharing rules that satisfy the participation constraints for a given number of potential participants.

[8]Even with a perfect match in shares, however, asymmetric information among participants may lead to contract failure due to strategic bargaining (Wiggins and Libecap 1985).

[9]The latter set of producers may be more likely to form a flat rate assessment per producer if the costs of contracting are lower than a head assessment.

factors *other than livestock inventories* that are correlated with the share of gains will reduce the likelihood of contract formation.

A group chooses abatement levels and a cost-sharing rule to maximize the value of total group profits subject to participation constraints. This problem can be thought of in two parts. First, for any given number of participants and assessment revenues, abatement levels are set (implicitly by setting τ) to satisfy first-order condition 3.2. Second, a cost-sharing rule s is chosen from a set of alternatives $\mathbf{s}$ to maximize the value of production through the rule's effect on participation rates. Associated with each cost-sharing rule is ρ, the correlation between the costs and benefits of a contract among producers. Although ρ is chosen via the cost sharing rule, for any given cost-sharing rule, ρ is parametric. The group's problem is to select A and $s \in \mathbf{s}$ to solve

$$\max_{A,\mathbf{s}} \Pi^c = n(\rho)\bar{R}(1-\delta(A)) - c^c A - f(n(\rho), \rho, \Omega) \tag{3.5}$$

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

where $\bar{R}$ is the average potential revenue of producers (assumed independent of n); $n\bar{R} = \sum_i R^i$, and n is a function of ρ. Ω describes characteristics existing institutions such as livestock associations or government agencies that affect the costs of contracting. Maximization of this problem leads to aggregate abatement levels of A^c, with

$A^p < A^c \leq A^*$.[10] Because the assessment τ is set to purchase the optimal abatement level for the group, if the contract incorporates all producers in the region ($n = N$), then $A^c = A^*$.[11]

The value of a predator control 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:

$$\begin{aligned} V &= \Pi^c - \Pi^p \\ &= \Big[n(\rho)\bar{R}\big(1 - \delta^c(A^c; z, l, \bar{w}, \delta_w)\big) - c^c A^c - f(n(\rho), \rho, \Omega)\Big] \\ &\qquad - \Big[n(\rho)\bar{R}\big(1 - \delta^p(A^p; z, l, \bar{w}, \delta_w)\big) - c^p A^p\Big], \end{aligned} \tag{3.6}$$

where $\Pi^p = \sum_{i \in n} \pi_i^p$ is the sum of profits under independent action. The exogenous variables of the problem are $\bar{R}$, z, l, δ_w, $\bar{w}$, c^c, c^p, ρ, and Ω, and the comparative statics of this problem follow from the Envelope Theorem. The comparative statics results for $\bar{R}$, c^c, and c^p are the most straightforward and are the direct effects on V

[10] Breaking $\sum_i R^i$ into n and $\bar{R}$ allows a relatively simple examination of the effects of changes in ρ while still allowing for heterogeneity as well as comparative statics with respect to the value of livestock inventories.

[11] Again, this holds because contracting costs are assumed not to be a function of abatement levels, and producers do not alter their levels of the assessed input in response to damage or assessment rates.

with respect to a change in their value. Specifically,

$$\frac{\partial V}{\partial \bar{R}} = n(\delta^p - \delta^c) > 0 \qquad \frac{\partial V}{\partial c^c} = -A^c < 0 \qquad \frac{\partial V}{\partial c^p} = A^p > 0. \tag{3.7}$$

The parameters $z, l, \delta_w,$ and $\bar{w}$ all act as shift parameters on the marginal product of abatement. Following Lueck (1994), the change in V with respect to any of these parameters is:[12]

$$\frac{\partial V}{\partial \mathbf{z}} = n\bar{R}(A^c - A^p) > 0. \tag{3.8}$$

Taking the optimal cost-share rule as given, the change in contract value with respect to a change in the correlation between benefit and cost shares is

$$\frac{\partial V}{\partial \rho} = \frac{\partial \Pi^c}{\partial \rho} = \left[n_\rho \bar{R}(1 - \delta^c) - f_\rho\right] - f_n n_\rho \gtrless 0 \tag{3.9}$$

The expression in brackets is positive, because the number of participants increase with an increase in ρ and (following Libecap (1989)) contracting costs decrease in ρ for a given number of participants. Contracting costs increase as the number of participants increase, however, so the sign of (3.9) is in general indeterminate. If the

[12]This result requires that $\frac{\partial^2 z}{\partial a \partial z}$ (and the analogs for l and $\bar{w}$) be constant in the range between A^c and A^p. To the extent that this does not hold, these comparative statics results can be viewed as approximations.

structure of the contract is such that an increase in the number of participants does not lead to much of an increase in contracting costs (f_n small), then the marginal impact of ρ on the contract value is positive, and the group as a whole will benefit with increases in the number of participants.

In some cases, producer assessments for predator control are voluntary; producers in a region may decide for themselves whether or not to participate, and non-participation does not result in censure. In other cases, participation is mandatory for all producers in a given region or organization (a county, state, or producer association, for example). These forms illustrate two basic ways to ensure participation. One is to distribute the costs of abatement (choose the cost-sharing rule) in such a way that all individuals find it in their interest to participate *given the participation of others*; that is, to assure the participation constraint in (3.5) is satisfied. As noted above, this structure has been called an *assurance problem* (Runge 1981, Rupasingha and Boadu 1998).

Damage abatement through predator control is a non-excludable good, and if an individual can reap the gains from someone else's increase in abatement under a voluntary contract while minimizing his own abatement costs by non-participation, he may have incentive to do so. To the extent that the cost-sharing rule does not induce participation by all producers and the free-rider incentive is significantly detrimental, a contract may stipulate mandatory participation and include provisions for coercion or punishment for non-payment if a majority or supermajority of producers in a

region or organization vote to impose it. Mandatory predator control cost-share arrangements come in two forms: private producer associations whose membership or participation requires the payment of dues earmarked for predator control, and public predator control programs, which mandate assessments by law, implemented at the state and county level and instigated by producer groups.

Gains from mandatory participation come from the increases in total wealth that accrue from more participants abiding by the rules of the contract. When non-participation by only a few landowners has a large impact on the benefits of group participation for the rest of the landowners, then mandatory participation becomes relatively important.[13] In the context of the model, if the ease of wildlife movement (z) between non-participant and participant landholdings is large, if the proportion of land not covered by the contract greatly affects the value of the contract to participants, or if non-participant land acts as a population source for predators, mandatory participation becomes more likely because the gains from inclusion become larger.

There are costs associated with imposing mandatory participation, and as argued by Libecap and Wiggins (1985), the same factors that affect the costs and likelihood of successful private contracts may also affect the costs and likelihood of successful implementation of mandatory public programs. As such, the foregoing analysis in this section relating to the net gains and costs of private contracting are applicable to contracting efforts that make use of public legal institutions as well.

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

In summary, The model predicts that the value of a cost-share contract for predator control among livestock producers, and the likelihood of contract formation, will increase in response to the following:

1. *an increase in the output price or inventories of the damaged inputs (livestock inventories, in this case).*
2. *an increase in the predator density.*
3. *an increase in the marginal propensity of the predator to impose damage.*
4. *an increase in the marginal cost of independent abatement techniques.*
5. *a decrease in the marginal cost of group abatement techniques.*
6. *an increase in aggregate producer landholdings as a proportion of the wildlife territory.*
7. *an increase in the spatial concentration of producers/participants within the wildlife's territory*
8. *an increase in the correlation between the cost-sharing rule and the incidental share of gains from the contract.*
9. *a decrease in the costs of measuring and collecting assessments and redistributing abatement effort among participants.*
10. *a decrease in the cost of enforcing participation.*
11. *Finally, existing institutions will be used as contracting mechanisms to the extent that they allow reductions in contracting costs.*

Each of these hypotheses will be examined and referenced in the next section.

3.3 Empirical evidence

The implications of the model for contracting over predator control will be examined in a number of settings, including a cross-state and historical overview of predator

control; the effects of predator density, livestock concentration, and existing institutions on public predator control programs in Texas; a county-level binary response model for the implementation of livestock head assessments in Montana, Colorado, and Texas; and an analysis of the level of centralization in public predator control in the West. A discussion of contract structure will be discussed first, because it provides useful background for subsequent sections.

3.3.1 Contract structure

A crucial feature of the model is that participants gain from the participation of others, and find it in their interest to participate in order to assure the participation of others. Yet, each has an incentive to deviate from the contracted abatement levels by shirking if shirking does not lead to contract disintegration. In some cases, usually with small groups, there are no formal mechanisms to ensure participation, yet cooperation exists. More often, particularly for larger groups, formal mechanisms are used to promote participation.

There are many historical and contemporary accounts of voluntary cost-sharing for predator control among neighboring livestock producers in which there is no formal mechanism used by the group to require and enforce participation. Today, voluntary participation of this sort appears often to be driven by reduced group abatement costs to participants relative to independent abatement costs. Gordon Tullock (1970) provides an example of aerial spraying of whole neighborhoods as a low cost alternative

for public mosquito abatement. Similarly, aerial hunting has become a common means of reducing coyote populations in the western states (Phillips and Nunley 1995). For legal and technical reasons, the use of helicopters or airplanes for hunting coyotes requires relatively large land areas for it to be a practical alternative (that is, for c^c to be low relative to c^p). In order to receive the low cost abatement method on his own land, a producer must share in the cost of renting the aircraft with nearby neighbors.

Similarly, the Texas Wildlife Damage Management Service (TWDMS) provides partial subsidies to landowners through state and federal funding for employing full time coyote trappers on private land. The TWDMS sets a (subsidized) trapper fee, and landowners form "trapping clubs" to share these costs in order to arrive at a land acreage size that fully employs the trapper (Nunley 1998, Savage 1998). These clubs range in size, with an approximate average of about 10 landowners per club. Occasionally large landowners will hire trappers independently through the TWDMS (Nunley 1998). Here again, there are economies of scale from the landowner perspective in the sense that adding participants reduces the share of costs to each participant; c^c decreases and the value of a contract increases (hypothesis 5).[14]

The effects of shirking and non-participation may be significant enough for a group to induce participation by other means. According to Young (1944, p. 363), after 8 years (1904–1912) funding its local wolf bounty program through voluntary contributions from its members, the Piceance Creek Stock Growers Association of Rio

[14]In this example, abatement costs are a function of group size. This is one of the many possible relationships that are not formally modeled in equation 3.6.

Blanco County, Colorado developed by-laws stipulating that cattlemen who did not pay their wolf dues could not participate with other association members 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).

Even today, a number of sheep producer associations in western states add an extra fee to their membership dues which goes toward predator control, and payment of these extra fees is as much a requirement for membership as the basic dues (table 1.6). The existence of the livestock association in conjunction with economies of scale in roundups provides an institutional arrangement that reduces the costs of promoting participation (hypothesis 10).[15]

Another means to induce participation is to require it by law, with penalties for non-participation. This form of cost-share arrangement is backed by statutory law in a number of western states and will be called "public" assessment programs. With private voluntary cooperation there is usually no preexisting means of counting and monitoring private livestock inventories on which to base the assessment. Public

[15]Roundups are similar in structure to the problem of cooperative predator control labor examined in section 2.2.1, except that the gains from the roundup are easily excludable, whereas the gains from predator control are not.

assessments, which are the dominant form of cost-share arrangement for predator control today, utilize existing tax assessment institutions. Because tallying livestock inventories is a preexisting element of tax assessments and is performed by a third-party (the government), utilizing taxation institutions will reduce contracting costs to the group and increase the value of a cost-share contract (hypothesis 9).

Private groups do not have access to the private tax information of their participants, and producers may be hesitant to share such information. Livestock inventories must be counted by someone either in the group or hired by the group, both of which are costly options, and possibly open to fraud. Furthermore, because inventories change annually, these counts must be carried out annually. Whereas public predator control assessments are usually based on livestock inventories, private groups such as the 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). This is consistent with hypothesis 9.

The model implies that *ceteris paribus*, the best input on which to base assessments will be that which is most closely correlated with damage rates (hypothesis 8). Because both acreage and livestock inventories are known by county or state assessors for tax purposes, the fact that livestock inventories (or associated quantities such as wool weight) are almost always chosen as the assessed input rather than acreage suggests that livestock inventories are more closely related to the benefit shares across producers than is acreage.

Private groups do not have equal access to information about livestock inventories and acreage, and were it not for a predator control contract among them, may not share such information. Two characteristics of land as an assessed input reduce the costs of counting and monitoring cost-shares relative to livestock inventories: land acreage ownership does not change as often as do livestock inventories, and landholding size is likely to be more difficult to misrepresent to the group than the size of a sheep herd. For private groups without cheap information about livestock inventories within the group, basing assessments on acreage reduces the costs associated with assessments and cost-sharing.

3.3.2 Distribution of cost-share contracts

The distribution and incidence of predator control cost-sharing contracts vary across space, time, and predator/livestock combinations. Each of these dimensions will be examined in the context of the model.

Wolves and cattle, coyotes and sheep

Three groups historically have been most active in predator control in the United States: cattle producers, sheep producers, and game hunters. The model predicts that the value of a predator control contract depends (among other things) on the value of livestock production in a region, the predator's population density, and the predator's propensity to kill livestock (hypotheses 1, 2, and 3, respectively). Each of

these three factors help explain when and where predator control contracts tend to form, and who participates.

Cattle production increased dramatically in the western states during the latter half of the 1800s. Young (1944, p. 377) wrote, "What eventually intensified the wolf problem in the West ... , more than any other factor, was the building up of [the] cattle industry..." Indeed, most accounts of cooperative predator control and cost-sharing in the West during the late 1800s relate to the efforts of cattle producers to rid the range of the wolf in the height of the cattle industry expansion of that period (Young 1944, Brown 1983).

By 1915 gray wolves were limited mainly to the rocky mountain states and northern Minnesota, Wisconsin, and Michigan, and red wolves were limited mainly to a few southern states west of the Mississippi river (Young 1944, p. 58). Wolf populations dwindled in the rocky mountains during the period after 1915 partly as a result of predator control efforts (Brown 1983). Coyote populations, on the other hand, have not declined like wolf populations. Since the early 1900s sheep producers, not the cattle producers, have been most active in contracting over predator control (Young 1978, Feldman 1996). One 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 very uncommon and limited to the occasional calf (Eadie 1954). As wolf populations diminished leaving only the smaller and less problematic coyote as the dominant threat, the marginal value of predator control to

cattle producers decreased (hypotheses 2 and 3) Thus, as the model predicts, with smaller wolf populations, cattle producers have less incentive to form contracts over predator control. In contrast, sheep producers still actively cooperate in predator control today because coyotes remain.

In the forested northern sections of the great lakes states, there has historically been relatively little livestock production (Dale 1960). in this region, the wolf and coyote were seen to be competing with game hunters — market hunters beginning in about 1860, and then sport hunter groups after that. Instead of livestock producers, these groups were the dominant forces and funding sources for developing and maintaining bounties and other predator control programs in these regions (Thiel 1993). Each of these points is consistent with the model.

Predator density, livestock concentration, and institutional heredity: a case study of Texas

Texas law has allowed county bounties since the mid-1800s. In 1915, the federal government and the state of Texas became active in predator control in Texas by hiring eight trappers to reduce wolf and coyote populations in the major sheep producing region in Texas, the Edwards Plateau. This was the predecessor of what is now the Texas Animal Damage Control Program (TADCP) which currently is composed of the USDA Wildlife Services, the Texas Animal Damage Control Service of Texas A&M University, and the Texas Animal Damage Control Association, which is a private

association (Phillips and Nunley 1995). The cost of predator control is split between the state and federal departments of agriculture and the producers requesting the predator control service. Often, groups of sheep and/or goat producers form local "trapping clubs" to hire trappers through the TADCP to work their ranches. The ranchers generally assess themselves based on acreage to cover the cost of the trapper (Savage 1998, Nunley 1998).

Despite the long history of predator control in Texas and a declining sheep and goat industry, in 1992 a referendum was held by the Texas Sheep and Goat Raisers' Association to impose assessments on sheep and goats, which would fund predator control. In application to the state for holding the referendum, the Texas Sheep and Goat Raisers' Association 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).

The referendum was based on the Texas Commodity Referendum Law of 1969 by which a number of other producer groups have instituted assessment programs, including Texas Corn Producers, Scurry County Cotton Producers, and Texas Citrus Producers. The TS&GCB referendum 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 contracting costs associated with developing large regional assessment programs such as the predator control referendum (hypothesis 9).

Another factor promoting the predator control referendum is that the coyote population in the major sheep producing region of the state has been increasing since the 1950s (hypothesis 2). The Edwards Plateau is virtually coincident with the central sheep and goat producing region of Texas (see figure 3.2).[16] This distribution of sheep across Texas has been consistent throughout this century. By 1950, predator control efforts had eliminated coyotes and wolves from the plateau, and with the help of a drought in the 1950's, producers managed to keep the plateau a "coyote-free zone" for most of the 1950s, with the assistance of the federal predator control program (Nunley 1995).

Figure 3.1 shows that the number of coyotes killed in the coyote-free zone of the 1950's has increased dramatically over time. Predator control efforts may have varied in intensity over these years, but this increase in the number of coyote kills suggests (though it does not imply) that the population of coyotes has increased substantially. As the model suggests, this increase in the predator population should lead to a larger potential value for cooperative predator control, and therefore a larger likelihood of cooperation (hypothesis 2). The large increase in coyotes killed between 1980 and 1990 is probably an indication of both larger coyote populations and increased control

[16]Goat densities are not included in the figure, but their distribution is essentially the same.

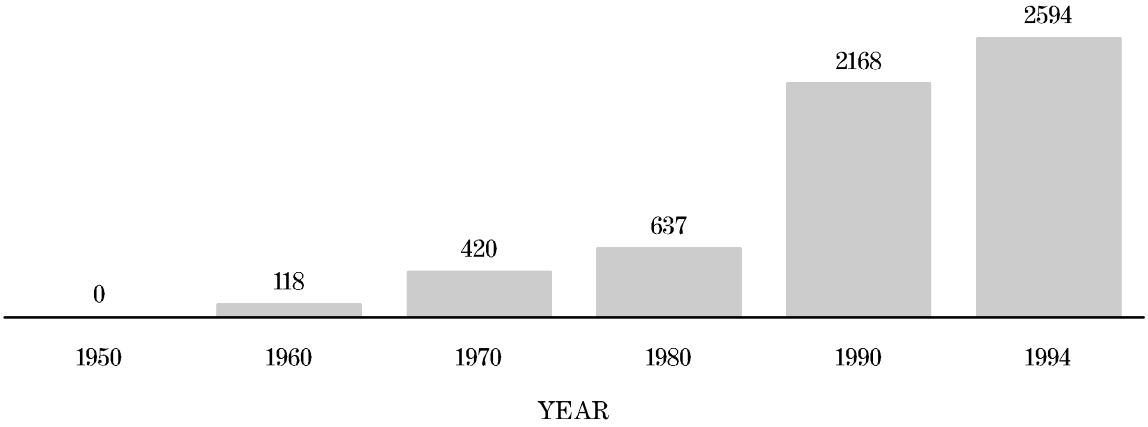


Figure 3.1: Number of coyotes killed in the "predator free zone" of the Edwards Plateau, central Texas, 1950-1994 (Nunley 1995).

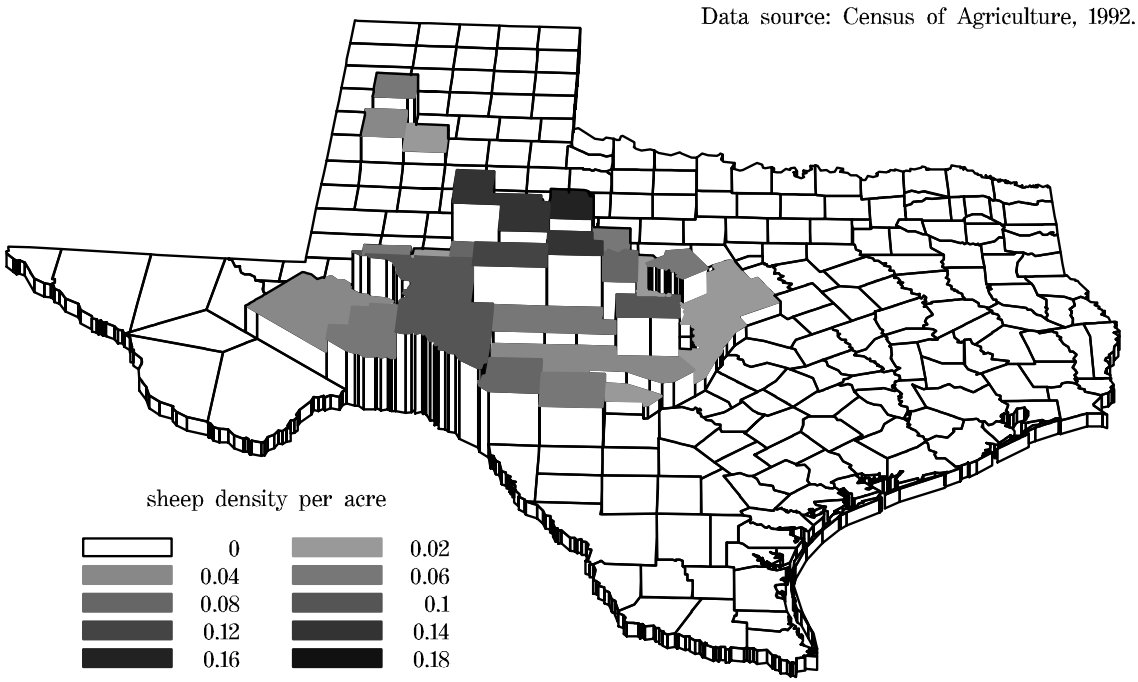


Figure 3.2: Sheep densities per acre of county land, 1992.

activities. The formation of a head assessment in 1992 to increase overall predator control efforts is consistent with the model.

Note also from figure 3.2 that the sheep and goat industry is quite concentrated, with 85% of production taking place in 10% of the counties. This geographic concentration means that, on average, sheep and goat producers are closer to each other, with less land owned by non-sheep producers. Land owned by sheep producers tends to be closer in proximity to each other, so that the effects of abatement on the land of one producer are likely to affect neighboring producers more (hypothesis 7). This concentration is given as the primary reason for focusing most predator control efforts on the Edwards Plateau in the early part of this century (Nunley 1998). It also makes a coalition among sheep and goat producers more likely than if their landholdings were more diffuse, because as a group they have more control over a given local area, thus internalizing more of their abatement efforts (hypothesis 7).[17]

Cross-state variation in predator control

Today, most predator control efforts are by sheep producers for reducing livestock losses to coyotes in western states (Feldman 1996, U.S. Department of Agriculture 1994). Western states account for almost 75% of reported livestock losses in the U.S. (U.S. Department of Agriculture 1995, U.S. Department of Agriculture 1996a).

[17] The sheep and goat industry is becoming smaller, however, and according to Nunley (1998), more of the land in the Edwards plateau is being sold to non-sheep/goat producers. Nunley speculates that this may have a negative impact on the maintenance of the assessment program in the future.

Table 3.1 shows sample means and t-statistics comparing mean livestock densities, coyote densities, predator losses, and coyote harvest rates between continental eastern and western states for the early to mid-1990s.[18] Cattle and calf densities are higher on average in the East than in the West (though not significantly so), but they suffer less from predators than do sheep. Sheep and lamb densities are higher on average in the West and suffer higher losses in the West.[19] Data on predator populations are sparse, but based on a limited number of observations, coyote densities are higher on average in the West despite higher coyote harvest rates, suggesting higher coyote carrying capacities in the West. Western cattle and sheep producers suffer a higher percentage of losses to coyotes and predators in general than eastern livestock producers.

The model predicts that sheep producer contracting over predator control should be more prevalent in the West, due to higher sheep and coyote densities (hypotheses 1 and 2). One indication that this is the case is provided by a breakdown of USDAWS funding sources, shown in table 3.2. *Funding Source* is a category used by the USDAWS to describe the type of individual or group with which is shares damage abatement costs for a given project. The first set of columns, *regional share of total by source* shows eastern states' expenditures as a percent of total, and western states' expenditures as a percent of total, for each source. For example, 96.2 percent of US-

[18]The 17 western states include Arizona, California, Colorado, Idaho, Kansas, Montana, North Dakota, Nebraska, New Mexico, Nevada, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

[19]No distinction is made in the available cattle inventory data between range cattle and other cattle. One of the primary predators of livestock in the East are dogs.

Table 3.1: East-West comparison of livestock and coyote densities and damage based on state level data.

	Mean			
	West (n)	East (n)	t-stat.	$P > \|T\|$
Cattle density	30.75 (17)	30.77 (31)	-0.01	0.99
Calf density	11.30 (17)	13.19 (31)	-0.75	0.46
Sheep density	3.75 (17)	1.91 (31)	3.09	0.00
Lamb density	3.05 (17)	1.69 (31)	2.63	0.01
Coyote density	1.66 (4)	0.29 (11)	2.32	0.10
USDAWS coyote harvest rates	0.05 (16)	0.00[2] (10)	8.19	0.00
F&G coyote harvest rates[1]	0.11 (13)	0.09 (26)	0.41	0.69
% cattle lost to coyotes	0.01 (17)	0.00 (31)	1.37	0.19
% calves lost to coyotes	0.25 (17)	0.05 (31)	4.21	0.00
% sheep lost to coyotes	1.13 (17)	0.29 (31)	3.96	0.00
% lambs lost to coyotes	3.63 (17)	1.20 (31)	4.66	0.00

"n" represents the sample size for each category. Densities are per square mile of land area in the state. [1] "F&G" coyote harvest rates stands for reports of trapping harvest originating from state Fish and Game Departments. Harvest rates refer to coyote kills per square mile. [2] 0.00 are due to rounding error. Actual values are positive and small. Sources: compiled from O'Toole (1996, tables 13, 14; 1991,1992 data) and USDA Wildlife Services data on 1994 coyote populations and harvest.

Table 3.2: Expenditures by USDAWS cooperators for protection of livestock, 1994.

	Regional share of total by source			Source share of total by region		
Funding Source	East	West	Total	East	West	Total
USDAWS	3.8	96.2	100	79.4	49.1	49.8
City	9.1	90.9	100	0.0	0.0	0.0
County	0.0	100	100	0.2	12.2	11.9
Fursales	0.0	100	100	0.0	0.3	0.3
Independent trust	100	0.0	100	0.1	0.0	0.0
Individual	1.0	99.0	100	0.1	0.2	0.2
Organization	0.0	100	100	0.1	13.8	13.5
Other federal	5.9	94.1	100	1.1	0.4	0.4
Revolving funds	1.6	98.4	100	0.3	0.4	0.4
State	1.9	98.1	100	18.7	23.6	23.4
Total	2.4	97.6	100	100	100	100

DAWS expenditures on livestock was devoted to western states, and 3.8 percent in the East, summing to 100 percent (in the first *Total* column). The second set of columns, *source share of total by region* shows the percent of expenditures in the East devoted to each category, the percent of western expenditures devoted to each category, and the percent of total U.S. expenditures devoted to each category, respectively. Each these columns sum to 100. For example, the USDAWS provided 79.4 percent of the expenditures in eastern states, and state government agencies provided 18.7 percent of the expenditures in eastern states.

In particular, note in table 3.2 that virtually all funds for predator control paid for by organizations come from the western states (under *regional share of total by source*), and organizations make up a much larger fraction of total expenditures in the West than in the East (under *regional share of total by region*). These organizations are primarily livestock producer associations or trapping clubs. Similarly, county expenditures on predator control are higher in the West than in the East. These county expenditures partially represent funds collected and dispersed through county predator control programs based on livestock assessments.

Another perspective on public predator control programs is provided by a comparison of states *with* livestock assessments to states *without* livestock assessments. Predator control programs of one form or another exist in virtually every state. In states where the livestock industries (sheep, in particular) are small in terms of value

of production and land use relative to other industries, predator control tends to revolve around these industries less than where these industries are relatively large.

The likelihood of a contract among a homogeneous group of producers increases as the potential gains from a contract among these producers increases. If various dissimilar groups can potentially gain from predator control, a contract among just one of these groups will not internalize all gains from joint predator control, and additional gains may be made by including all groups in such contracts. Further, contracting over a specific assessment schedule across heterogeneous groups will be more difficult. Industry-specific assessment programs, therefore, become less valuable than more general predator control programs as heterogeneity among interested parties increases. An extreme example of the problem would be the design of an assessment schedule for both sheep producers and suburbanites to deal with both livestock losses and suburban predator control which is an increasing problem in many parts of the West.

Table 3.3 provides t-tests that compare various characteristics of states with livestock assessment program to states with no livestock assessments. The model predicts that livestock assessment contracts among sheep producers will be more likely when damage rates are high, when the value of sheep production per producer is high, when the value of sheep production in a region is high, when sheep producers account for a large proportion of the beneficiaries of a contract (hypotheses 1 and 6). All but the last of the t-tests presented in table 3.3 are consistent with these hypotheses.

Table 3.3: Tests of differences in means of various characteristics of states with and without sheep assessments.

Variable	Assess	(n)	No assess	(n)	t	Pr> $\|t\|$
Value of sheep inventory per farm	22.08	9	3.30	41	2.90	0.020
Value of sheep per square mile	4.15	9	1.05	39	2.62	0.030
Sheep farms as a % of all farms	9.35	9	4.74	41	3.65	0.001
Pastureland as a % of all land	64.8	9	19.6	41	5.17	0.000
Human population density	23.22	9	212.47	39	2.19	0.033
% of lamb crop lost to coyotes	4.28	9	1.51	40	4.19	0.000
% of calf crop lost to coyotes	0.24	9	0.10	40	2.59	0.013
USDAWS harvest per square mile	0.048	9	0.018	17	2.90	0.007

Source: Census of Agriculture (1992), U.S. Department of Agriculture (1995) and U.S. Department of Agriculture (1996a). Tests are based on equal variances unless an F-test for equal variances is rejected at $\alpha = 0.10$.

The tests show that lamb loss rates, the value of sheep per sheep-producing farm, the average value of sheep per square mile, sheep farms as a proportion of all farms, and total sheep/lamb inventory are all statistically larger in states with assessments than in states without. Further, predator control assessments are less likely in highly populated areas.

The calf crop losses t-statistic (second to last) tests the null hypothesis that the percentage of cattle producers' calf crops lost to coyotes is the same for states with sheep-producer assessments and states without. The null hypothesis is rejected. The mean percentage of calf losses in assessment states is higher than in no-assessment states. This is inconsistent with the model to the extent that cattle producers stand to gain from contracted increases in predator control, but are not included in the assessment program. A logistic regression was also performed for the probability of

a state having a livestock assessment versus a state not having one. The signs of all but one of the variables (*sheep farms as a percent of all farms*) were the same as in table 3.3, but the coefficients were statistically insignificant with p-values ranging from .13 to .52. These low significance levels are likely to result in part from the small and unbalanced sample (nine assessment states and 39 non-assessment states). Thus, the results of this logistic regression support the results in table 3.3, but only weakly, so are not presented.

County assessment programs

Predator control livestock assessments are codified in the statutes of nine western states (table 3.4).[20] Of these, all counties are either required by state statute to participate or they may opt out by voting against an assessment. In Wyoming, participation is "mandatory", but counties can opt out of the program by voting to set the assessment to zero.[21] By contrast, no Nebraska county imposes head assessments even though Nebraska statutes allow it. 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 object of this section is to apply the theoretical model presented above to explain the distribution of head assessment programs across counties within these three states.

[20] the following discussion and table 3.4 is based on 1992-1998.

[21] Hank Uhden, Wyoming Department of Agriculture. Personal communication, 1998. No Wyoming counties currently set an assessment rate of zero; assessments range between 60 and 80 cents per head.

In Montana, the owners of 51 percent of all sheep, 51 percent of all cattle, or both may by petition institute or change a per-head assessment on all sheep and/or all cattle growers in the county. These assessments are collected with other county assessments, but placed in a separate fund specifically for predator control in that county.[22] In addition to these per-head fees, statewide livestock inspection fees are also used for predator control. As in most states, funding comes from various sources. The Montana Department of Fish, Wildlife, and Parks also pays for about one tenth of the predator control in the state. More importantly, predator control is carried out in most Montana counties by the USDA APHIS Wildlife Services, which pays approximately 50 percent of the bill (Uhden 1996). In addition, a state statute allows county commissioners, upon petition of 51% of county livestock producers, to institute a bounty program.

The Colorado program is similar to that of Montana, but with some differences. Assessments are not to exceed 25 cents/head on sheep and 30 cents/head on cattle. The statute stipulates that feedlot cattle and sheep are not to be assessed.[23] Additional funding for predator control comes from county range improvement funds, and the USDA APHIS Wildlife Services contracts with all counties, again providing approximately 50 percent funding. Despite these similarities, 52 of 56 Montana coun-

[22]Montana code §81-7-104 to §81-7-305.

[23]Colorado code §35-40-201 to §35-40-207. Presumably this is because feedlot cattle are not as susceptible to predator losses than range cattle.

Table 3.4: Livestock county assessment programs for predator control, 1992.

State	Number of counties	Petition process for mandatory assessment	Industry	Assessment based on	Funds used within county
CO	5 of 63	51% - needed only to change participation requirements	Sheep and / or cattle	Head of livestock	Yes
ID	All	Mandatory by state statute	Sheep	Lbs. of wool	Yes
MT	52 of 56	51% - needed to initiate or change	Sheep or cattle	Head of livestock	Yes
NE	None	67% - needed to initiate or change.	Sheep and /or cattle	Head of livestock	Yes
NV	All	Mandatory	Sheep	Head of livestock	No
SD	All	Mandatory	Sheep and cattle	Head of livestock	NA
TX	111 of 254	Mandatory	Sheep	Head of sheep	Multi-county district
UT	All	Mandatory	Sheep, cattle, turkey	Lbs. of wool for sheep, head for others.	No
WY	All	No petition. Elected representatives request changes	Sheep and cattle	Head of livestock	Yes

Source: State statutes, conversations with USDAWS regional directors, and Uhden (1996). NA=not available.

ties maintain predator control assessments on sheep and cattle, but only five of 63 Colorado counties do so.

The organization of the Texas assessment program is somewhat different than that of Colorado and Montana. First, the Colorado and Montana assessments are made for both cattle and sheep, whereas in Texas, assessments are made only on sheep and goats. Second, the counties do not act independently in Texas, but are grouped into four districts — three in which assessments are made and predator control is carried out through the Texas Sheep and Goat Predator Management Board (TS&GPMB), and one district in which no assessments are made and no predator control is carried out by the TS&GPMB.[24] Of 254 counties, 111 are in one of the three assessment districts (McSwain 1996). No county included in one of the assessment districts may opt out of the district, but a county referendum may be held to introduce a county into one of the existing districts. For example, in 1994 Young County elected to add itself to district III of the referendum area (Texas Sheep and Goat Commodity Board 1994). Assessments are in the form of point-of-sale deductions of not more than 20 cents per head.

A logistic regression is used to explain the distribution of active livestock assessment programs for the three states.[25] For Montana and Colorado, each county may be seen as one observation on the choice to impose a livestock head assessment. The

[24]Although counties in MT and CO are free to act independently, they are able, and often do, cooperate with adjacent counties in predator control.

[25]Logit was used rather than probit due to convergence problems with probit estimation.

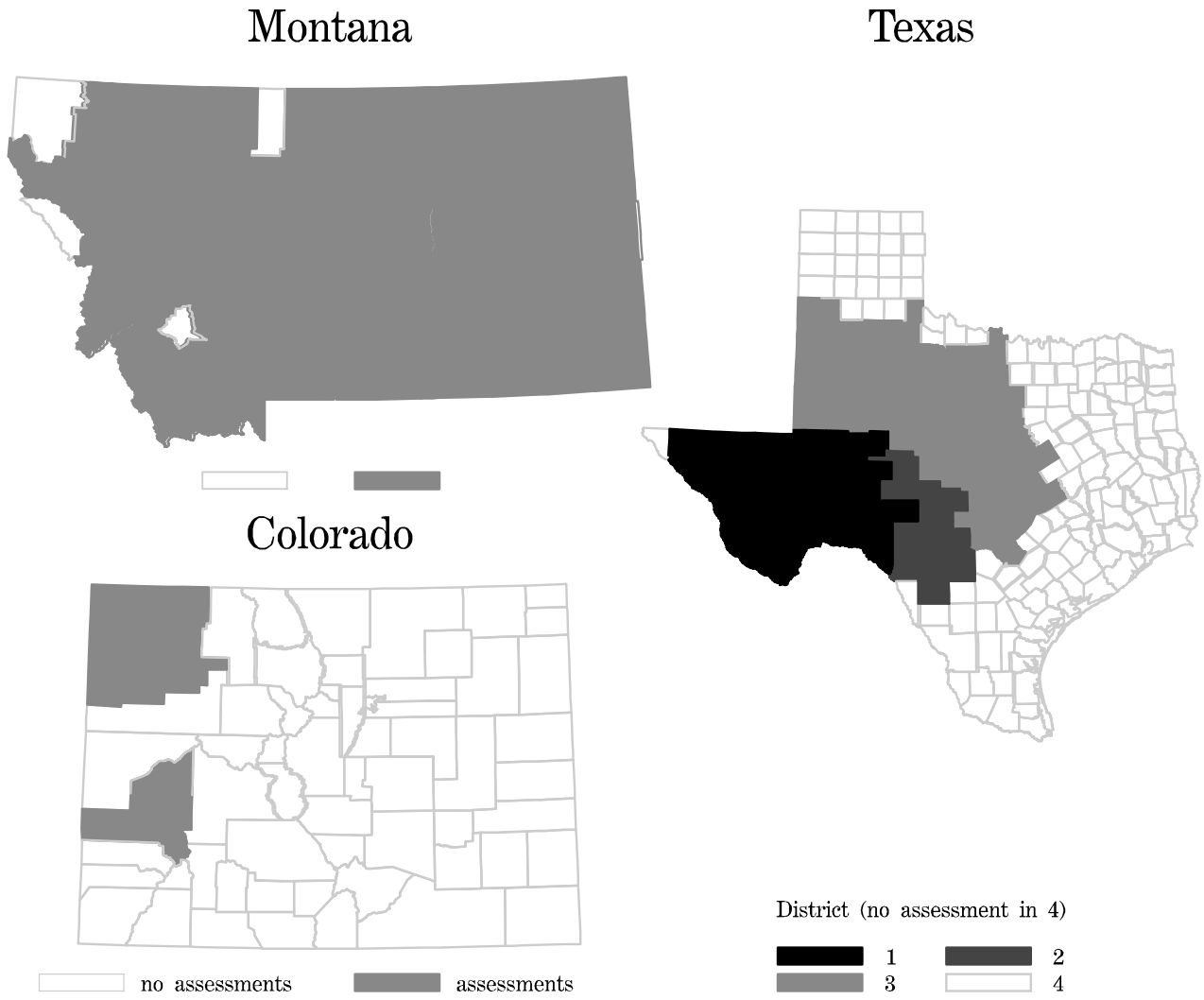


Figure 3.3: County predator control livestock assessments, Montana, Colorado, and Texas.

Texas assessment program is divided into four districts, so it is not clear whether the appropriate choice unit is the county or district, because the initial 1992 vote for implementation of the assessment was based on producers within a district rather than each county. However, to the extent that districts are delineated in an attempt to maximize the likelihood of passing the referendum, characteristics of producers in each county will provide information about the likelihood of passing the referendum. Furthermore, because counties may vote to be included in a district on any election year (biennial), it seems appropriate to treat non-participating counties as individual units as well. Therefore, each County in Colorado, Montana, and Texas is included as one observation, except for one county with incomplete data (San Juan County, CO).

Table 3.5 shows the regression results. Human population data are linearly interpolated from the 1990 and 1997 U.S. Census Bureau county population estimates. The remaining data are from the 1992 Census of Agriculture: *pasture as a proportion of county* is total pastureland (item#60073) divided by total county land (item#60002); *sheep per pasture acre* and *cattle per pasture acre* are sheep-lamb and cattle-calf inventories (items #170002 and 140002) divided by total pastureland. The Census of Agriculture provides various series broken down into categories. For example, sheep and lamb inventories are broken down into five categories based on inventory size (1-24 head, 25-99 head, etc.), for which total inventories and the number of farms in that category are reported. *Coefficient of variation, sheep inventories* is calculated

Table 3.5: Logistic regression results for county predator control head assessments.

-2 Log L=325.04;	Dependent variable:	obs
χ^2=187.17 (p=0.0000)	assessment=1	168
Correctly predicted: 80.9%	no assessment=0	204

Variable	Elasticity	Z-stat	P-value	Mean
Intercept	-0.769	-4.17	0.000	
Pasture, proportion of county	0.658	4.51	0.000	0.41317
Sheep per pasture acre	0.160	3.25	0.001	21359.1
Cattle per pasture acre	-0.046	-0.85	0.393	67069.0
Human population density	-0.049	-0.88	0.377	0.10330
Coefficient of variation, sheep inventories	0.001	1.65	0.100	1.50957
Average farmsize	0.151	2.27	0.023	2026.87
Coefficient of variation, farmsize	-0.177	-1.94	0.053	3938.78
Montana dummy variable	0.285	4.15	0.000	0.15053
Colorado dummy variable	-0.193	-2.72	0.007	0.16666

as $\frac{1}{\overline{INV}}\frac{1}{N}\sum_i(\overline{INV}-\overline{inv_i})^2$, where $\overline{INV}$ is the overall average per-farm inventory and $\overline{inv_i}$ is the within-category per-farm average inventory (items #170001–170012). *Coefficient of variation, farmsize* is calculated in the same way (items #60020–60043). Due to the categorical nature of the underlying data, the variance measures used to calculate the coefficients of variation are likely to underestimate the true variances, but they will be monotonically related.

In general, the regression coefficnents presented in table 3.5 support the predictions of the model. A larger percentage of county land devoted to grazing leads to a larger probability of livestock assessments (hypothesis 6). This result is consistent with Pridgen (1980) and Rook and Carlson (1985), who found that cotton farm-

ers were more willing to join a pest management group if a large proportion of the farmer's land is planted in cotton. Similarly, high sheep and cattle density per grazing pasture acre leads to a higher probability of an assessment program (hypothesis 2).

Human population is included in this regression in an attempt to address an abatement cost issue. Aerial shooting is used widely as an abatement tool, but is likely to be used less in more densely populated areas. If marginal group abatement costs are higher in densely populated regions as a result, the value and likelihood of contract formation will decrease (hypothesis 5).[26]

The model does not provide a direct prediction for the effects of farmsize, but it has been discussed as a potentially important factor in contracting in the context of wildlife and wildlife law (Lueck 1991, Lueck and Yoder 1997). Large average farmsize should have a negative impact on the likelihood of contract formation because more of the gains from abatement on large landholdings are internalized by the landowner himself (abatement externalities are small). On the other hand, larger landholdings may promote the use of aerial hunting, thereby reducing the costs of predator control over large areas. Further, with fewer landowners in a given area, contracting and coordination costs will likely be smaller for a given local predator control project. Table 3.5 shows a positive relationship between average farmsize and assessment programs, which suggests that larger farm sizes may promote assessment programs by lowering group abatement and contracting costs.

[26]It may also reflect the attitudes of suburban and urban populations about predator control, who may tend to place more value on or be more sympathetic to predator populations.

If the distribution of benefits from the increased abatement perfectly coincides with producer inventory shares (and hence cost-shares), then an increase in the variance of livestock inventories should have no effect on the likelihood of assessment implementation. If the benefit and cost shares do not coincide, heterogeneity over other margins that lead to these differences may reduce the likelihood of assessment implementation. With this in mind, it is interesting to note that the coefficient on *coefficient of variation, farmsize* is significantly negative, whereas that for the coefficient of variation for sheep inventories is positive, with a P-value of .10. Holding variation in sheep inventories constant, this suggests that heterogeneity in landholding sizes leads to reductions in the likelihood of contract formation (hypothesis 10). That the likelihood of a livestock-based assessment is positively correlated with heterogeneity in livestock inventories may represent a comparative advantage of public livestock assessments relative to private assessments, which are commonly based on acreage.[27]

One further difficulty in this analysis has to do with the appropriate time period to use for the explanatory variables. For the state of Texas, this is not a problem. The Texas predator control referendum was held in 1992, which is a year that explanatory data are available from the Census of Agriculture. For Montana and Colorado, however, it is not so simple. Each county has the opportunity to opt into or out of an

[27]The regression presented in table 3.5 was also estimated with various subsamples of the data, including using the means of county data within a Texas district as a single sample point for that district, thereby treating a district as the unit of choice rather than the county. The results were generally consistent with the results presented here.

assessment program (or change the assessment) in any given year. Further, in order get information on the last change made in each of the counties in these states, it would be necessary to contact each one of them. Therefore, 1992 explanatory data and the 1992 assessment status (assessment or no assessment) for each county is used.

3.3.3 Contract scale: county versus statewide assessments

A uniform assessment for an entire state may be optimal where livestock production and predator habitat is homogeneous across counties. In heterogeneous states, however, where livestock production levels differ significantly across space and predator populations face different biological constraints, more decentralized predator control may allow a better match between assessment rates and the distribution of contract benefits.

Table 3.6 presents a series of t-tests for differences in the means of a set of variables between states with county-level assessment programs and states with statewide assessment programs.[28] The variables attempt to address the issue of cross-county variance in production and grazing practices in each state. An increase in the variance of county-level observations for each of the variables in table 3.6 (except the grazing permit variables) is an indication of higher heterogeneity, and should therefore be expected to be associated with county-level assessment programs (hypothesis 8).

[28]States with mandatory statewide assessments are Idaho, Nevada, South Dakota, and Utah. States with county level assessments are Colorado, Montana, Nebraska, Texas, and Wyoming. See table 3.4 for further description.

Table 3.6: Tests for differences in inter-county variances between states with county assessment programs and states with statewide assessment programs

Within-state variances (across counties)	State (N=4)	County (N=5)	T	$Pr>\|T\|$
Cattle/calf inventory (farms)	2.84E+04	6.71E+04	-1.024	0.360
Cattle/calf inventory (head)	9.66E+08	2.69E+09	-1.577	0.184
Sheep/lamb inventory (farms)	1.10E+03	1.22E+03	-0.221	0.832
Sheep/lamb inventory (head)	2.46E+08	6.99E+08	-1.649	0.167
Land in farms, (acres)	2.63E+11	3.36E+11	-0.452	0.665
Pastureland (farms)	3.40E+04	7.96E+04	-1.162	0.304
Pastureland (acres)	2.36E+11	2.72E+11	-0.229	0.825
Grazing permits (farms)	1.54E+03	1.07E+03	0.898	0.399
Grazing permits (acres)	1.60E+11	8.03E+10	0.541	0.620
Sheep density on pastureland	1.87E-04	2.43E-04	-0.366	0.725
Cattle density on pastureland	1.72E-03	3.05E-03	-0.766	0.469
Pasture as % of county land	4.08E-02	6.02E-02	-1.484	0.181

[1]T-statistics are based on unequal variances if Pr(H_o: equal variances)< .10. Equal variances assumed otherwise. Source: 1992 Census of Agriculture.

Because grazing permits for a particular county are often held by producers from other counties, county-level assessment programs become more complicated. Therefore, more land used under grazing permits, or more farms with permits are likely to be associated with statewide or mandatory assessments. Although none of the test statistics in table 3.6 is significant at the 10% level, each of them are of the expected sign. The tests are based on nine observations, accounting for all states with livestock assessments for predator control. These results are consistent with the hypothesis that there is a tradeoff between contracting costs and internalizing predator control externalities.

It is also possible that statewide assessment programs are managed at a state level of centralization because county-level governments are relatively small or weak. This possibility is tested indirectly with a t-test for human population density, under the supposition that county governments will be stronger in counties (and states) with higher human population densities. Human population densities averaged 0.08 people/acre in the four statewide assessment states (N=160) and 0.16 in the five county assessment states (N=477). A t-test comparing these population densities in the states with statewide-assessments versus county-level assessments results in t=1.47 (632 degrees of freedom), with a p-value of .14. Thus, although the point estimates indicate that population densities are on average twice as large in county-assessment states, the hypothesis that population densities of the two sets of states are different is not rejected at the 10 percent level.

3.4 Summary

This chapter extends the model of a cost-share contract that places an assessment on a private input, the revenues from which are then put toward purchasing an input that can be characterized as common property or a public good. The implications of this model are then explored in the context of predator control in the United States. The model implies that the potential value of a predator control contract increases as the predator's propensity to damage increases, as the number of predators in a

region increases, as the value of production in a region increases, as more of the predator's territory is covered by the contract, as the mobility of the predator across landholdings increases, and if there are economies of scale in abatement. Further, the value of a contract increases and a contract is more likely to form in circumstances where contracting costs are low, and when the cost-shares are more closely correlated with the gains from a contract. These implications are examined in various contexts, including an examination of changes through time of predator control in Texas, a cross-state analysis of livestock assessments, an analysis of the structure of private predator control contracts, and an analysis of the distribution of county assessment programs in three western states.

Predator control contracts appear to be structured to reduce the costs of developing and maintaining a cost-sharing arrangement. The costs to participants tend to be distributed so as to be correlated with gains from a contract. Sheep-producer assessments tend to occur where the potential gains are highest (which is where damage rates are highest), where sheep inventories are highest, and where inventories per farm are large. Where sheep producers are a less dominant industry in a region and others also benefit from predator control, assessments specific to the sheep industry are less likely.

T-tests for differences in the variance of certain livestock producer characteristics across counties have low statistical significance, but are consistent with the hypothesis that assessments are implemented at the county level when cross-state variation

among livestock producers is high, and at the state level when cross-county variation is low. For states with county-level livestock assessments, sheep producers tend to impose assessments on themselves in counties with a lot of pastureland, with a high density of sheep, where average farm sizes are low, and where the variance in sheep inventories and farm size is small.

Despite a long history of public and cooperative private predator control in Texas, only in 1992 did Texas sheep producers begin mandatory assessments for predator control. Two factors have changed in recent years that, in light of the model, may have instigated the formation of the assessment program. Coyote densities have increased dramatically in recent years in the area with the highest concentration of sheep and goats, and a state referendum law and previous successful referenda most likely lowered the costs to sheep producers of developing the assessment program.

CHAPTER 4

Deer & Crops

4.1 Introduction

Two fundamental means of addressing wildlife damage exist: damage can be reduced through the use of abatement inputs, and by altering productive input use. The existing economic literature on wildlife damage focuses on abatement practices and, other than a few simulation exercises, there are no empirical applications of economic models of wildlife damage. This chapter begins to fill two voids in this literature by presenting a theoretical model of productive-input response to wildlife damage and applying it in the form of an acreage allocation model with different damage rates across crops. The model can easily be adapted to a broad class of multi-output production settings in which damage to outputs or factors of production is important. Crop selection in the face of insect pest damage is one potential application of the model that has also received relatively little attention.

The model is applied to crop choice in the face of deer-inflicted crop damage in Wisconsin. An acreage allocation model and damage equations are estimated for four crops with high damage rates: feed grain, alfalfa, soybeans, and sweet corn. Estimation is based on damage data from the Wisconsin Bureau of Wildlife Management (BWM) for 1993-1996 and county level data from various other sources.

The model and empirical application focus primarily on the response of producers to differential damage by wildlife, but as discussed in sections 2.2.4 and 2.2.5, compensation and abatement programs affect the incentives of landowners by altering the

marginal costs of wildlife and damage. Implications for wildlife agency compensation programs and deer population management policies are discussed.

Deer are a highly valued resource in Wisconsin. The state ranks among the top five in terms of total hunting expenditures, the percentage of its population who participate in non-consumptive wildlife related activities, and the number of hunter days for big game, with deer being the primary big game species (U.S. Fish and Wildlife Service 1991). Agricultural land is important in sustaining these activities. Nixon, Hansen, Brewer, and Chelsvig (1989) find that farm crops comprised 84, 48, 47, and 60 percent of the aggregate volume of food eaten in spring, summer, fall, and winter respectively for a sample of deer in an agricultural region of central Illinois, and that more deer are located in row crops than in any other single habitat in each season except winter. Also, biological carrying capacities and average hunter harvest rates tend to be higher in agricultural regions than in forest regions (Vander Zouwen and Warnke 1994). Agricultural land and production practices clearly provide substantial support for deer, and the incentives of agricultural landowners are therefore an important element of deer management.

Deer are consistently named as the biggest wildlife problem to U.S. crop producers (Wywialowski 1994, Conover and Decker 1991, McIvor and Conover 1994). Wywialowski (1994) finds that 34 percent of crop producers surveyed in the Great Lakes region reported some crop damage from hoofed mammals (primarily deer), and Wywialowski (1996) finds that Wisconsin has among the highest deer-attributed loss

rates. Feed corn, alfalfa, soybeans, and sweet corn are the focus of this paper because they are widely grown in Wisconsin, and they sustain relatively high deer damage rates. Feed corn and alfalfa are most widely grown, whereas soybeans and sweet corn account for smaller acreage shares and are more regional, with a few counties accounting for the majority of both the state's total production and the total value of damage sustained for those crops (table 4.1). Feed corn suffers the highest aggregate assessed deer damage, accounting for 73.2 percent of total losses for the four crops (50.7 percent of assessed deer damage to all agricultural commodities for which damage was reported). Soybeans, alfalfa, and sweet corn accounted for 12.5(8.6), 10.8(7.5), and 3.5(2.4) percent of losses to the four crops (all crops) respectively.[1]

The WIBWM Wildlife Damage Abatement and Claims Program incorporates three approaches to addressing wildlife damage. It provides 50 percent cost-share abatement support for farmers through participating county agencies, a depredation permit ("hotspot" permit) system that allows landowners with special permits to shoot problem deer, and it provides compensation up to $5,000 per farmer per year for damage claims (increasing to $15,000 for fiscal year 1998). Farmers sustaining damage by deer, geese, and bear are eligible, and 80 to 90 percent of estimated damage is due to deer. Surcharges on Wisconsin bonus deer permit fees earmarked for expenditure on damage claims and abatement generated almost $3.5 million in 1996,

[1] Other crops for which damage is reported include small grains such as wheat, oats, and barley; corn and hay silage; orchard crops such as apples and cherries; vegetables such as pumpkins, snap beans, strawberries, and cabbage; potatoes, and Christmas trees.

Table 4.1: Wisconsin land use for crop production, 1992.

Variable	N*	Mean	Std. Dev.	Minimum	Maximum
Land use and ownership as a % of total land in county.					
Land in farms	70	49.3	24.5	2.1	88.0
Cropland	71	35.3	20.3	0.7	69.6
Harvested cropland	71	28.9	17.7	0.4	61.1
Harvested crop acreage as a % of total harvested cropland.					
Feed corn	65	28.4	13.3	1.0	54.1
Alfalfa	69	25.7	8.9	8.5	52.0
Other hay	69	23.1	15.6	3.3	70.5
Corn for silage	69	10.0	4.8	0.9	20.6
Soybeans	60	7.2	7.7	0.3	40.8
Vegetables	62	4.2	5.3	0.0	27.4
Sweet corn	52	2.0	2.5	0.0	9.7
Small grains	65	1.9	0.9	0.4	3.9

*Number of producing counties with non-missing observations in the Ag. Census.
Source: Ag. Census, 1992.

with almost $1 million put toward abatement and $1.7 million toward compensation. For the 1995 fiscal year, 11.4 percent of the total departmental budget went to the wildlife damage program. Wisconsin's BWM damage estimates in 1996 averaged $2,813 per claimant (farm), and 1,266 claimants received on average $2,324 in compensation.

When BWM representatives assess claims, they may recommend the use of abatement techniques. The use of some forms of abatement capital by landowners become requirements for receiving compensation, and the basis of the abatement costs shared by the landowner and the agency (this connection between compensation and abate-

ment is common with compensation programs, and is discussed in section 2.2.5). Commonly implemented abatement methods include the installation of various types of fencing, the use of lure crops and scaring devices, and the application of chemical deterrents. Most or all implementation of required abatement is carried out after its associated damage claim has been filed for a given year.[2]

The BWM issued 394 hotspot permits to landowners in 1995, under which 3,908 deer were killed (as compared to general bow and gun permit kills of 467,271). Most crop damage occurs before hunting season, which generally is held in late October (figure 4.2; Hotspot permits allow farmers (or hunters at the farmers request) to shoot deer out of season on land suffering crop damage. Issuance is contingent on reasonable prior abatement by landowners and evidence of at least $1,000 of deer damage to crops. The land must be open to hunting for the following hunting season, and the landowner must also sign a contract agreeing not to deny a hunter's request for access to his land unless 2 hunters per 40 acres are already on his land at the time of the access request.

As shown in figure 4.1, hotspot permits were recommended most often, followed by fencing and various other forms of damage abatement. This heavy use of hotspot permits is consistent with the model of compensation programs in section 2.2.5. First, the first-order-conditions of the model imply that as long as lethal means of abatement

[2]Cami Peterson, BWM. Personal Communication.

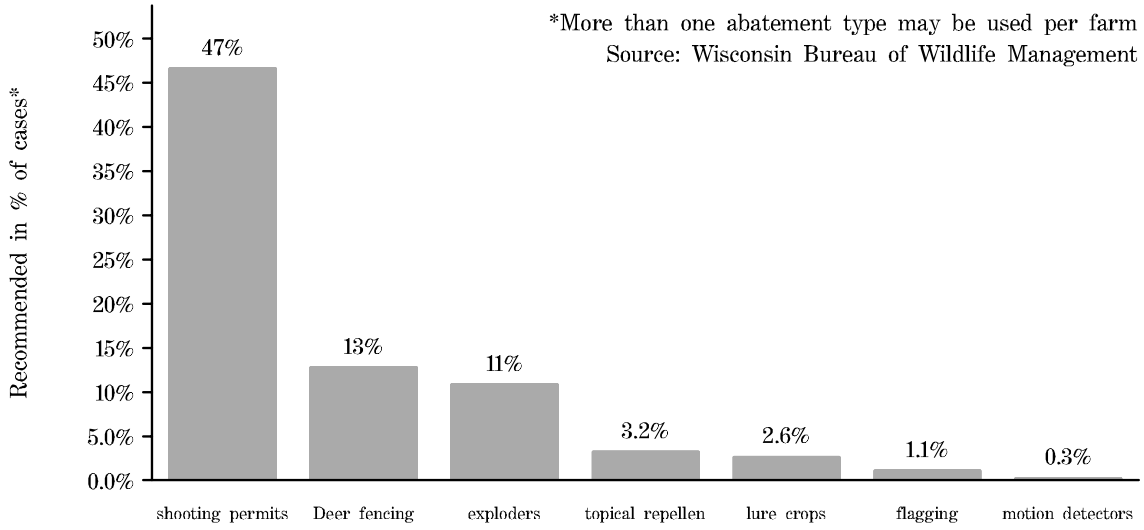


Figure 4.1: Abatement requirements for claims submission, percent of claimants

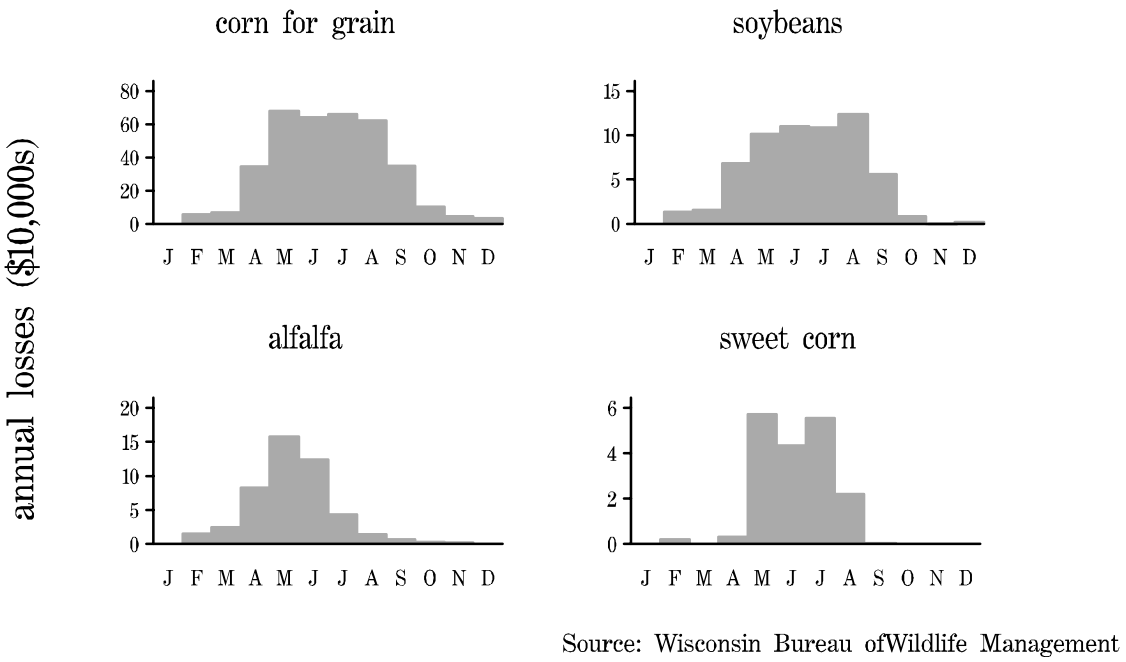


Figure 4.2: Deer damage by month, crop

provide some damage relief, it will be pursued, albeit to a lesser extent under a compensation contract.

Second, the fact that non-lethal methods of abatement are recommended far less often is an indication that non-lethal alternatives tend to be less productive (have a low marginal product) for reducing crop damage by deer. Recall that compensation programs tend not only to reduce incentives to pursue lethal abatement, but also tend to reduce farmers' incentives to pursue nonlethal abatement. When nonlethal abatement methods are rarely used by farmers to begin with, this moral hazard result is less of a problem (see equation 2.45). At the same time, despite their high cost, fences are the non-lethal alternative most recommended.[3] This is consistent with the hypothesis that compensation contract stipulations will tend to be built upon easily monitorable inputs.

Third, hotspot permits are often made available to hunters, so some of the potential welfare losses from killing deer to reduce damage are captured as benefits accrued by these hunters. These benefits may be lower than the benefits accrued from a regular hunting permit due to time, location, and other restriction placed on them. Finally, by maintaining a hotspot permit system, the BWM reduces the incentive for expending resources on covert abatement behavior (poaching to reduce damage) and/or habitat modification. Providing a legal means of pursuing lethal means of

[3]Although cost breakdowns are not available, expenditures on fences are likely to be much higher relative to other abatement alternatives than figure 4.1 suggests, because costs per farm are much higher for installing fences.

damage abatement is consistent with a joint wealth maximization framework in that it reduces the need for farmers to expend time and effort hiding their actions, and monitoring effort by wildlife managers. Furthermore, by reducing poaching of this sort in this manner provides information about deer harvests that would otherwise be more difficult to infer for herd management purposes.

Wildlife damage programs such as those provided by the BWM may also be useful tools for addressing private abatement practices, habitat provision and hunter access issues. By reducing the costs of wildlife to landowners, wildlife damage programs may reduce landowner incentives to destroy habitat or otherwise harm wildlife populations. The right of landowners to control hunter access to their land becomes a critical issue for herd management in regions where private agricultural land is a major source of wildlife habitat (Gardner 1997, McShea, Underwood, and Rappole 1997a, Vander Zouwen and Warnke 1994, Witmer and DeCalesta 1992, McCabe and McCabe 1997). Agency damage abatement and compensation support contingent on access rules provides a method for inducing landowners to allow more hunters onto their land, which allows an agency more control over the wildlife they manage.

4.2 A model of crop damage and crop choice

Consider first the structure of the production relationship between agricultural outputs, productive inputs, damage, and determinants of damage. Total damage to a

particular output cannot exceed potential output (Lichtenberg and Zilberman 1986). To impose this restriction, let the realized output of a crop be $\tilde{y} = y(1 - \delta)$ where y is potential output and the damage rate $\delta \in [0, 1]$ is the proportion of total output damaged. Previous research applying cross-sectional acreage allocation models at the county level have illustrated the importance of including physical and geographic data as determinants of land productivity and crop choice (Wu and Segerson 1995, Moore and Negri 1992). Potential output will therefore be modeled as $y = y(x, \mathbf{v})$, where x is a variable productive input and $\mathbf{v}$ is a vector of exogenous land and weather characteristics.

Abatement inputs are distinct from productive inputs in that they affect realized output by reducing the damage rate, and therefore enter the production relationship through the damage function (Lichtenberg and Zilberman 1986, Chambers and Lichtenberg 1994). A defining characteristic of wildlife is that its territorial boundaries often do not coincide with the boundaries of landholdings (Lueck and Yoder 1997). For a given wildlife density, the availability of non-crop forage and cover and its spatial relationship to crops within the wildlife's entire territory may affect an individual producer's damage levels (Matschke, deCalesta, and Harder 1984). This implies that the damage rate should be modeled as a function of land-use patterns on all land in the wildlife's territory. Let $\mathbf{z}$ represent a vector of factors exogenous to crop choice that affect the wildlife population's distribution and dependence on crops in a region

for a given population size w, and let a be the abatement input level. The production function for a crop can then be characterized as $\tilde{y} = y(x, \mathbf{v})(1 - \delta(w, \mathbf{z}, a))$.

Following common convention (Moore and Negri 1992, for example), assume technical non-jointness across crops in land inputs and crop outputs. Assume that farmers maximize profits by allocating fixed total acreage $\bar{x}$ over J crops so that $\sum_{j=1}^{J} x_j = \bar{x}$,where x_j is acreage allocated to crop j. This constraint requires crop acreage decisions to be determined jointly even when production is technically non-joint across crops (Shumway, Pope, and Nash 1984). Wildlife agency policy enters the landowner's decision process in the form of compensation for crop damage and abatement cost subsidies. Specifically, let ρ be the fraction of abatement costs not covered by the agency, and γ the fraction of damage not covered by the agency (this form for the compensation rate represents a simplification of the actual compensation structure). Given damage rates that can vary across crops, the profit maximization problem for farmer i over J crops is

$$\max_{a_j, x_j} \sum_{j=1}^{J} \Big(p_j y_j(x_j, \mathbf{v})[1 - \gamma \delta_j(w, \mathbf{z}, a_j)] - \rho c_j a_j \Big) \tag{4.1}$$

$$\text{subject to} \qquad \sum_{j=1}^{J} x_j = \bar{x},$$

where c_j is the marginal cost of the abatement input for crop j. The first-order conditions for the Lagrangian of this problem are

$$a_j: \quad -\gamma p_j y_j \frac{\partial \delta_j}{\partial a_j} - \rho c_j \quad = 0 \tag{4.2a}$$

$$x_j: \quad p_j \frac{\partial y_j}{\partial x_j}(1 - \gamma \delta_j) - \lambda \quad = 0 \qquad \forall\ j = 1 \ldots J \tag{4.2b}$$

$$\lambda: \quad \bar{x} - \sum_{j=1}^{J} x_j \quad = 0 \tag{4.2c}$$

where λ is a Lagrange multiplier associated with the constraint. The first-order conditions 4.2a imply that the optimal abatement level will equate the value of the marginal product of abatement (accounting for the level of compensation) with the marginal cost of abatement (accounting for abatement support).

Equations 4.2b imply that optimal acreage allocation will equalize the marginal shadow value of land across crops. If $\rho = \gamma > 0$, abatement levels are set exactly as if no compensation or abatement support were provided by the agency (equation 4.2a), but (4.2b) implies that more acreage will be allocated to high damage crops as compared to $\rho = \gamma = 0$. This incentive is apparently recognized by the BWM. Their compensation policy requires the farmer to have grown a particular crop for at least 5 years before damage to that crop is eligible for compensation. This is consistent with an attempt to reduce the moral hazard problem associated with compensation, and it reveals a recognition of the premise of this paper: that producers may respond to increases or reductions in damage rates by altering their crop choices.

No data on abatement levels or abatement prices are available, so in order to progress toward an estimable econometric model, a_j, c_j and ρ will be dropped from the analysis. The damage rate is then $\delta_j(w, \mathbf{z})$ which is determined exogenously. Following arguments made by Chambers and Lichtenberg (1994), let $\tilde{p}_j = p_j(1 - \gamma\delta_j(w, \mathbf{z}))$. With all of the determinants of δ_j exogenous, the damage rate is much like an per-unit tax, and the realized output price $\tilde{p}_j$ is much like an "after tax" output price. The acreage demand equations implied by the first-order conditions are $x_j = x_j^*(\tilde{\mathbf{p}}, \mathbf{v}, \bar{x})$, and will form the basis of the econometric model to be developed in section 4.3.

Consider now some specific determinants of deer damage to crops. Empirical evidence from the deer population biology literature indicates that crop damage is directly related to deer density (Matschke, deCalesta, and Harder 1984, Vecellio, Yahner, and Storm 1994, McNew and Curtis 1997). This literature also provides guidance for choosing elements of $\mathbf{z}$ in $\delta(w, \mathbf{z})$. An important element of the distribution of deer in relation to crops is the spatial relationships between cropland and forest cover (Nixon, Hansen, Brewer, and Chelsvig 1989). Producers in heavily wooded areas tend to sustain more crop damage than those in lightly wooded areas (Beringer, Hansen, Heinen, and Giessman 1994, Alverson and Waller 1997), and crops farther away from forest cover tend to be damaged less (Thomas 1954, Hartman 1972). Shope (1970) shows that crop damage rates are negatively related to field size, and Wywialowski (1996) finds loss rates to be consistently higher in edge units than in non-edge units.

The availability of non-crop forage also affects the extent to which crops are utilized by deer (Matschke, deCalesta, and Harder 1984). Timber clear-cuts, the associated edge habitat, and early successional forests tend to provide more forage and sustain higher deer populations than late successional forests (Alverson, Waller, and Solheim 1988). Forest types affect deer distribution as well. Both sexes favor early-successional upland forests of less than 60 years old, and nursing does avoid flood-prone bottomland forests and mature oak-hickory forests (Nixon, Hansen, Brewer, and Chelsvig 1989).

Because the comparative statics results of interest are intuitively straightforward, their formal derivation is relegated to appendix A.1. The following are some implications of the comparative statics and the existing wildlife management literature on deer distribution and deer damage.

1. *As the output price of a crop increases, acreage allocation to that crop increases.*
2. *As damage rates increase for a given crop (holding damage levels for other crops constant), acreage allocation to that crop decreases.*
3. *As wildlife density increases, acreage will be shifted toward crops for which the marginal damage of wildlife is low (i.e. the damage of the marginal deer is low).*
4. *For a given wildlife density, factors that tend to increase deer proximity or dependence on crops will have a positive marginal impact on damage and will induce more acres to be allocated to low damage crops. These include: deer density in the region, crop proximity to cover, proximity to wildlife refuges or other sources, poor quality/quantity of non-crop food sources, low rainfall, low forest harvest rates, low proportion of land with grassy or herbaceous cover.*
5. *As agency compensation increases, more acres will be planted to high-damage crops.*

Each of these hypotheses are testable in the context of the model in section 4.3.

4.3 Econometric model

In a stochastic environment, output prices and damage rates are not known by farmers at harvest time. The predicted values from estimated damage and price equations will be used as expected values for the expected price and damage rates in the acreage demand equations. Many functional forms have been used to estimate damage rates in the context of insect pest damage (Fox and Weersink 1995). The logit function is used here because it both restricts the predicted values to be in (0,1), and it provides a functional form that is linear in parameters. The damage equations are

$$\log\left(\frac{\delta_j}{1-\delta_j}\right) = \alpha_{j0} + \alpha_{jw}w + \boldsymbol{\alpha}'_{jz}\mathbf{z} + u_j, \qquad j = 1\ldots J, \tag{4.3}$$

where $\boldsymbol{\alpha_j}$ are crop-specific parameters to be estimated, $\mathbf{z}$ is (as previously described) a vector of factors affecting wildlife distribution and dependence on crops, and u_j is an error term. By inverting the predicted values from these logit equations, first-order approximations of the expected values of δ_j are calculated. Appendix A.3 provides further explanation of the relationship between the expected value of the logit of the damage rate and the expected value of the damage rate itself.

Output price expectations are estimated separately from the damage equations with an integrated VAR(2) process using National Agricultural Statistics Service

(NASS) state level annual price data (1950-1996) for each of the four crops. Following Wu and Segerson (1995), the largest of predicted price and support price is used for crops subject to price supports (Soybeans and corn; not applicable for 1996). These are used in conjunction with estimated damage expectations to calculate the after-damage output prices, $\hat{\tilde{p}}_j$.

The acreage demand equations are derived from a normalized quadratic profit function, which is a second-order approximation to any profit function (Shumway 1983). Because of the land constraint $\bar{x}$, the acreage demand equations cannot be retrieved via Hotelling's lemma, and must be derived directly from the first-order conditions 4.2a – 4.2c (Moore and Negri 1992).

Notice that $\hat{\tilde{p}}_j = \hat{p}_j(1 - \hat{\delta}_j) = \hat{p}_j - \widehat{p\delta}_j$. This form allows $\hat{p}_j$ and $\widehat{p\delta}_j$ to enter an empirical acreage demand equation separately, which allows a specification test for the relationship between output prices and damage rates. If the null hypothesis for a test of $\boldsymbol{\beta}_{jp} = -\boldsymbol{\beta}_{j(\delta p)}$ cannot be rejected, then imposing the structure of $\tilde{p}_j$ is appropriate.

The resulting acreage demand equations are

$$x_j^* = \beta_{j0} + \boldsymbol{\beta}_{jp}'\hat{\mathbf{p}} + \boldsymbol{\beta}_{j(\delta p)}'\widehat{\mathbf{p}\boldsymbol{\delta}} + \boldsymbol{\beta}_{jv}'\mathbf{v} + \beta_{j\bar{x}}\bar{x} + \varepsilon_j, \qquad j = 1 \ldots J. \tag{4.4}$$

Linear homogeneity in prices is imposed by dividing all $\widehat{p\delta}_j$ by a numeraire good (an input price index provided by USDA NASS is used). As noted by Moore and

Negri (1992), no cross-equation restrictions are implied by the model for this demand system. In the present case, output prices are state-level data covering only four years, so there is virtually no cross-sectional variation in output prices and they provide virtually no explanatory power in the estimated acreage allocation model. Therefore, $\boldsymbol{\beta}'_{jp}\hat{\mathbf{p}}$ are omitted from the acreage demand regressions and no specification test for the structure of $\tilde{p}_j$ is possible.

4.4 Data

The BWM maintains a field-level database of wildlife damage to crops that is based on assessments made by agency personnel for the purpose of processing damage claims submitted by farmers. Wisconsin counties that participated in BWM's Wildlife Damage Abatement and Claims Program for the years 1993-1996 are represented, providing a total of 257 county-level observations over 4 years.

The field-level damage rate for a given crop and year is calculated from BWM variables as

$$\delta = \frac{\text{acres damaged} \times (\text{yield on undamaged acres} - \text{yield on damaged acres})}{\text{field acreage} \times \text{yield on undamaged acres}}.$$

The sample means of these field-level estimates for each county, crop, and year are then used as the county-level damage rate to construct the logit for damage equation estimation.

Deer densities are provided by the BWM based on Deer Management Units (DMUs), so it is necessary to map DMU estimates into county estimates. This mapping is done based on land area using data provided by the BWM that provides breakdowns of county areas into DMU areas. The deer population for county i is calculated as $D_i = \sum_j D_j p_{ij}$ where D_i is the deer population estimate for county i, D_j is the deer population for DMU j, and p_{ij} is the proportion of county i land area in DMU j. Deer density w_i is the county deer population D_i divided by the total county land area from the Census of Agriculture (1992). The density estimates represent deer densities for the winter before the growing season. Because most reported crop damage occurs before the hunting season begins (late October for the gun season), this is taken to be the predetermined (exogenous) deer population for the subsequent crop-growing season.

NASS provides annual data on harvested acres and output prices, and the 1992 Census of Agriculture estimate of total cropland in a county is used as the value for total available cropland. Data on forest cover and growing stock removal rates are from the USFS Forest Inventory Database. Other land characteristics are sample means of National Resources Inventory (1992) samples for each county.

Table 4.2: Summary statistics of data used in estimation.

Variable (N=257)	non-zero*	Mean	Std. Dev.
δ_{corn}[1]	156	0.136	0.094
δ_{alfalfa}[1]	188	0.159	0.168
δ_{soybeans}[1]	100	0.168	0.100
$\delta_{\text{sweet corn}}$[1]	39	0.194	0.222
deer density per sq. mile[1]	257	16.482	7.037
prop'n of county managed by WI DNR[1]	249	0.015	0.017
feed corn, acres harvested[2]	236	43,985	35,795
alfalfa, acres harvested[2]	248	33,707	21,111
soybeans, acres harvested[2]	211	12,230	13,455
sweet corn, acres harvested[2]	131	3,626	3,985
harvested cropland, prop'n of county[2,5]	257	0.294	0.169
price, feed corn (bu.)[2]	257	2.688	0.107
price, alfalfa (ton)[2]	257	77.973	10.370
price, soybeans (bu.)[2]	257	5.967	0.473
price, sweet corn (bu.)[2]	257	17.257	1.397
total value of the 4 crops/year ($mil)[2]	257	23.624	19.329
rainfall index[3]	257	130.663	23.578
grassy/herbaceous cover, prop'n of county[3]	257	0.334	0.104
prime farmland, prop'n of county land[3]	257	0.331	0.206
erosion index[3]	257	0.529	0.173
irrigated land, prop'n of county land[3]	241	0.027	0.061
flood prone, prop'n of county land[3]	253	0.047	0.043
root zone problems, prop'n of county land[3]	253	0.197	0.135
steep slope (> 6%), prop'n of county[3]	257	0.104	0.057
forest cover, prop'n of county[4]	257	0.409	0.240
growing stock removal, prop'n of stock[4]	223	0.020	0.012
forest cover, prop'n on farms[4]	64	0.160	0.144
farm operator, years on farm[5]	257	20.506	1.090
principal occupation, prop'n of farm operators[5]	257	0.661	0.071
lives on farm, prop'n of farm operators[5]	257	0.876	0.040
full owner, prop'n of farm operator[5]	257	0.482	0.046
average farm size, acres	257	237.051	39.562

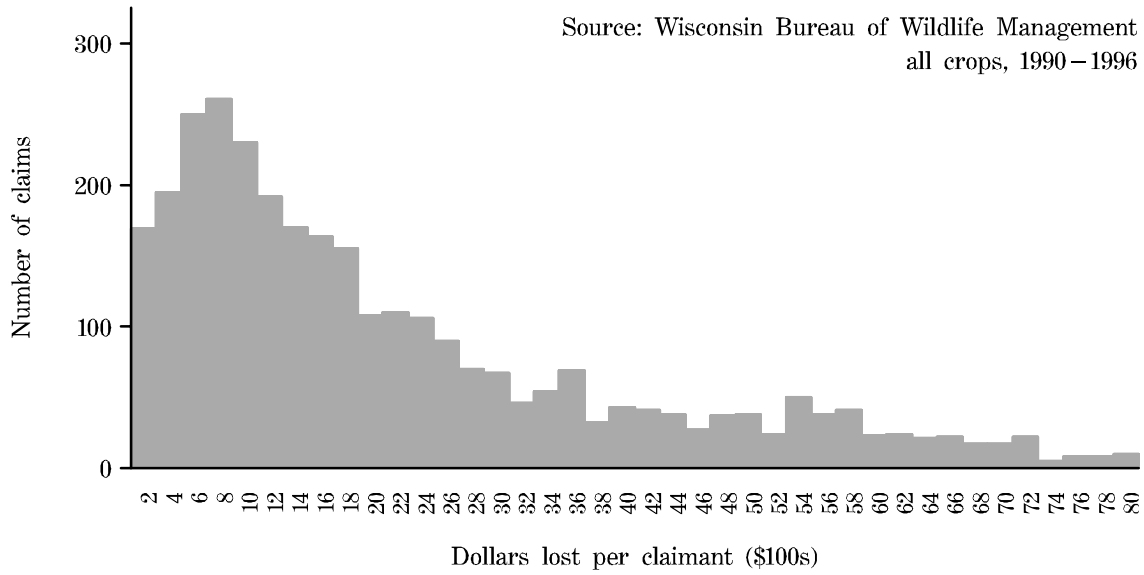
*"Non-zero" gives the number of non-zero observations (out of 257). Sources: [1]Wisconsin Department of Natural Resources; [2]USDA National Agricultural Statistics Service; [3]National Resources inventory, 1992; [4]USFS Forest Inventory Database 1996; [5]Census of Agriculture, 1992.

4.5 Estimation issues

Soybeans and sweet corn are grown only regionally in Wisconsin, so many counties have zero acreage allocated to these crops (table 4.2). This censoring at zero results in inconsistent Ordinary Least Squares estimates, and indicates that a Tobit model is appropriate for estimating acreage equations. Estimation of a system of demand equations in this fashion calls for a multivariate Tobit estimation procedure if cross-equation restrictions were implied by the model, or if the vector of exogenous variables vary across equations. Neither of these conditions hold in this case, however. The acreage demand equations being estimated here contain identical vectors of exogenous variables, and no cross-equation restrictions apply for this model. Therefore, each acreage demand equation may be estimated with independent Tobit estimation procedures.

The structure of the damage equations and how damage rate expectations are introduced into the acreage demand equations is a more difficult problem. Two methods of generating wildlife damage data are common. One method is to survey randomly-sampled producers (Wywialowski 1994, McNew and Curtis 1997). Another is to maintain data as byproducts of damage abatement and claims programs such as that maintained by the BWM. An advantage of the latter data collection method is that damage estimates are generally based on standardized sampling techniques performed by agency personnel. The disadvantage is that data collected through

Figure 4.3: Distribution of claims



agency programs tend to suffer from selectivity bias, because data are collected only if producers make initial contact with the agency by submitting a claim for compensation. Because the BWM provides a deductible of $250 per year for damage claims and places other requirements on farmers receiving compensation, farmers suffering low levels of total damage may be under-represented.

A comparison of survey data and BWM data illustrates the selectivity problem. Based on a survey of producers, Wywialowski (1994) finds that approximately 34 percent of field crop producers reported suffering crop damage by deer in 1992 in the Great Lakes states. Of these field crop producers reporting damage, 58 percent estimated total field crop damage to be less than $500. In contrast, only 1.65 percent of Wisconsin farmers submitted claims for deer damage compensation (based on BWM

and Census of Agriculture data). Furthermore, the number of BWM claims increases as a function of total losses before it decreases, with a modal number of claims in the \$800-\$1,000 range and relatively few claims under \$500 (figure 4.3). In light of the survey results, this suggests that many farmers who sustain low levels of damage do not submit claims. A lack of submitted claims in a participating county results in a missing county level damage estimate even though it is likely that some farmers suffered deer damage to crops but did not report it. Therefore, Heckman's two step method for addressing selectivity bias is used to estimate damage equations.

In the first step of Heckman's method, a probit model is estimated by maximum likelihood where the dependent variable is a binary variable indicating whether the observation is missing or observed.[4] The explanatory variables for this regression are factors that affect the likelihood of damage being reported, which is hypothesized here to include factors that increase the expected net benefits to farmers of submitting a claim, the number of farmers in a county, as well as how well-known the compensation and abatement program is by farmers in a given county. A formal analysis of the determinants of this first-stage regression is beyond the scope of this chapter, but the variables used as explanatory variables and their coefficients are presented in table 4.4.

For each predicted value from the first stage regression, an inverse Mill's Ratio is calculated and included as an explanatory variable in the second step equation,

[4]The logit model is used instead of a probit model, because of convergence problems with the probit for the soybean damage equation.

which is then estimated by ordinary least squares.[5] With the inverse Mills Ratio accounted for, this second stage regression is designed to explain the size of damage estimates *given a non-zero observation on damage*, and is analogous to equation 4.3. Specifically, the second stage damage regression becomes

$$\log\left(\frac{\delta_j}{1-\delta_j}\right) = \alpha_{j0} + \alpha_{jw}w + \boldsymbol{\alpha}'_{jz}\mathbf{z} + \alpha_{j\eta}\eta_j + u_j, \qquad j = 1\ldots J, \tag{4.3$'$}$$

where $\eta_j = \frac{\lambda(\gamma'_j w_j/\sigma)}{\Lambda(\gamma'_j w_j/\sigma)}$ is the inverse Mills ratio, $\Lambda(\cdot)$ is the cumulative density function of the selection process, $\lambda(\cdot)$ is the probability density function for the selection process, $\gamma'_j w_j$ is the inner product of coefficients and explanatory variables from the first stage regression, and σ is the standard deviation of the errors from the first-stage regression.

Another characteristic of the dataset is that it consists of pooled data, with primarily cross-sectional variation; the estimation is based on 257 observations, for an average of 64.25 observations for each of the four years. The panel-data characteristics of the data are addressed in the acreage demand equations by assuming fixed effects across years by including dummy variables for 1994-1996 in all acreage equations. It is tempting to include annual dummy variables in the damage equations for the same reason. The problem is that they would not represent any specific information source, but rather would amount to an *ad hoc* means of accounting for otherwise unexplained

[5]The dependent variable in the second stage is the logit of δ, which is undefined for $\delta = 0$. For observations with no damage estimate, an arbitrarily small value is used in order for the logit to be defined. The size of this value does not affect the results because these observations are treated as missing in the second step of the regression.

annual changes in damage expectations. If the farmer foresees these shifts based on information omitted from the regression, then inclusion of the dummy variables would be justified. Although the choice of whether to include the annual dummy variables is not clear-cut, they are omitted from damage regressions.

Estimation proceeds as follows: the damage equations are estimated using Heckman's two-step method and the predicted values for each damage equation are then multiplied by the (estimated) expected output price of the crop to get the price-weighted expectation of damage, $\widehat{p\delta}_j$. These enter as explanatory variables in the acreage demand equations, which are then estimated by the Tobit method.

The estimated standard errors of the coefficients on the $\widehat{p\delta}_j$ must be corrected for errors-in-variables bias that results from using $\widehat{p\delta}_j$ in place of the original data $p\delta_j$. The asymptotic covariance matrix for the estimates resulting from the estimated acreage demand equations with $\widehat{p\delta}_j$ as explanatory variables is $\hat{\sigma}^2(\hat{\mathbf{x}}'\hat{\mathbf{x}})^{-1}$, where $\hat{\mathbf{x}}$ is the vector of explanatory variables including the instruments $\widehat{p\delta}_j$, and

$$\begin{aligned}\hat{\sigma}^2 &= \frac{1}{n}(y_i - f(\hat{\mathbf{x}}_i\hat{\boldsymbol{\beta}}))'(y_i - f(\hat{\mathbf{x}}_i\hat{\boldsymbol{\beta}})) \\ &= \frac{1}{n}\hat{\boldsymbol{\varepsilon}}'\hat{\boldsymbol{\varepsilon}},\end{aligned} \tag{4.5}$$

in which i is an index on observations. In order to get the correct standard errors for the parameter estimates, $\hat{\mathbf{x}}_i$ in (4.5) must be replaced with the original data $\mathbf{x}_i$, which includes the original values for $\mathbf{p}\boldsymbol{\delta}_i$ (See Greene (1993, p.605) for further discussion).

Finally, White's general test failed to reject heteroskedasticity at $p \leq .05$ in all damage and acreage equations. Heteroskedasticity is therefore corrected (internally by Limdep) by weighting the standard error in each likelihood function by $e^{\boldsymbol{\beta}'\mathbf{x}_i}$, so that $\sigma_i = \sigma e^{\boldsymbol{\beta}'\mathbf{x}_i}$.

4.6 Results and discussion

The main focus of this chapter is an estimation of acreage response to deer damage, and data limitations require estimation at the county level. However, field-level damage data were provided by the BWM, and a field level analysis of damage will also be presented that may provide a clearer picture of the distribution of deer damage than the more aggregate acreage allocation model. Problems with aggregation of the damage data to the county level will become clear through a comparison of the field-level results presented in this section with the acreage allocation results in section 4.6.2.

4.6.1 Field-level estimation of crop damage

The advantages of this field level model are that the response variable and field acreage data are not aggregated in any way. Further, deer population density data are provided by deer management unit, not by county. When damage is estimated at the county level, deer population densities must be transformed into county densities based on relative area overlap as discussed in section 4.4. Deer management units are,

Table 4.3: Field level estimation of crop damage

Dependent variable: δ N=6640; $\chi^2(16)$=2114.4: p=.0000		
Independent variable	Marginal estimate	Sample means
Constant	-2.58E-01***	
DMU deer density[1]	1.93E-03***	20.004
Dummy, corn for grain	3.85E-02***	0.627
Dummy, soybeans	6.08E-02***	0.120
Dummy, sweet corn	4.98E-02**	0.024
Total field acreage[1]	-2.45E-03***	25.009
% forest cover[2]	2.56E-01***	0.381
% grassy/herbaceous cover[3]	-4.77E-04	36.044
% county flood prone[3]	-3.39E-01**	0.053
Avg. crop yield [1]	1.10E-06	90.678
% forest on farms[3]	1.92E-01	0.005
Saplings, % of forest[3]	-4.14E-02	0.110
% county land irrigated[4]	-3.96E-01***	0.018
Rainfall index[3]	-3.96E-04	138.374
County land, % in crops[4]	2.09E-01***	0.372
% county, Aspen-Birch forest[2]	-7.19E-01***	0.058
% county, Oak-Hick. forest[2]	5.74E-02	0.139

*,**, and *** represent significance at the 10, 5, and 1 percent level, respectively. Sources: [1]WI BWM; [2]USFS Forest Inventory; [3]National Resources Inventory; [4]Census of Agriculture, 1992. Marginal values are calculated using equation A.15.

however, the more appropriate unit because unlike counties, their borders have been delineated along physical barriers such as highways and rivers that tend also to best define the geographic range of a given deer population. The population estimates in the vicinity of a given field are likely to be estimated better by deer management unit data than the county translations. Recall that damage levels are expected to increase with deer density, poor non-crop forage, high quality crop forage, field size, and field

proximity to cover and other essentials. Differentials in hunting pressure may also impact damage. The results presented in table 4.3 from a regression of the logit of damage on various county-level explanatory variables generally support each of these hypotheses.

A few of the most interesting and important results are worth noting. Both deer density and field size (total acres in field) are of the expected sign and significant. Average yield of undamaged acres represents the productivity of the field, its sign is as expected (positive), but insignificant. Grassy and herbaceous cover provides forage for deer, so as the percent of county land with this type of cover increases, deer reliance on crops is expected to decrease; the results support this hypothesis. Aspen-Birch forest types are considered to be preferred habitat for deer (U.S. Department of Agriculture 1986).[6] This would suggest that as the proportion of land with Aspen-Birch cover increase, reliance on crops will decrease. By the same logic, as the percentage of county land in crops increases, a population's reliance on crops increases. Further, as rainfall increases, non-irrigated forage should increase in forage value relative to irrigated crops, and reliance on irrigated crops should decrease. Each of these hypotheses are supported by the results. Finally, the dummy variables for each crop (alfalfa is represented by the intercept) show differences in damage levels after accounting for the effects of the other explanatory variables. Alfalfa generally suffers the least as a percent of total yield, with corn for grain, sweet corn, and soy-

[6] Also, personal communication with Keith McCaffrey, WIBWM.

beans suffering progressively higher damage rates. As a whole, the results presented in table 4.3 are consistent with received information from the deer management and population ecology literature.

4.6.2 Acreage response model results

Damage regression parameter estimates are presented in table 4.4, and are based on equation A.15 (appendix A.2). The set of estimates at the top of the table are from the first-stage regression of Heckman's two-step method. The first thing to note is that the inverse Mills ratio (the last coefficients at the bottom of the table) is strongly significant for each crop, so a sample selection model is justified. Each column represents a regression for one of the four crops, in which the dependent variable is a *one* if at least one claim was submitted for that crop/county/year, and *zero* otherwise. The explanatory variables include factors hypothesized to affect the probability of farmers submitting damage claims. Deer density estimates are all positive, but insignificant for two of the four crops. As hypothesized, counties with high deer densities are more likely to have damage claims submitted than counties with low deer densities. The number of years a county has participated in the Wisconsin Damage Abatement and Claims Program strongly affects the probability of claims submission; the longer a county has participated, the less likely it is to have no claims submitted for any given crop.

Table 4.4: Elasticities of damage w.r.t. explanatory variables.

	dependent variable: damage rate			
	$\delta_{\text{feed corn}}$	δ_{alfalfa}	δ_{soybeans}	$\delta_{\text{sweet corn}}$
	Heckman first stage[1]			
Constant	-1.681**	-3.520***	-1.296	-0.282
Deer density	0.236	0.284**	0.232	0.087**
Rainfall index	-0.141	0.114	0.152	-0.186*
% harvested cropland	0.375	0.858***	-0.286	-0.070
% grassy cover	-0.139	-0.067	-0.160	0.097
% managed by DNR	0.141***	0.050	0.136***	-0.002
% forest cover	0.139	0.466	-0.900***	-0.115
Average farm size	0.228	0.976***	0.914***	0.173*
Growing stock	-0.089	0.054	-0.089	-0.001
Years in program	0.984***	0.488***	1.123***	0.167***
Number of farms	-0.097	0.830***	0.801***	-0.087
Harvested cropland	-0.297	-0.287	-0.798***	0.077
	Heckman second stage elasticities			
R-squared	0.780	0.873	0.724	0.537
Constant	-38.27***	-57.56***	-28.35***	-15.77***
Deer density	8.09***	5.82***	5.31***	4.33***
Rainfall index	2.60	6.71***	5.81**	-10.23***
% harvested cropland	9.39***	13.21***	0.53	-1.99
% grassy cover	2.77*	-1.21	0.44	3.43***
% managed by DNR	1.39***	0.88***	2.07***	0.45**
% forest cover	6.03***	5.53***	-5.24**	-6.87***
Average farm size	-1.65	12.45***	5.71**	9.54***
Growing stock removal	0.62	1.11***	0.54	0.53
Inverse Mills ratio	10.40***	10.28***	10.11***	9.07***

One, two and three stars after an estimate indicates P-values of less than or equal to .01, .05, and .10 respectively. [1]The values presented here are the unit change in predicted probability with respect to a % change in the explanatory variable, which is equivalent to the marginal effect at the sample means multiplied by the mean of the explanatory variable.

The second stage Heckman coefficients are estimates of the effects of explanatory variables on damage rates given that at least one claim was submitted in a given crop, county, and year. They tend to be statistically stronger than the first-stage estimates, and when they are statistically significant, they tend to be the same sign across equations. Elasticities on deer densities are all positive and strongly significant. As the proportion of county land managed for wildlife by the Wisconsin Department of Natural Resources increases, damage rates tend to increase, and as the percent of harvested cropland in a county increases, damage rates tend to increase, although the coefficient on sweet corn damage is negative but insignificant. Many of the other explanatory variables, particularly those associated with land cover variables, are not of the expected sign.

The acreage demand estimates are presented in table 4.5, and are based on equation A.16. As found in previous studies, land characteristics tend to perform well in explaining crop patterns (Moore and Negri 1992, Wu and Segerson 1995). Differences in acreage allocation due to differences in land characteristics follow from a comparative advantage for producing one crop over another. There is therefore no reason to expect the coefficients to be the same sign across crops for a given land characteristic. For example, as the percentage of the county categorized as "prime farmland" increases, acreage of three of the crops tends to increase for that county, but acreage allocated to alfalfa decreases. This suggests that alfalfa has a comparative advantage

Table 4.5: Acreage elasticities.

	Dependent variable: acres			
	Feed corn	Alfalfa	Soybeans	Sweet corn
R-squared[1]	0.872	0.840	0.576	0.458
Constant	-2.755***	1.721***	-10.654***	-9.603**
$\widehat{p\delta}_{\text{feed corn}}$	0.008	-0.001	0.004	0.100
$\widehat{p\delta}_{\text{alfalfa}}$	-0.004	-0.005	-0.027	-0.087*
$\widehat{p\delta}_{\text{soybeans}}$	-0.003	0.001	-0.018	-0.015
$\widehat{p\delta}_{\text{sweet corn}}$	-0.005	0.004	-0.012	-0.065**
Prime farmland	0.055	-0.314***	1.787***	1.408***
Erosion index	0.132	0.324***	-0.652**	-2.196***
Irrigated	-0.039***	-0.016*	-0.018	0.515***
Years on farm	0.780*	-0.781**	3.925***	10.788***
Flood prone	-0.026	0.080***	-0.044	0.458**
Rainfall index	0.739***	-0.082	3.490***	-0.461
Steep slope	-0.147*	0.119*	0.185	-0.342
Farm size	0.727***	-1.010***	1.380***	-1.667
Root zone problems	0.094*	0.103**	0.424***	-0.748**
Harvested cropland	1.252***	0.852***	0.844***	2.046***
1994 dummy	0.067***	0.010	0.063	0.039
1995 dummy	0.058***	0.009	0.061	-0.136
1996 dummy	0.053***	-0.015	0.070*	-0.175*
Deer density (indirect)	-.0038	-.0048	-.0525	-.0408
Compensation rate	.0032	.0014	.0407	.0239

One, two and three stars after an estimate indicates P-values of less than .01, .05, and .10 respectively. [1]R-squared are from the Ordinary Least Squares regression from which starting values for Tobit estimation were taken.

for production on poorer farmland relative to the other crops, and that the other crops have a comparative advantage on prime farmland relative to alfalfa.

The impact of expected price-weighted damage rates on acreage allocation is weak. Of the four own-damage elasticities, three are negative as hypothesized, but the coefficient for feed corn is positive. Only the own-damage coefficient on sweet corn is significant at greater than the 10 percent level (after correcting the standard errors for the errors-in-variables problem). Note, however, that the elasticity magnitudes are positively correlated with the mean damage rates for each crop as presented in table 4.2. Sweet corn, which is not as widely grown and on average suffers a higher damage rate than the other crops, appears to be more readily substituted in favor of other crops when damage rates are high.[7]

The point estimates from the acreage demand equations can be used to estimate the effects of changes in wildlife management policy. The potential impact of two policy instruments, compensation and deer population control, are examined below. To the extent that the BWM has control over deer densities through hunter harvest

[7]An alternative specification was also estimated, but the results are not reported. The system of damage and acreage equations was estimated jointly using a full-information, non-linear least-squares algorithm that did not account for sample-selectivity or censorship. The results were qualitatively similar in that deer density was associated with higher damage rates and higher crop-specific damage rates were associated with reductions in acreage. However, the results are different in that the deer density coefficients of the damage equations were (with one exception) statistically insignificant, and the effects of damage rates on acreage allocation were all highly significant (t-statistics ranging from -2.3 to -11.8), with large elasticity estimates (-7 to -117). The limited-information method that accounts for sample selection and censorship was chosen because of the strong evidence shown above that these issues matter with these data.

policies and other management tools, manipulation of deer densities can be viewed as a policy instrument that can affect deer damage levels.

The deer density affects acreage shares indirectly through all of the $\tilde{p}_j$'s. Elasticities of acreage demand with respect to deer density are calculated based on equation A.17, and are presented at the bottom of table 4.5. They show that as deer density increases in a county, acreage allocation to all four high-damage crops decreases, with changes to feed corn and alfalfa being small relative to changes in soybean and sweet corn acreage. This result is intuitively plausible given the magnitudes of elasticities of acreage with respect to the $\widehat{p\delta}_j$. Because $\bar{x}$ is fixed, the change in the acreage not allotted to these four crops with respect to a change in the deer density can be calculated also (equation A.18). At the sample means, the elasticity of the residual acreage with respect to the wildlife density is 0.062, which is to say that as the wildlife stock increases by 10 percent, crop acreage allocated to uses other than the four crops examined here increases by 0.6 percent.

The BWM has provided compensation for damage up to $5,000, minus a $250 per farmer/year deductible. Under this arrangement, total compensation accounted for 82% of total eligible claims submitted to the BWM in 1996. Although the proportion of farmers growing these crops in each county who submit claims is small, the results can provide estimates of acreage responses to changes in compensation rates for expectant claimants. Recall that the after-damage output price for a crop is $\tilde{p}_j = p_j(1 - \gamma\delta_j)$ after accounting for the compensation rate γ. Table 4.5 shows the

estimated percent change in acreage with respect to a unit change in the compensation rate γ (equation A.19). The percent change in crop acreage allocated to other crops resulting from a unit change in γ is -0.031.

4.7 Summary

Crop damage can be reduced by using abatement inputs and by altering productive input levels. The existing economic literature on wildlife damage focuses entirely on abatement practices, and virtually no published empirical applications of wildlife damage models exist. This chapter begins to fill two voids in the literature with a model allowing endogenous productive-input response to wildlife damage, and an econometric analysis of crop acreage allocation in the face of deer-inflicted crop damage.

A county-level model of crop acreage allocation consisting of four crop acreage and damage equations representing feed corn, alfalfa, soybeans, and sweet corn is estimated using Wisconsin data for the years 1993-1996. Acreage response estimates are statistically insignificant for three of the four crops, but sweet corn, which suffers relatively high damage rates and is less widely planted, responds negatively to expectations on damage rates. Damage rates, in turn, are robustly responsive to deer densities.

Implications with respect to changes in deer densities and compensation levels are illustrated and briefly discussed based on the point estimates from the model. As the deer density increases, acreage allocation to each of the four high-damage crops examined here decreases, and acreage allocation to other crops increases. The flip side of this result is that as the compensation rate increases, acreage to the four high-damage crops increase and acreage to other crops decrease. These point estimates are not statistically different from zero, however.

These results have bearing on at least three wildlife management issues. This analysis supports other studies that show deer damage can be reduced by reducing deer densities. Reducing the costs to landowners of deer damage through compensation may induce landowners to plant a higher proportion of acreage to high-damage crops than in the absence of compensation, possibly leading to higher overall damage rates and damage claims. At the same time, it may be reasonable for compensation and abatement policies to be viewed by agencies as a means of affecting the provision of wildlife habitat and forage on private land.

CHAPTER 5

Conclusion

In its search for sustenance and cover, wildlife imposes costs on property owners. Ungulates and birds consume field crops, predators attack livestock, and rodents feed on granary stocks. In response, a mosaic of private and public institutions has evolved to address these problems. Private sector involvement includes individual landowners and firms, private agricultural groups, and a growing private animal damage control industry. The public sector is actively involved in wildlife damage control as well, including county agencies, state wildlife agencies, and departments of agriculture at both the state and federal level.

Wildlife territories usually encompass numerous landholdings, effectively making them a common pool resource much like oil reservoirs, insect pests, river fisheries, and groundwater. Land use and abatement choices by one landowner may help or hurt his neighbor, depending on how these choices affect the wildlife stock on his neighbor's land, and on the value that his neighbor places on the wildlife. When these external effects are not accounted for, economic inefficiencies result from the misallocation of productive resources; when these inefficiencies are large enough, contractual arrangements may evolve to correct them.

This dissertation is an examination of contractual responses to wildlife-inflicted damage to agricultural property. Chapter 1 introduces the problem of wildlife damage. It first provides a discussion of various wildlife damage abatement techniques used in various contexts. Institutional responses in the form of private and public contracting are then discussed, including input sharing arrangements among private

agricultural producers and damage abatement and compensation programs maintained by some departments of agriculture and wildlife agencies.

A rationale for contracting over wildlife damage is developed in chapter 2, followed by a set of formal models representing prevalent cooperative/contractual arrangements, including labor-sharing, abatement cost-sharing, and damage sharing contracts, as well as an analysis of the choice between bounty and wage payment mechanisms for predator control. The structure of each these contracts is defined in part by difficulties associated with monitoring abatement labor effort.

Chapter 3 builds on the model of a cost-share contract developed in section 2.2.2, and applies it to an examination of the structure and distribution of livestock assessments for control of livestock predator populations in the United States. The model implies that the value of a contract over predator control is a function of various factors, including the value and spatial concentration of livestock production in a region, the predator density, the proportion of the predator's territory used for livestock production, the marginal cost of independent abatement effort and the marginal cost of cooperative abatement effort. The model also implies that the structure of contracts will reflect the relative costs of contracting, and that existing institutions will be used in cases where they reduce contracting costs. State and county level data, as well as anecdotal evidence provide broad support for the main predictions of the model.

Chapter 4 examines the incentives of agricultural producers to change production practices in response to wildlife damage, as well as the incentive effects of compensa-

tion and abatement programs maintained by some wildlife agencies for some species. An acreage allocation model is developed and applied to crop choice in the face of deer-inflicted crop damage in Wisconsin. An acreage allocation model and damage equations are estimated for four crops with high damage rates: feed grain, alfalfa, soybeans, and sweet corn. Of the four crops, sweet corn suffers the highest damage rates on average, and the estimation results suggest that crop producers respond to high sweet corn damage rates by reducing acreage to sweet corn. Damage rates, in turn, are shown to be positively related to deer density, which is consistent with received population biology theory and existing empirical studies of deer damage to crops. An analysis of field-level deer damage rates provides broad and strong evidence of land use characteristics as determinants of crop damage rates that is also generally consistent with population biology literature and empirical studies of deer.

The economic literature on wildlife damage is small, consisting primarily of reports of wildlife damage estimates. In-depth economic analyses are few. This dissertation expands the literature in a number of ways. First, it includes a formal examination of the structure of a number of prevalent forms of implicit contracts over wildlife damage that previously have not been examined. Compensation as a contracting mechanism has been examined in the context of a principal-agent model, but the model developed here provides some implications about the relative value of compensation as a contracting mechanism, and lays the groundwork for empirical analysis. Second, the theoretical model of abatement cost-sharing and the empirical application presented

in chapter 3 expands the literature on cooperative contracting over common property and public goods. Third, the empirical model is readily applicable to a wide variety of other problems in which differential damage rates across outputs are important. One obvious example that has not received much attention is the effect of insect damage on crop choice.

Many avenues exist for future research on the economics of wildlife-inflicted property damage, including numerous potential extensions of the work presented in this dissertation. Theoretical extensions include, but are not limited to, a more detailed development of the implications of the structure of livestock assessments on their value as a cost-sharing arrangement, an examination of damage rates as a source of information about the value of habitat for wildlife production, the use of compensation and abatement support as incentives for the provision of hunting access where access to private land is a limiting factor in game management, and a dynamic analysis examining the implications of bounty versus wage payments with respect to extermination of species. Possibilities for empirical work include more complete applications of some of the models developed in chapter 2, possibly including a more in-depth analysis across species, space, and time of bounties versus wage payments as a means for damage abatement, and the development of an econometric model to improve estimates of aggregate damage based on self-selected damage data that are byproducts of a number of public agency abatement and compensation programs.

Much of the world's wildlife habitat is provided by private landowners, and wildlife-inflicted property damage can play an important part in the incentives for habitat provision on private land. The impact of wildlife damage on the incentives of private landowners is therefore important, and the relevance of the problem extends far beyond the United States. In regions such as eastern and southern Africa where community involvement in wildlife management is increasingly being considered as essential, wildlife damage issues may also affect the incentives of local communities to protect and sustainably manage wildlife populations in that part of the world.

APPENDIX A

APPENDIX

A.1 Comparative statics

This appendix presents the comparative statics of maximizing profits from allocating acreage among three crops subject to a proportion of output damaged δ^j, which may differ across crops, and a compensation rate γ which is the same fraction of damage regardless of crop type. The Lagrangian is

$$\mathcal{L} = \sum_{j=1}^{3} p_j y^j(x_j)(1-(1-\gamma)\delta^j(w,\mathbf{z})) + \lambda(\bar{x} - \sum_{j=1}^{3} x_j). \tag{A.1}$$

Letting $g \equiv (1-\gamma)$ and subscripts x on y^j denote acreage applied to the jth crop, the first order conditions are

$$p_j y_x^j(1-g\delta^j(w,\mathbf{z})) - \lambda = 0 \qquad j = 1\ldots 3 \tag{A.2}$$

$$H = \begin{pmatrix} p_1 y_{xx}^1(1-\delta^1) & 0 & 0 & -1 \\ 0 & p_2 y_{xx}^2(1-\delta^2) & 0 & -1 \\ 0 & 0 & p_3 y_{xx}^3(1-\delta^3) & -1 \\ -1 & -1 & -1 & 0 \end{pmatrix} \tag{A.3}$$

The sufficient condition for negative semi-definiteness is that the determinant of this 4×4 bordered Hessian is negative:

$$\begin{aligned} |H| = -\big[& p_1 p_2 y_{xx}^1 y_{xx}^2 (1-g\delta^1)(1-g\delta^2) \\ & + p_1 p_3 y_{xx}^1 y_{xx}^3 (1-g\delta^1)(1-g\delta^3) \\ & + p_2 p_3 y_{xx}^2 y_{xx}^3 (1-g\delta^2)(1-g\delta^3)\big] \leq 0. \end{aligned} \tag{A.4}$$

Acreage demand equations that follow from (A.2) are $y^j = y^j(\mathbf{p}, \boldsymbol{\delta}(w,\mathbf{z}), \bar{x})$, where $\boldsymbol{\delta} = (\delta^1, \delta^2, \delta^3)'$. The first order identities are:

$$p_i y_x^j(\mathbf{p}, \boldsymbol{\delta}(w,\mathbf{z}), \bar{x}) \cdot (1-g\delta^j(w,\mathbf{z})) - \lambda \equiv 0 \qquad j = 1\ldots 3 \tag{A.5}$$

The comparative statics are:

$$\frac{dx_1}{dp_1} = y_x^1(1-\delta^1)\frac{[p_2 y_{xx}^2(1-g\delta^2) + p_3 y_{xx}^3(1-g\delta^3)]}{|H|} \geq 0 \tag{A.6}$$

$$\frac{dx_1}{dp_2} = -\frac{p_3 y_x^2 y_{xx}^3 (1-g\delta^2)(1-g\delta^3)}{|H|} \leq 0 \tag{A.7}$$

$$\frac{dx_1}{d\delta_1} = -gp_1y_x^1\frac{[p_2y_{xx}^2(1-g\delta^2)+p_3y_{xx}^3(1-g\delta^3)]}{|H|} \leq 0 \tag{A.8}$$

$$\frac{dx_1}{d\delta_2} = \frac{gp_2p_3y_x^2y_{xx}^3(1-g\delta_3)}{|H|} \geq 0 \tag{A.9}$$

$$\frac{dx_1}{d\bar{x}} = \frac{p_2p_3y_{xx}^2y_{xx}^3(1-g\delta^2)(1-g\delta^3)}{|H|} \geq 0 \tag{A.10}$$

$$\frac{dx_1}{dw} = \frac{g^2}{|H|}\Big[(1-\delta^2)p_2y_{xx}^2(p_3y_x^3\delta_w^3 - p_1y_x^1\delta_w^1) + (1-\delta^3)p_3y_{xx}^3(p_2y_x^2\delta_w^2 - p_1y_x^1\delta_w^1)\Big] \tag{A.11}$$

Recognizing that the first order conditions (A.2) imply $p_jy_x^j = \lambda$ for all j, (A.11) can be rewritten as

$$\frac{dx_1}{dw} = \frac{\lambda g^2}{|H|}\Big[(1-\delta^2)p_2y_{xx}^2(\delta_w^3-\delta_w^1) + (1-\delta^3)p_3y_{xx}^3(\delta_w^2-\delta_w^1)\Big]. \tag{A.12}$$

The comparative statics with respect to elements of $\mathbf{z}$ are mathematically identical to (A.12), and differ qualitatively only through the sign of δ_z^j. Elements of $\mathbf{z}$ that tend to increase damage for a given deer density will have the same sign as (A.12), and elements that tend to decrease damage for a given deer density will have the opposite sign. The comparative statics result for compensation parallel those for w and $\mathbf{z}$, an illustration of the symmetric effects that target wildlife densities and compensation have on landowner decisions:

$$\frac{dx_1}{dg} = \frac{\lambda g}{|H|}\Big[(1-\delta^2)p_2y_{xx}^2(\delta^3-\delta^1) + (1-\delta^3)p_3y_{xx}^3(\delta^2-\delta^1)\Big], \tag{A.13}$$

and the comparative statics with respect to γ are simply the negative of (A.13):

$$\frac{dx_1}{dg} = -\frac{dx_1}{d\gamma} \tag{A.14}$$

A.2 Elasticities

The dependent variables of the damage equations are the Logit of damage, so a variable's coefficient is not equivalent to the marginal effect of that variable. Rather,

$$\frac{\partial\delta_j}{\partial z_k} = \alpha_k\mathcal{P}(\boldsymbol{\alpha}'\mathbf{Z})(1-\mathcal{P}(\boldsymbol{\alpha}'\mathbf{Z})) \tag{A.15}$$

where $\mathcal{P} = \frac{\exp[\boldsymbol{\alpha}'\mathbf{Z}]}{(1+\exp[\boldsymbol{\alpha}'\mathbf{Z}])}$ is the inverse of the Logit (the logistic function) , $\mathbf{Z}$ is the full set of regressors, including the inverse Mills ratio and the wildlife density. Marginals and elasticities for the damage equations are calculated at the sample means of non-missing observations as $\frac{\partial \delta_j}{\partial z_k}\frac{\delta_j}{z_k}$.[1]

Because the acreage equations are estimated with a Tobit model, the marginal effect of any explanatory variable v_k is

$$\frac{\partial x}{\partial v_k} = \beta_k \Phi\left(\frac{\boldsymbol{\beta}'\mathbf{V}}{\sigma}\right) \tag{A.16}$$

where $\mathbf{V}$ is the full vector of explanatory variables, Φ is the cumulative density function for the non-zero observations and σ is the standard deviation of the (unobserved) continuous latent variable theoretically underlying x_j (see Greene (1993) for a more complete discussion of this method). The elasticity of acreage with respect to β_k is then $\frac{\partial x}{\partial v_k}\frac{v_k}{x}$, estimated at the sample means of the non-zero observation on acreage.

The impact of a determinant of the damage rate on acreage allocation works through the vector $\widehat{\mathbf{p}\boldsymbol{\delta}}$. For example, the marginal impact of a change in the deer density on the acreage of crop k is

$$\begin{aligned}\frac{\partial x_k}{\partial w} &= \sum_j \frac{\partial x_k}{\partial p\delta_j}\frac{\partial p\delta_j}{\partial \delta_j}\frac{\partial \delta_j(w)}{\partial w} \\ &= \sum_j p_j \frac{\partial x_k}{\partial p\delta_j}\frac{\partial \delta_j}{\partial w}\end{aligned} \tag{A.17}$$

where the second fraction (on the bottom) is given by equation (A.16) and the second fraction is given by (A.15). This marginal effect is then multiplied by $\frac{x_k}{w}$ (the sample means) for the elasticity.

The change in the acreage not allotted to these four crops is calculated in the following way. Because $\bar{x}$ is fixed, the sum of changes in total acreage is fixed. Letting x_r denote the residual acreage not allotted to the 4 crops, setting the sum of the marginal changes equal to zero, multiplying through by w/x_r, and moving the sum to the right hand side results in

$$\frac{\partial x_r}{\partial w}\frac{w}{x_r} = -\frac{w}{x_r}\sum_j \frac{\partial x_j}{\partial w}. \tag{A.18}$$

[1] An additional complication arises for variables such as deer density that enter as explanatory variables in both the first and second stage regression. The total marginal effect of w includes the direct effect on the damage rate estimates plus an indirect effect through the Mills ratio that accounts for w's effect on changing the likelihood of a non-zero observation (Greene 1993). The indirect effect is of no particular interest here, so only the direct effects (e.g. α_w) are used in calculating the elasticities presented.

Finally, the change in acreage for crop k with respect to a change in the compensation rate for those expecting damage and compensation is

$$\begin{aligned}\frac{\partial x_k}{\partial \gamma} &= \sum_j \frac{\partial x_k}{\partial \hat{\hat{p}}} \frac{\partial \hat{\hat{p}}}{\partial \gamma} \\ &= -\sum_j \widehat{p\delta}_j \frac{\partial x_k}{\partial \gamma \widehat{p\delta}_j}. \end{aligned} \tag{A.19}$$

A.3 Transformations of the predicted logit as approximations for expected damage rates

We want to recover $\mathrm{E}[\delta]$ from $\mathrm{E}[\log\left(\frac{\delta}{1-\delta}\right)]$, but the problem is that

$$\mathrm{E}\left[\log\left(\frac{\delta}{1-\delta}\right)\right] \neq \log\left(\frac{\mathrm{E}[\delta]}{1-\mathrm{E}[\delta]}\right),$$

so the expectation of the logit cannot simply be inverted to recover the exact expectation of δ. This section shows that the estimates for expected damage rates used as explanatory variables in the acreage equations are first-order approximations of true expected damage rates.[2] To begin, let the true distribution of δ be the logistic function $\Lambda(\mathbf{x}'\boldsymbol{\beta}+\varepsilon)$ and the inverse of this function (the Logit) be $\Lambda^{-1}(\delta) = \mathbf{x}'\boldsymbol{\beta}+\varepsilon$, with $\mathrm{E}[\varepsilon] = 0$. Applying a Taylor's series approximation of Λ around $\mathbf{x}'\boldsymbol{\beta}$ leads to

$$\begin{aligned}\delta = \Lambda(\mathbf{x}'\boldsymbol{\beta}+\varepsilon) &\simeq \Lambda(\mathbf{x}'\boldsymbol{\beta}) - \Lambda'(\mathbf{x}'\boldsymbol{\beta})\left(\mathbf{x}'\boldsymbol{\beta} - (\mathbf{x}'\boldsymbol{\beta}+\varepsilon)\right) \\ &\simeq \Lambda(\mathbf{x}'\boldsymbol{\beta}) + \Lambda'(\mathbf{x}'\boldsymbol{\beta})\varepsilon. \end{aligned} \tag{A.20}$$

Because $\mathrm{E}[\varepsilon]$=0 by assumption, taking the expectation of (A.20) results in

$$\mathrm{E}\left[\delta\right] \simeq \Lambda(\mathbf{x}'\boldsymbol{\beta}).$$

This in conjunction with $\mathbf{x}'\boldsymbol{\beta} = \mathrm{E}[\Lambda^{-1}(\delta)]$ implies that an approximation of expected damage rates to be used in the acreage equations may be calculated via the logistic function using predicted values from a linear regression on the logit of δ:

$$\hat{\delta} \simeq \frac{\exp\left(\mathbf{x}'\hat{\boldsymbol{\beta}}\right)}{1+\exp\left(\mathbf{x}'\hat{\boldsymbol{\beta}}\right)}. \tag{A.21}$$

where $\hat{\boldsymbol{\beta}}$ are parameter estimates from the logit regression.

[2] This method follows Greene (1993, p.57). Despite this transformation problem, the logit is used in estimation to provide a estimable linear model to address sample selection problems.

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