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Externalities, Uncertainty, and Compensation for Crop Damage from Wildlife: A Principal-Agent Approach

Economic conflicts increasingly characterize competition for U.S. and Canadian landscapes by agriculture, wildlife, human population pressure, and recreational needs. While modern agriculture has often destroyed wildlife habitat it has also increased habitat for some recreational wildlife species such as Canada geese. The Canada goose population has grown significantly in North America because of management policies designed to meet the increasing demand for recreational resources, as well as from the increased carrying capacity due to agricultural activity [GAO]. The increased population and its associated benefits for recreational use has not come without a cost. For example, Wisconsin's 30,000 acre Horicon marsh concentrates large numbers of geese migrating through an agricultural region, where they consume and trample hundreds of thousands of dollars of agricultural produce. The Wisconsin wildlife damage program (WWDP) attempts to optimize net recreational benefits and farm revenues by regulating levels of damage abatement effort provided by farmers and compensation recreational hunters pay farmers for agricultural losses. Yet after 25 years of struggle with the Horicon "farmer problem," farmers, hunters and the state wildlife management agency, the Wisconsin Department of Natural Resources (DNR), continue to be dissatisfied with the results.

The problem, as is common with many natural resource issues, involves environmental uncertainty, externalities, and unobservable actions. Traditional economic theory examines each problem in detail, yet does not adequately characterize their simultaneous occurrence. The expected utility hypothesis, for example, determines a Pareto-optimal risk-sharing solution under uncertainty. The Coase theorem suggests that externalities alone do not pose a problem to the efficient management of resources. However, externalities and uncertainty together often results in asymmetric information between economic agents, and thus creates a situation in which, except for special cases, the traditional first-best Pareto-efficient allocation is unattainable. An alternative approach is to consider the WWDP as a principal-agency problem.

The purpose of this paper is to characterize a WWDP compensation schedule which would provide incentives for the farmer (agent) to apply optimal but unobserved levels of abatement effort to control the Canada geese on susceptible fields, thereby reducing damage, while being compensated for abatement and crop losses with surplus benefits from recreational hunters (principal). A standard externality approach does not hold because uncertainty inherent in wildlife management and damage abatement techniques along with unobservable levels of on-farm abatement effort lead to asymmetric information in the compensation scheme. This work finds that the current program deals with the informational asymmetry by placing all risk with the farming community, and further, fails to recognize opportunity costs borne by farmers for their contribution of on-farm abatement effort.

The next section describes the nature of the Horicon problem. The theoretical model is then described; first by developing a symmetric information model for compensation, then by introducing unobservable on-farm effort as an informational asymmetry which motivates the agency approach. Results of the agency model are then summarized and compared with the first-best. The paper concludes by using the results to comment on Wisconsin's current compensation program and to recommend areas for further research.

ECONOMIC CONFLICTS AT HORICON MARSH

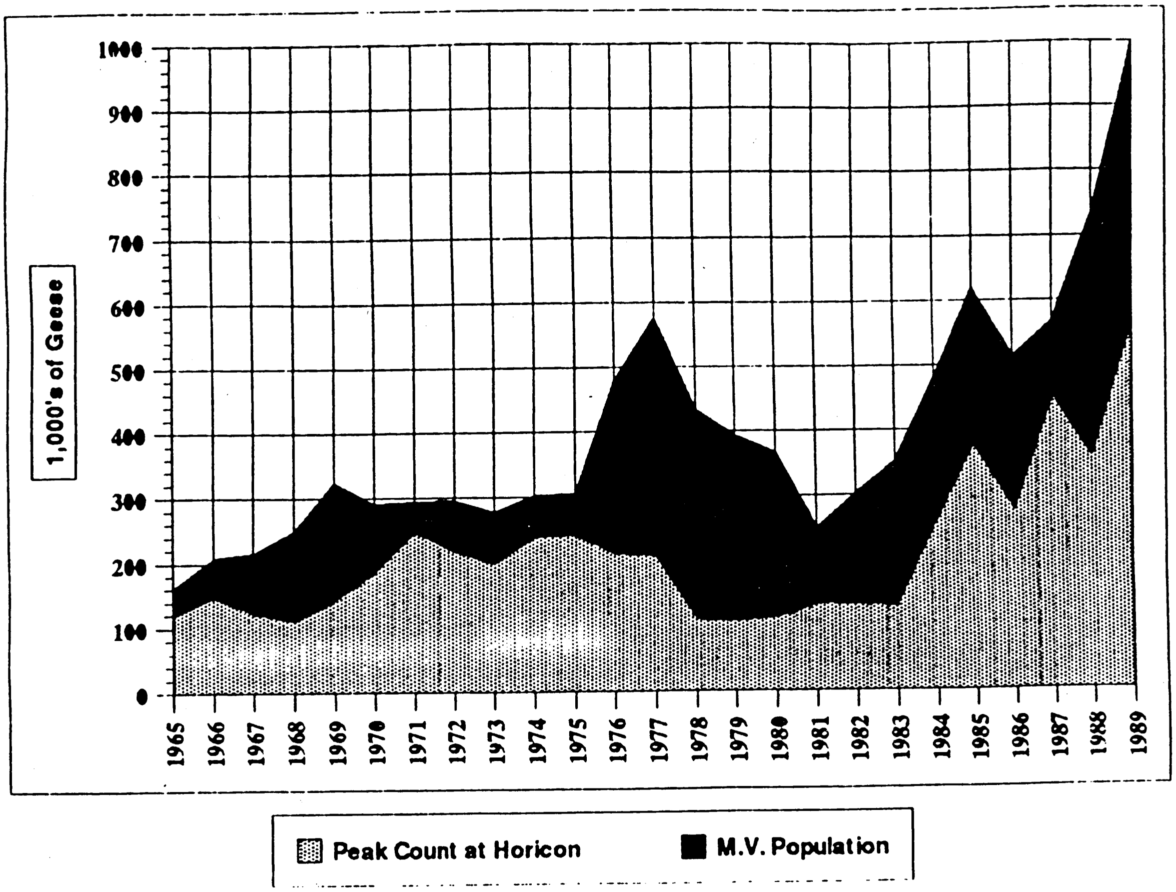
For management and administration purposes, each of North America's several distinct Canada goose populations belongs to one of four migration flyways. The Mississippi flyway encompasses the range of four Canada goose populations migrating from western James Bay, Canada to northern Mississippi. Half-way through their migration, these geese find Horicon Marsh, where a federal wildlife refuge and high quality forage on the surrounding agricultural lands concentrate a large proportion of

Mississippi flyway geese. The number of geese in the flyway, and thus at Horicon, is growing. Horicon Marsh hosted about 400 geese in 1949, over 500,000 in 1990, and the number increases annually. Figure 1 compares numbers of geese on Horicon marsh during the one day each season with the most geese (the "peak count") with numbers of geese in the Mississippi Valley population annually from 1965 to 1989.

Goose population goals and hunting quotas for each of the 14 Mississippi flyway states and provinces are increasing annually, reflecting wildife management objectives of providing greater recreational opportunities throughout the flyway [GAO]. Although no attempt has been made to place a value on recreational benefits of Mississippi flyway Canada geese, evidence indicates these benefits are significant [Bishop and Heberlein; Stier and Bishop; Rollins; Keith; Kuentzel and Heberlein]. Each year, more hunters apply for than receive the limited number of goose hunting permits allowed by the federal quota for Wisconsin. Bishop and Heberlein estimated hunters were willing to pay $21 in 1978 for a permit to shoot one goose in the Horicon zone (24,600 acres surrounding the marsh) during the first two weeks of October.

Annual increases in Wisconsin's Canada goose hunting quotas between 1979 and 1990 are illustrated in figure 2. Canada goose harvests for each of the Mississippi flyway states and provinces are given for 1988 in table 1. Of the 4 Mississippi flyway populations of Canada geese, the Mississippi Valley Population (MVP) makes up more than 90% of the geese using Horicon Marsh. Between 1988 and 1990 the MVP and associated harvest quotas have almost doubled. By 1990, the flyway population was estimated at an all-time high of 1.4 million geese. At the suggestion of Wisconsin wildlife managers, the 1990 Wisconsin hunting quota was increased from 115,200 MVP geese by an additional 80,000 tags -- to be used in the Horicon zone where the birds were causing significant damage.

Figure 1



1,000's of Geese
1000
900
800
700
600
500
400
300
200
100
0
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
Peak Count at Horicon
M.V. Population

Figure 2

Wisconsin Canada Goose Harvest Quotas: 1979-1990

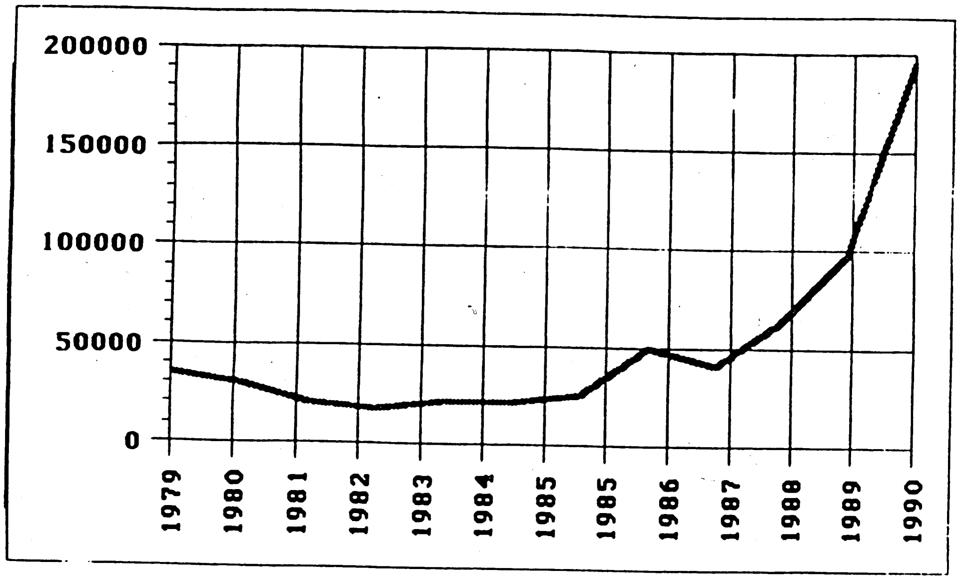


Table 1

Harvests From the 4 Major Canada Goose Populations in States and Provinces of the Mississippi Flyway

State or Province	PERCENT FROM MVP POPULATION	1988 HARVEST Total	1988 HARVEST MVP
Wisconsin	92	66,471	61,153
Illinois	87	64,900	56,463
Michigan	34	69,182	23,522
Ontario	28	68,920	19,298
Kentucky	73	19,242	14,047
Tennessee	50	17,049	8,525
Manitoba	13	60,409	7,853
Indiana	48	13,032	6,255
Minnesota	7	80,792	5,655
Missouri	11	27,142	2,986
Iowa	15	11,032	1,655
Ohio	3	21,929	658
Mississippi	45	992	446
Alabama	7	2,121	148
Arkansas	41	146	60
Louisiana*	--	249	0
Total		531,197	208,724

During spring, geese migrate to northern nesting areas as quickly as possible. During autumn, geese move more leisurely to southern wintering areas; hunting pressure and lack of open water and forage force the birds south. The number of days geese stay at Horicon each fall has been increasing over time, since body heat from their large numbers keeps ice from forming until late in the season; nearby agricultural fields supply forage; and a federally-imposed state goose hunting quota and the sanctuary of the wildlife refuge depress hunting pressure.

These conditions have created a serious damage problem near Horicon, where geese eat crops including seeding alfalfa, winter wheat, and standing corn, and trample almost as much as they consume [Heinrich and Craven]. In 1985, with half as many geese using the marsh as do today, Horicon area farmers reported crop losses of between $990,000 to $1,500,000 from Canada geese. Private and public damage abatement costs estimated for the same year totaled $430,000. Over 77% of reported losses up to that time occured within a 10 mile radius of Horicon marsh, with most of the rest within 25 miles [Craven and Heinrich; Hunt; Rollins]. Craven and Heinrich identified over 5,000 farms potentially affected by goose damage in 1985.

Modern agriculture, by opening previously forested lands and providing forage, has helped to increase the carrying capacity of Canada goose habitat.[1] Wildlife ecologists do not know how many geese the flyway might support, but predict populations could continue to expand considerably [Craven and Heinrich]. Federal wildlife management objectives allow continued expansion of the population to meet recreational demand throughout the flyway [Rusch; GAO]. But because the geese are so highly concentrated near Horicon marsh while they are in Wisconsin, increasing numbers of geese particularly affect Horicon area farmers, who feel they pay too much to feed geese produced to benefit others.

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[1] Corn is supplied for the geese on overwintering refuges created in the southern parts of their range, such as in southern Illinios.

Non-migratory wildlife costs and benefits may be locally controlled by state wildlife management. For example, unacceptable deer damage is controlled through increased deer harvests and permanent fencing which deer only rarely fly over. Migratory species pose different problems. A large proportion of the geese that fly through Wisconsin, must move safely through the state to supply hunters in southern states and for reproduction. Therefore goose hunting in Wisconsin is controlled by federally set annual harvest quotas. As a result, hunting pressure alone is insufficient to control damage from geese feeding on private lands near Horicon marsh.

Horicon area farmers received significant income by leasing out goose hunting rights to their farms until the mid 1960's, when the market for leases was destroyed by a change in hunting regulations requiring (1) all geese shot in Wisconsin be tagged, (2) only hunters who receive permits drawn in an annual lottery receive these tags, and (3) each permitee receive a limited number of tags per season (typically 1 to 3). These rules were imposed to more effectively monitor the goose harvest and to more equitably spread goose hunting benefits over more hunters in Wisconsin and the flyway. The market for private leases virtually vanished once hunters were faced with the uncertainty of getting a permit in a given year, a tag limit, and an ample supply of public hunting grounds on and near Horicon marsh. Horicon area farmers are still able to rent out blinds on a daily basis. However, low rental rates, time and burdens associated with rentals, and lack of weekday demand leave Horicon area farmers with limited benefits from geese and significant costs of feeding them. Thus, institutional changes in hunting regulations intended to increase benefits to hunters also increased the net costs of geese to area farms.

Crop Damage and Abatement

Severity of crop damage is correlated with weather, when geese are most concentrated at Horicon relative to crop cycles, number of geese, farm distance from Horicon marsh, hunting pressure near and on Horicon marsh, and on-farm abatement effort. Weather and timing of peak populations at Horicon are observable stochastic events (bird counts are regularly done for wildlife management purposes). Number of geese, also observable, is a function of federal policy and stochastic environmental processes. Distance from the marsh is not stochastic and is easily observable. Hunting pressure, controlled by regulation, discussed below, is observable as the numbers of goose hunting tags and permits the DNR issues hunters by geographic zone and time period. Finally, on-farm abatement effort, described below, is unobservable to the DNR.

Hunting Pressure

Within limits set by federal harvest quotas for Wisconsin, the DNR regulates hunting pressure to create a pressure gradiant, heavier near Horicon, lighter elsewhere in the state, to help disperse geese from Horicon and to decrease the probability of severe crop damage. This is accomplished by regulating the number of tags issued by geographic zone and time within each zone. For example, a hunter who wins a permit for the Horicon zone may receive 3 tags; but must use each tag in a different 2 week time segment or weekday.[3]

Recreationists bear the costs of this sometimes complex regulatory system. For example, the system is often revised annually as the goose population and harvest quotas are changed. Because costs of technical research, policy design, public hearings, and other out-of-pocket costs of regulations are absorbed into the DNR wildlife management budget (largely from hunting license sales), they come at the expense of other wildlife management needs. In addition, a hunter, who has already faced the uncertainty of receiving a permit, and perhaps is unable to hunt in a preferred area, time segment, or day

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[3] During the last several seasons the DNR has received an emergency quota of 4,500 tags to distribute in lots of 20 to Horicon area farmers who, after using all on-farm damage abatement proceedures as recommended by the DNR, have sustained $1,000 worth of damage before the season's close. Farmers may not sell or use the tags themselves, but must distribute them, two at a time, to hunters with valid permits [Nigus, 1990].

of the week, who has taken the time to become aware of annual changes in the system, can easily blame regulation for detracting from the benefits of the hunting experience.[4]

Effectiveness of hunting pressure to control crop damage from geese is subject to uncertainty. Wildlife managers might predict, using past experience and wildlife models, how a given increase in the number of Horicon zone tags issued might be expected to affect the rate at which geese disperse from the area. However, the accuracy of these predictions is subject to uncertainty caused by random environmental events in Wisconsin and elsewhere in the flyway which affect goose behavior. Environmental conditions are unknown prior to the season's start when the DNR implements hunting regulations. Therefore, only expected effects of hunting pressure on goose dispersal and on crop damage can be estimated [Rusch *et al*].

On-farm Abatement

The most effective on-farm abatement is hunting pressure on susceptible fields. Other tactics include using flourescent flags and exploding propane cannons, and patroling of fields by people, dogs, and trucks. All methods are time consuming and carry significant direct and opportunity costs.

As with hunting pressure, the effectiveness of on-farm abatement effort is uncertain, depending upon types of tactics, effort levels applied, numbers of geese, distance from Horicon marsh, and random environmental factors. In a random fashion, abatement tactics which work well in one field may not work well in another or during another time. Random variation is attributable to environmental factors which affect

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[4] One measure suggested by wildlife ecologists as being most effective for controlling crop damage-- restricting all Wisconsin goose hunting to the Horicon zone to force the fastest goose dispersal rate--has not been seriously considered because hunters would pay too high a price.

goose feeding behavior.[5] All else being equal, the probability of successful on-farm damage abatement increases with effort.

To summarize, note that crop damage varies with three types of variables: (1) Stochastic variables mutually observable by the DNR and farmers *ex post*, i.e. after regulatory and abatement decisions are made. These variables include weather, when geese are most concentrated at Horicon marsh, how long they stay, and the number of geese in the flyway. Their values are influenced by federal policy, hunting pressure regulations, and random environmental effects. (2) Non-stochastic variables mutually observable *ex ante*, such as field distance from the marsh and crop variety. (3) Finally, on-farm abatement effort applied by farmers which is unobservable by the DNR. Further, it is not possible to use other variables observed *ex post* to deduce effort levels due to stochastic components. That is, severe damage might be due to low levels of abatement effort or bad luck.

Compensation: The Wisconsin Wildlife Damage Program

The DNR administers the WWDP, funded with about $1 million annually by hunters from a $1 surcharge on all sport-hunting licenses sold in the state. Participating farmers receive abatement assistance, and when possible, partial compensation for damages not prevented by recommended abatement practices. The current program relieves costs of damage statewide caused by deer, bear and geese by helping landowners purchase abatement equipment, providing technical assistance, assessing crop losses, and processing damage claims. Funds remaining after meeting administrative and abatement costs are divided among all eligible damage claimants in proportion to their approved

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[5] For example, the adaptable Canada geese become accustomed to objects in the fields, including booming propane canons. Farmers can slow the process by regularly changing time intervals between explosions and repositioning canons. However, by the end of the season, undaunted geese can be seen grazing adjacent to exploding canons.

claims. There is rarely money enough to fully compensate claims. Program administration costs and damage funds are not separated by deer, bear and geese.

The WWDP assumes farmer abatement effort lowers overall crop damage costs (compensation + abatement) for relevant ranges of recreational benefits and crop prices. Farmers are therefore required to provide abatement effort to be eligible for compensation. Since WWDP damage specialists are unable to work individually with all farmers experiencing problems, a set of overall guidelines has been prepared listing minimum on-farm abatement activities all farmers must perform to be eligible for compensation. Farmers must enroll before the season starts and formally agree, by signed legal afidavit, to provide the recommended abatement effort.[6]

But since the DNR cannot observe on-farm abatement effort, farmers who anticipate compensation face moral hazard -- to agree to a given level of abatement effort *ex ante*, then claim compensation when they have not in fact applied the agreed upon effort. Moreover, as the season progresses and random events are realized, farmers may find that abatement effort levels recommended *ex ante* are above or below what they feel is appropriate. It is almost impossible for the DNR to determine how much effort was applied, how much damage was prevented by diligent abatement effort, and how much damage would have occurred regardless of the level of effort applied.

While discontent with the increasing goose population at Horicon marsh has been festering for over 30 years, the WWDP seems to have created more problems. It has been difficult defining what acceptable levels of abatement effort should be, at what rates

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[6] Specific steps for reporting damage, fileing and assessing claims are as follows. Within 72 hours of the first signs of depredations for which claims <u>might</u> be filed, the farmer must notify WWDP technicians; failure to do so makes the farmer ineligible to file any claim. If possible, a technician inspects the field, may recommend further specialized abatement activities, and may, if the problem is totally out of control, help supply some labor for abatement effort.[6] Many times the geese are gone and the damage done when the technician arrives, and the damage is assessed. A separate assessment is made for each occurance. Assessment is based on a standard formula to estimate expected crop yield based on the condition of the crop after the geese have left (random samples are taken on a grid over the field).

farmers should be compensated, and how much damage hunters should bear responsibility for. The DNR and hunting groups claim that some farmers abuse the program by not applying recommended abatement effort and claiming losses from geese which may have been prevented. Hunting groups oppose any increase in the damage surcharge they pay on their hunting licenses unless they can see for certain that farmers are doing their part. Hunting groups insist that farmers who charge hunters fees should not receive compensation for damages because hunting pressure is an abatement service, and to receive compensation would be "double-dipping" (therefore the WWDP requires that any hunting revenues be deducted from damage claims). Farmers insist they bear an unfair share of the burden of feeding geese, oppose any increases in the Canada goose population, and oppose, on principal, signing afidavits.

What are optimal levels of on-farm abatement effort, compensation for abatement and crop damage, and expected utility for hunters and farmers? How would such an allocation be achieved? A solution that would maximize the sum of net agricultural returns and recreational benefits is demonstrated below first under symmetric information, where one might imagine a wildlife damage policy which would set optimal hunting regulations, and offer farmers abatement and crop compensation for the optimal abatement effort and damage levels. This is the standard externality approach, and indeed is very much like what the WWDP attempts to accomplish. However, unobservable on-farm effort and environmental uncertainty together lead to informational asymmetry which precludes a traditional first-best solution. A principal-agent approach more closely models the Horicon problem and offers suggestions for improvement.

THEORETICAL MODEL

Given perfect information and zero transactions costs, hunters throughout the flyway and Horicon area farmers would be able to develop a Coasian contract leading to a

Pareto optimal allocation of recreational goose benefits and agricultural production. But in the face of significant transactions costs, real world society might instead determine that a third party, possessing special knowledge and organized to reduce transactions costs, should manage wildlife for the benefit of the various interest groups. The responsibility of this third party, the DNR, is to design a socially optimal rule for allocating resource benefits and costs between hunters and farmers. For simplicity we assume there is only one farmer.

An index of on-farm abatement effort per acre, a, is defined as an increasing concave function of several inputs such as farmer time, goose blind rentals, abatement equipment units, and modified agricultural practices. a is divided into n discrete effort categories, each including input combinations defined to be similarly effective in preventing goose damage:

$$a = [\, a_1, \ldots, a_n \,]. \quad [1]$$

Categories are indexed such that a increases with effort; a_1 is lowest effort and a_n is highest effort. a is bounded from above and below, beyond which points additional abatement inputs are technically ineffective. The farmer's cost of abatement effort, c, is assumed to be increasing with a, $c_a > 0$:

$$c = c(a). \quad [2]$$

The DNR selects from a set of hunting regulations, represented by the index q, to manipulate hunting pressure throughout the state. q is ordered such that increasing q corresponds with more aggressive goose dispersal from Horicon Marsh:

$$q = [q_1, \ldots q_t]. \quad [3]$$

The cost of q, in terms of recreational benefits foregone, increases with q. q is bounded by end points q_1 and q_t, beyond which the DNR is unable to further influence geese at Horicon for a given federal state harvest quota and total goose population.

Goose-use, g , is a seasonal index composed of the estimated number of geese at Horicon, arrival date, and length of stay. g is an *ex post* observable random variable that is decreasing in q and varies with environmental factors, denoted θ.

$$g = g(q, \theta). \tag{4}$$

Assume θ is randomly distributed according to $f_\theta(\theta)$. Because g measures intensity with which Canada geese use the entire Horicon area, it is correlated with crop damage on each farm. Crop damage on each farm decreases in a, but a does not influence goose-use of the Horicon marsh.

The proportion of crop yields undamaged by Canada geese, m, is also an *ex post* observable random variable described by:

$$m = m\,(g, a), \qquad \text{where } 0 \leq m \leq 1 \tag{5}$$

m is decreasing in goose-use and increasing in abatement effort: $m_g < 0$, $\partial m_a > 0$, and $m_{aa} < 0$. Since g is random, so is m, with a probability distribution derived from $f_\theta(\theta)$. The farmer and DNR have identical beliefs about distributions of g, m, and their joint distribution, conditional on a and q.

Recreational benefits from geese using Horicon marsh accrue according to benefit function β and are implicitly set when flyway and state policy decisions are made with regard to the target flyway population size and state goose harvest quotas which are components of g:

$$\beta = \beta(q, g(q, \theta)) \tag{6}$$

Recreational benefits increase with goose use at Horicon, so that $\beta_g > 0$ and $\beta_{gg} < 0$ and decrease with increasing costs of regulation, so that $\beta_q < 0$ and $\beta_{qq} < 0$.[7] q influences benefits directly through costs of hunting regulations and indirectly through g.

The farmer without compensation seeks to maximize expected utility, which is increasing with net farm revenues, mrY, and decreasing with costs of abatement effort, $c(a)$:

$$\max E[\text{utility}] = \max E\,[v\,(rYm\,(g,a)) - c(a)] \qquad [7]$$

Y is potential crop yield per acre with a market-derived net value r. mrY is, by definition, net of all costs except abatement costs. The farmer is assumed risk-averse with a twice differentiable expected utility function, v, additively seperable in net farm revenues and abatement costs.[8] The farmer will apply a until the marginal value of a equals marginal cost: $c_a = rYm_a$.

First Best Model: Risk-sharing and Symmetric Information

The first-best risk-sharing case is defined such that on-farm abatement effort is costless and either directly or indirectly observable by the DNR.[9] The DNR's problem is to optimally spread risk and find first-best (fb) a^{fb} and q^{fb} which would maximize the sum of expected net benefits to farmers and recreationists while internalizing costs of feeding geese. The costs transferred form hunters to the farmer is $pY(1-m)$, where p is

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[7] Recreational benefits foregone from increased q are assumed greater than benefits created elsewhere by geese dispersed from Horicon marsh. External costs to private lands elsewhere of geese dispersed from Horicon is assumed to be insignificant. Stier, Heinrich and Craven show that most landowners receive aesthetic benefits from geese and are willing to tolerate some losses. q is assumed to disperse geese so that their densities remain within tolerable levels beyond the Horicon area.

[8] Separability, used to simplify the problem, is equivalent to stating there are no income effects; $c(a)$ does not vary with income.

[9] *Ex post* observation of both damages and random events allows inference of abatement effort so compensation can be based on enforcable contingent contracting.

compensation per damaged unit, $Y(1-m)$. Markets for agricultural products are assumed unaffected by Horicon area crop losses. As with the farmer, hunters are assumed to be risk averse with a von Neumann-Morgenstern utility function denoted by u. The maximization problem for the DNR is:

$$\max_{a,\,q} E\left\{ u\left[\beta(q,g) - p[Y(1-m)]\right] + v\left[Y[rm + p(1-m)]\right] - c(a)\right\} \tag{8}$$

which yields the following first order conditions:

$$c_a(a) = \left[r - p(1 - u'/v')\right] YE[m_a] \tag{9}$$

$$- u' E[(\beta_q + Ypm_q)] = v' Y(r - p)E[m_q] \tag{10}$$

Condition [9] indicates the farmer exerts a until the marginal cost of abatement effort equals the expected change in the marginal value of net farm revenues weighted by the ratio of marginal utilities. Condition [10] implies the DNR uses q to disperse geese from Horicon until the expected marginal change in recreational benefits to hunters is equated with the expected marginal change in revenues to farmers. Both conditions together, [11], indicate a^{fb} and q^{fb} are achieved where the ratios of marginal productivities of a and q and their relative costs are equated:

$$- \frac{u'}{v'} \frac{\beta_q}{c_a} = \frac{m_q}{m_a} \tag{11}$$

Given symmetric information, efficient levels for regulation and abatement effort are q^{fb} and a^{fb}. There remain two issues. First, at what level will farmers be compensated? Second, what rules will govern the transaction? Recall that the simplified first-best case assumes a is costlessly observable so that random states of nature can be determined precisely. Optimal a^{fb} and q^{fb} depends in part on p, given *ex ante*, and v' / u'. Compensation level p is a value judgement reflecting the policy choice of which proportions of the costs of feeding geese are to be paid by hunters and farmers.[10] The role of compensation in under symmetric information is purely distributional. Since the contract --the farmer's promise to exert a^{fb} in return for q^{fb} and compensation rate p-- is enforcable, the transfer can simply be made as a lump sum once g and m are mutually observed (so long as transactions costs are zero or are optimally shared).

The Principal-Agent Model

In reality, the DNR cannot observe abatement effort.[11] As the problem is thus far defined, the DNR could still infer a *ex post* after observing undamaged crop yields m, goose-use g, and environmental events θ; thus an enforcable first-best risk-sharing contract could still be devised. However, if abatement effort is not inferrable from information available *ex post* to the DNR because a second source of uncertainty prevents infering whether a particular outcome, m, is due to abatement effort or bad luck, then a contract for compensation based on the above approach will be subject to moral hazard.

Suppose for given q and a, severity of crop damage is subject to further uncertainty due to unpredictable results of abatement effort, represented by the random variable ε. Assume both the farmer and wildlife managers have identical beliefs about ε's distribution, denoted $f_\varepsilon(\varepsilon)$. The proportion of undamaged crops (marketable farm yields) is now expressed as:

$$m = m(a, g(q,\theta),\varepsilon) \qquad [12]$$

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[10] a^{fb} can increase or decrease in p depending on r, attitudes toward risk and rates of change of $c(a)$ and $m(a)$. Using [8] and m_a, c_{aa}, >0, $m_{aa} <0$, then it can be shown that: If $u' > v'$, or if $(u'- v') > Y(1-m) [pu'' + v'' (r-p)]$, then a^{fb} is increasing in p. If $u' = v'$ then a^{fb} is not affected by p. Otherwise a^{fb} is decreasing in p. From [10], the relationship also depends on $E(m_{qa})$.

[11] Although the recreational community is the principal, the model developed here frequently refers to the DNR's authority to set policy.

The properties of m are as defined as in [5], but with the addition of ε. Both g and m are assumed to be costlessly observable to the DNR and farmer. However, ε is never directly observed. Because the DNR cannot observe a, ε is not inferrable from *ex post* observation of g and m. Thus, the DNR has limited information about the farmer's actions. But because random variables g and m are correlated with unobservable effort and environmental events they can provide some information, albeit imperfect, on abatement effort.

A principal-agent approach is used to develop a compensation schedule which would efficiently use whatever imperfect information is available to the DNR, since it cannot observe or infer farmer effort. The model developed here uses the Mirrlees-Holmström first-order approach to the principal-agent problem to derive criteria for a compensation schedule that would promote an efficient trade-off between first-best risk-sharing and abatement incentives. To focus on the farmer's incentives under a compensation program where on-farm abatement effort is not observable, the model is simplified by holding hunting regulations, q, constant:

$$q = q^o \qquad [13]$$

This is not an unreasonable assumption, for the model as it is presented here covers a short-term period, one season. Between seasons, q is not appreciably changed due to high transactions costs. We will return to policy options afforded by q.

The principal-agent approach differs from the first-best in that the compensation payment is a function of random variables g and m and serves as both compensation and incentive. The goal is to determine that compensation schedule which most efficiently uses information from g,m to provide the farmer with an incentive to choose an optimal abatement effort level: i.e. structuring $p(g,m)$ so that the farmer receives the full marginal return of abatement effort.

Distributions of g, m, conditional on a and q^o, and their joint distribution are written:

$$\varnothing_g = \varnothing_g\,(g\,;\,q^o)\text{, derived from } g = g\,(q^o,\,\theta) \text{ and } f_\theta(\theta)$$

$$\varnothing_m = \varnothing_m\,(m\,;\,a,q^o)\text{, derived from } m = m\,(g(q^o,\,\theta),\,a,\,\varepsilon) \text{ and } f_\varepsilon(\varepsilon)$$

$$\emptyset = \emptyset\,(g,m\,;\,q^o,\,a)\text{, derived from } \varnothing_m \text{ and } \varnothing_g$$

It has been established that $m_a \geq 0$, implying that $\Phi_{ma}(m;\,g,\,a) \leq 0$, where $\Phi_m(m;\,g,\,a) = \int \varnothing_m\,dm$, and Φ_{ma} is the derivative of Φ_m with respect to a. Further assume: (1) for each a, the above inequalities are strict for at least some values of m; (2) upper and lower bounds of $\varnothing_m$ are identical for all a, that is $\varnothing_m(m;\,a,q^o) \equiv 0$ for $m \notin [m_0,\,m_1]$ and $\varnothing_m(m;\,a,q^o) > 0$ for $m \in (m_0,\,m_1)$, $\forall\, a$;[12] (3) changing a shifts the probability density of m in a first-order stochastic dominance, that is $\Phi_m\,(m;\,g,\,a_1) \leq \Phi_m\,(m;\,g,\,a_2)$ when $a_2 > a_1$, $\forall\, g,\,m$. Finally, (4) the distributions satisfy the Monotone Likelihood Ratio Property (MLRP) and the Concavity of the Distribution Function Condition (CDFC) so the farmer's first-order condition, below, can be a valid incentive constraint to the DNR's joint benefit maximization problem.[13]

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[12] Assumption 2 means there exists a worst-case scenario of random events at Horicon where no amount of abatement effort will alter the inevitable outcome m_0. Similarly, m_1 is defined as the best-case outcome of minimal or no damage regardless of the level of a.

[13] Rogerson shows MLRP, which implies first-order stochastic dominance, and CDFC, a type of diminishing stochastic returns to scale, guarantee existence of a solution. MLRP holds Φ_a/Φ and $\emptyset_a/\emptyset$ to be monotonically increasing in m, guarding against all but unimodal distributions. Distributions exhibiting MLRP include the normal, poisson, uniform, and exponential distributions. CDFC defines $\Phi(g,m;\,a)$ to be concave, so the increased probability of observing a given g,m pair from an additional unit of abatement effort is increasing at a

decreasing rate: for $\Phi\,(g,\,m;\,a) = \int_{g_0}^{g} \int_{m_0}^{m} \emptyset\,(g,\,m;\,a)\,dm\,dg$

$$\Phi(g,m;\,\lambda\,a + (1-\lambda\,a)\,a') \leq \lambda\,\Phi(g,m;\,a) + (1-\lambda)\,\Phi(g,m;\,a')\ ,\ \forall\, a,\,a'\,;\ 0 \leq \lambda \leq 1$$

Under these assumptions, higher undamaged farm yields observed near Horicon allows statistical inference that the farmer supplied more effort, a. $\o_m$, $\o_{mm}$ are well defined as shown in Figure 3. Increasing abatement effort shifts $\o_m(m; g, a)$ to the right, increasing the probability of observing higher yields and decreasing the probability of observing lower yields.

The Farmer's Problem. - - Farmer expected utility is a function of net farm revenues, abatement effort and crop loss compensation, less abatement effort costs. The compensation rate is a function of values for g and m observed *ex post*:

$$p = p(g,m) \qquad [14]$$

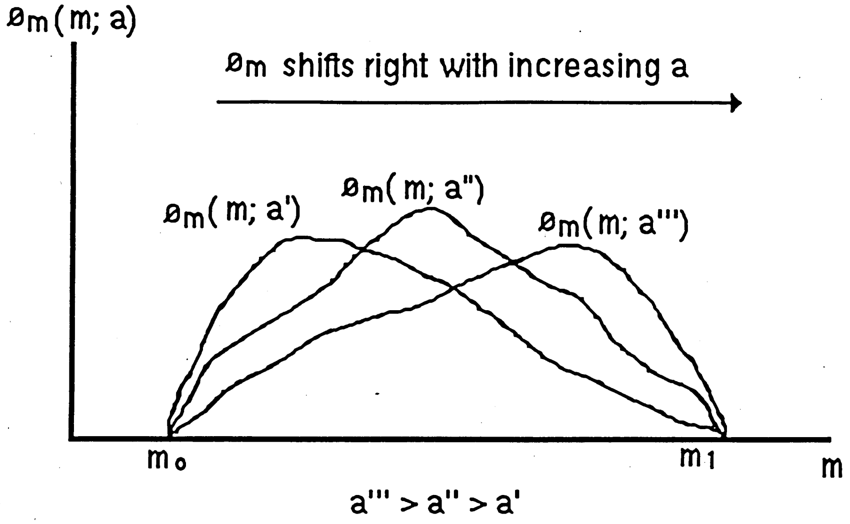
Random g and m are treated as state variables, invariant to q and a; probability distributions for g and m are conditional on DNR and farmer choices for a and q.

The DNR seeks to structure $p(g,m)$ so to maximize the sum of net social benefits. This could be done by presenting to the farmer $p(g,m)$ as a set of tables with values for g and m in columns and rows with compensation rates given for ranges of g,m pairs. There might be separate sets of tables by crop variety and weights applicable according to distance to Horicon marsh. The farmer takes the form of $p(g,m)$ as fixed, $\hat{p}$,and chooses a to maximize expected utility with respect to the joint distribution over m and g. In the farmer's optimization problem the compensation schedule is fixed at $\hat{p}$, in contrast to the principal-agent problem, where the optimal payment rule $p(g,m)$ is to be established. Thus, $(1-m)Y\,\hat{p}(g,m)$ is reimbursement for crop damages, rYm is net returns from marketable farm yields, and $c(a)$ is disutility from abatement effort, where $c_a > 0$. The farmer's optimization problem is thus:

$$\max_a \left(\int_{g_0}^{g_1}\int_{m_0}^{m_1} v\left[(1-m)Y\,\hat{p}\,(g,m) + m\,rY\right]\o\,(g,m;a,q)\,dm\,dg \;-c\,(a)\right) \qquad [15]$$

Figure 3

First-Order Stochastic Dominance



Increasing abatement effort shifts ø$_m$(m; g, a) to the right, increasing
the probability of observing higher yields and decreasing the probabilities of observing lower yields.

Yielding:

$$\int_{g_0}^{g_1}\int_{m_0}^{m_1} v\left[(1-m)Y\,\hat{p}\,(g,m) + m\,rY\right]\emptyset_a(g,m;a,q)\;dm\,dg \;=\; c_a(a) \qquad [16]$$

The farmer expends effort until the expected marginal value of effort, in terms of expected incremental changes in utility from crop revenues and compensation collected, is equal to the marginal disutility of providing that effort, as in the first-best equation [9]. However, unlike the first-best, instead of a choice variable it is more appropriate to speak of a choice distribution; the farmer effectively chooses from among a family of joint probability distributions for g and m which are conditional on the choice of a. As a increases, probabilities of observing a given m stochastically dominate distributions from lower a, thereby increasing the probabilities of observing a given m and of achieving a higher compensation rate.

The Joint Problem: Optimal Incentives. -- The DNR seeks to determine a^*, given that the farmer receives compensation for effort and crop losses. The problem is written:

$$\underset{p(g,m),\,a}{\text{Max}}\;\int_{g_0}^{g_1}\int_{m_0}^{m_1} u\left[\beta(g) - (1-m)Yp(g,m)\right]\,\emptyset\,(g,m;a,q)\;dm\,dg \qquad [17]$$

Subject to:

$$\int_{g_0}^{g_1}\int_{m_0}^{m_1} v\left[(1-m)Yp\,(g,m) + m\,rY\right]\emptyset\,(g,m;a,q)\;dm\,dg\; - c\,(a) \geq R^o \qquad [18]$$

$$\int_{g_0}^{g_1}\int_{m_0}^{m_1} v\left[(1-m)\;Y\;p\,(g,m) + m\,rY\right]\emptyset_a(g,m;a,q)\;dm\,dg \;=\; c_a(a) \qquad [19]$$

The above program maximizes the recreational benefits of goose-use at Horicon, net a payment to the farmer for feed consumed by the geese and the on-farm abatement effort according to the compensation schedule $p(g,m)$. The farmer's first-order condition is used as an incentive constraint, equation [19], for the farmer to supply a^*. The reservation constraint R^o, equation [18], an exogenous policy decision, explicitly determines the distribution between the farmer and DNR of the costs and benefits of feeding geese farm crops at Horicon (a role played by given p in the first-best case above). If, for example, it is assumed that $R^o = Yr$, then farmers engaging in goose benefit production will be no less well-off than if geese were not at Horicon and the farmer received the market value for full undamaged yields.

Note that a does not appear in the joint production function; a is not observable, and therefore not directly contracted for. Rather $p(g,m)$ covers both crop losses and abatement effort, the level of each selected by the farmer. Incorporating the farmer's first order condition and reservation constraint, both of which do contain a as the farmer's choice variable, into the problem ensures the compensation schedule coordinates incentives so that the optimal a chosen by the farmer to optimize farm revenues also optimizes net recreational benefits. The result is the DNR does not need to observe on-farm abatement because it is determined through $p(g,m)$.

The lagrangian L is formed by associating multipliers λ and μ with the first and second constraints respectively. Differentiating L with respect to p and a yields:

$$\frac{\partial L}{\partial p} = 0 = -\, u'\,(1-m)Y\,\emptyset + \lambda\, v'(1-m)Y\,\emptyset + \mu\, v'(1-m)Y\,\emptyset_a$$

$$\frac{\partial L}{\partial a} = 0 = \int_{g_0}^{g_1}\int_{m_0}^{m_1} u\,[\,\bullet\,]\emptyset_a\, dg\, dm + \lambda\left(\int_{g_0}^{g_1}\int_{m_0}^{m_1} v\,[\,\bullet\,]\emptyset_a\, dg\, dm - c_a\right)$$
$$+\, \mu\left(\int_{g_0}^{g_1}\int_{m_0}^{m_1} v\,[\,\bullet\,]\emptyset_{aa}\, dg\, dm - c_{aa}\right)$$

Noting that the middle term in the second expression is simply the farmer's first order condition, and is equal to 0, the above first-order conditions can be rewritten:

$$\lambda + \frac{\mu\, \emptyset_a}{\emptyset} = u'/_{v'} \qquad [20]$$

$$\int_{g_0}^{g_1} \int_{m_0}^{m_1} u\, \emptyset_a + \mu\,[v\, \emptyset_{aa} - c_{aa}]\ dm\, dg = 0 \qquad [21]$$

Substituting expected value operators for integral notation helps to simplify expression [21] for clearer interpretation, where 'E' is the expected value operator and $V = v[\bullet] - c$, the farmer's utility [as suggested by Rees]:

$$E\,[u\, \emptyset_a] = -\mu\, E\left[d^2V/_{da^2}\right] \qquad [21\text{-}a]$$

This general form permits no analytical solution, but qualitative insights from this case apply to all examples derived from it. From [21], the optimal compensation schedule, $p^*(g,m)$, equates expected marginal changes in recreational benefits, $E[u\, \emptyset_a]$, with marginal changes in incentives, $E[d^2V/da^2]$, necessary for the farmer to choose a^*, weighted by the shadow value of the incentive constraint, $-\mu$. With the optimal compensation schedule, the optimal abatement effort, a^*, is determined by the incentive constraint [19]; that is, the farmer receives the full marginal value of her effort.

Inspection of [20] indicates that $p^*(g,m)$ depends upon attitudes toward risk, reflected in u'/v', and upon how $\emptyset_a/\emptyset$ varies with g and m. If $\log \emptyset(g,m,a)$ is thought of as the likelihood function for a model with a as the unknown parameter to be estimated and g,m as endogenous variables, then for a given (g,m,a^o) the larger the likelihood function, the more likely the observed values of g and m indicate that the true value of a is indeed a^o.[14] In this way g and m are imperfect monitors of the farmer's effort level. The

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[14] However intuitive this interpretation $\emptyset_a/\emptyset$, as Hart and Holmström [1986] point out, the DNR does not actually statistically infer anything about the farmer's efforts. As the problem is presented, the DNR knows what effort the farmer will provide. Making compensation a function of $\emptyset_a/\emptyset$ guarantees incentives consistent with that level of effort. Rather, analysis of statistical inference properties of the first order condition helps to clarify why and how the incentive constraint must deviate from the otherwise Pareto-optimal risk-sharing solution without asymmetric information.

less information g and m are able to provide on a, the smaller will be the change in the likelihood function with respect to a, $\emptyset_a/\emptyset$. Therefore, larger $\emptyset_a/\emptyset$ indicates that g and m are more informative on a and the contract is capable of inducing greater levels of effort. Conversely, an very low $\emptyset_a/\emptyset$ might suggest available information is insufficient to induce enough effort to make the cost of contracting worthwhile.

Note that the solution can be a first-best pareto optimum if and only if the incentive constraint is not binding, $\mu = 0$. However, Holmström shows that so long as $c_a > 0$, and $\emptyset_a/\emptyset$ is increasing in m, guaranteed by MLRP and CDFC, then the incentive constraint will be binding, $\mu > 0$. Since $\emptyset_a/\emptyset$ is not constant and the incentive constraint is binding the agency solution is strictly Pareto inferior to the symmetric information first-best solution-- a reflection of contracting costs under asymmetric information.

Consider a direct comparison of p^* with p^{fb} using Holmström's results. Define the first-best contract p^{fb} to be that contract which would result if information was symmetric (so that a is either observable or inferable after the fact). In this case the second term on the left hand side of [20] would be absent in the first-order condition under symmetric information; instead, the ratio of marginal utilities would simply be equated with the constant λ (the shadow value of relaxing the farmer's reservation utility level). Thus we see that when moral hazard is not a problem, the first-order condition would simply be a rearrangement of the standard result that maximizes expected utility; the marginal expected utility of wealth, whether it be in terms of recreational benefits or agricultural revenues, should be equated across all states of nature.

As noted above, under symmetric information compensation has a distributive role with an arbitrary value determined by policy (via the reservation constraint), but because we use it to refer to the symmetric information solution, denote it as p^{fb}. Taking λ as a fixed weight reflecting given R^o, we can assign λ the value it would have under symmetric information with a given p^{fb}. The first-best risk-sharing solution would require that the left-hand side of [20] be constant, dependent only on relative attitudes toward risk:

$$\lambda = \frac{u'^{\,fb}\left[\beta(g) - (1 - m)\, Y p^{fb}\,(g,m)\right]}{v'^{\,fb}\left[(1 - m)\, Y\, p^{fb}\,(g,m) + m\, rY\right]} \qquad [22]$$

Substituting from [22] into [20] for fixed λ gives:

$$\frac{u'^{\,fb}}{v'^{\,fb}} + \mu\,\frac{\varnothing_a}{\varnothing} = \frac{u'^{\,*}}{v'^{\,*}} \qquad [23]$$

Using the fact that u'^*/v'^* is increasing in p^* (and $u'^{\,fb}/v'^{\,fb}$ is increasing in p^{fb}), p^* can be characterized in relation to p^{fb} over the joint probability of observable (g,m) pairs. Optimal compensation under asymmetric information is greater, equal or less than optimal compensation with symmetric information according to:

$$p^*\,(g,m) \overset{\geq}{<} p^{fb} \text{ when } (g,m) \text{ are such that } \varnothing_a \overset{\geq}{<} 0 \qquad [24]$$

Recalling the discussion of $\varnothing_a/\varnothing$ above, the higher this ratio, the more likely the distribution is based on the farmer's application of effort a^*. This is the basis for the structure of optimal p^*. Compensation will be at a rate greater than that under a first-best situation when $\varnothing_a$ is increasing, or when the probability of observing the realized (g,m) pair is more than likely due to the true distribution being based on a^*. Similarly, where $\varnothing_a$ is decreasing, incentive preserving compensation will be less than that of first-best optimal risk-sharing. The difference between p^{fb} and p^*, attributable to the incentive effect, is proportional to $\varnothing_a/\varnothing$.

Consider the compensation schedule's incentive effects from the farmers viewpoint. Equation [19] implies the farmer should equate marginal expected utility of abatement effort with marginal disutility of that effort. Increasing $p^*(g,m)$ over values of (g, m) where increased effort increases the probability of observing m (i.e., m where $\varnothing_a(g,m) \geq 0$) increases the magnitude of the marginal expected utility of that effort. Since increasing abatement effort shifts the cumulative density of m to the right, values of m for which $\varnothing_a(g,m) \geq 0$ will tend to be "high".[15] Similarly, by decreasing the farmer's share of benefits relative to her share under p^{fb} at points where more effort decreases the probability of "low" m, the contract $p^*(g,m)$ provides an incentive to exert effort to avoid such outcomes.

To summarize, the contract p^* uses deviations from optimal risk-sharing to induce more effort at outcomes (g,m) for which the absolute value of $\varnothing_a$ is large. That is, the failure of the contract p^* to equate the marginal utility of the farmer across all states is more severe the more greater the probability of such an outcome. The deviation between the symmetric and asymmetric information cases results from the added incentive-preserving role of p^*. Thus compensation has two roles: (1) both p^{fb} and p^* redistribute costs and benefits of feeding geese and (2) p^* additionally provides optimal abatement incentives, given g and m, since the farmer is most likely to receive the full value of marginal return on effort from p^* when a^* is exerted. That is p^* is structured so that the rational farmer chooses abatement level a^*.

One aspect of this idealized system may seem counterintuitive. All other things being equal on two farms with the exception of final crop yield, m, the farm with the larger yield could receive greater compensation. At first, this seems backwards, since

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[15] Intuitively, a high value for m should dictate a higher p^* because it indicates a higher probability that the farmer expended more abatement effort. However, as explained in footnote 13, that is not the underlying rationale for choosing $p^*(g,m)$.

larger crop yields may mean less goose damage. However, higher yields, all else equal, may signal more effective abatement, which would deserve a positive reward.

Information Costs. -- Any random variable correlated with unobservable effort or states of nature is a valid monitor of unobservable effort. The value of monitors g and m in determining $p^*(g,m)$ comes from their informational content alone (the value of g and m is represented elsewhere in the utility functions). Holmström and Shavell show that so long as the existing monitors do not meet the requirements of being a sufficient statistic, a contract based on any new and costless information is unambiguously superior. When monitors are not costless, agency costs, defined as $(v-c+u)^{fb} - (v-c+u)^*$, are reduced by finding monitors which add more information and/or cost less.[16] In general, monitors are more valuable the more variation they introduce into the ratio $\varnothing_a/\varnothing$. Thus a contract based on additional, but costly, information may not be better, and may be inferior to a contract with less information due to the cost of acquiring that information. In the case of costly information, the contract must also incorporate how the costs of monitoring are to be shared.

IMPLICATIONS

Using an agency approach to analyze the current WWDP leads to several implications for abatement levels, program funding, risk-sharing, who pays for compensation, who may receive compensation, and how much compensation is paid. The schedule might appear to the farmer as a set of tables, where compensaton rates are given for various ranges of observed values of g, m and any other variables correlated with damage. Farmers would need to document their final crop yeilds, either as is done now through DNR assessments or by sales receipts. Farmers would take it upon themselves to

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[16] The welfare costs of not observing a can also be shown to increase with the farmer's risk aversion and with the variances of θ and ε.

make their own abatement decisions, based on the schedule. Invariably, compensation payments and actual damages would not match for each season, but over time, would average out. It is unlikely that R^o would be set to reflect full compensation, but a value for R^o would need to be chosen that would explicitly reflect how much responsibility farmers and hunters must accept for crop damage from geese.

Under an agency type program, instead of a minimum level of abatement effort set *ex ante* by the DNR with the farmer's "promise" to exert this effort being a requirement for compensation, the farmer chooses an effort level in response to incentives. Any farmer is eligible for the hypothetical program, however the compensation rate will vary across farmers depending on undamaged yields and other observable variables built into the contract, such as distance from the marsh and crop type.

The current WWDP does not compensate the farmer for abatement effort. After administrative and abatement assistance costs (for purchasing abatement equipment and technical advice) are covered, remaining funds are split in proportion to claims among all eligible claimants statewide for deer, bear and geese damages. Therefore in years when damages from any of the three covered game species are especially severe due to unfavorable random events, there is less funding available for compensation. In contrast, under the agency approach compensation and abatement payments are co-determined. Furthermore, in years when goose damage in the Horicon area is high, say because of weather conditions that lead to a late harvest or because the goose flock is unusually large, the overall level of payments will be larger than when goose damage is low. The model above does not include administrative costs, but they could be included and shared between hunters and farmers.

A $1 surcharge on all Wisconsin hunting licenses funds the existing WWDP for all damage statewide by deer, bear and geese. However, the agency approach depends on the degree of correlation between random variables which serve as monitors and unobserved effort. Additional random events elsewhere in the state and over the entire year which are tied to recreational benefits, regulation, abatement, and damages associated with other game species would likely introduce so much random noise to make the agency approach intractible. Agency results indicate no reason for combining the goose damage with the rest of the program. The damage surcharge for geese could be collected separately from the surcharge for damage by other species, perhaps when hunters receive their goose permits. In this way funding available for compensation would be more directly correlated with benefits, costs, and risks from geese using Horicon marsh.

Risk under the current WWDP would not seem to be optimally shared between hunters and farmers. Hunters pay a fixed amount each year (and face risks associated with q of being unable to hunt in the zone and on the dates of their choice), while farmers bear the burden of random outcomes. In an agency context, it would appear as though either farmers are risk neutral while hunters are risk averse, or that information costs to build in risk-sharing are prohibitive. The first alternative seems unlikely. The second may be the case so long as damage compensation for geese is combined with that for deer and bear.

Note the potential difficulty of collecting compensation from hunters after the season closes, especially in contrast to the low marginal cost of collecting a surcharge with the purchase of hunting licenses before the season opens. This might be handled by setting up the program with a one-time endowment. Then damage surcharges could be added to the price of hunting licenses of the following year, or charged when hunters obtain the goose permits (which are now absolutely free). Annual variation in damages would imply variation in the magnitude of damage surcharges on hunting licenses, however this would be smoothed somewhat by the large number of hunters relative to farmers. Variation in license surcharge costs could be smoothed further by using part of the endowment as a buffer.

The current WWPD has a deductible, which can be shown to exist in an optimal agency compensation schedule as well. However, the WWDP also has a maximum ceiling of $10,000 per farmer per season. The per farmer rule holds regardless of how much crop land the farmer owns or how many claims the farmer has filed (each damage occurance is handled in a separate claim). The DNR justifies this because the current program fund is limited by the set $1 hunter surcharge. In years where there is heavy damage, the current fund does not increase, so the rule limits the amount of compensation any one farmer may receive on equity grounds. There would be little justification for such a rule under an agency approach.

SUMMARY AND CONCLUSIONS

Farmer eligibility for current WWDP compensation depends upon strict adherence to abatement effort levels recommended *ex ante*. Since on-farm abatement effort is not observable, a moral hazard problem is encountered. Only farmers who sign a legally binding afidavit promising to exert the recommended effort are eligible to apply for compensation. However, only *ex post*, after abatement effort is applied, is the proportion of losses to be covered by compensation known. The effective compensation level is tied to damages occurring at other times and areas state-wide by other animals, to the absolute number of state hunting license sales (rather than the number of animals taken, for instance), the number of total claims to be processed, and available funds after abatement materials and administrative costs are covered. Furthermore, farmers are not compensated for their abatement effort or for opportunity costs associated with abatement.

The agency approach indicates that Horicon area farmers may have problems with the program at least in part because it fails to address economic concerns involving costs of on-farm abatement effort and the levels of uncertainty and risk they must face. Because the severity of damages depends upon random events out of the farmers' direct control, they may be required to take abatement steps that they believe are useless simply to remain eligible for an uncertain level of compensation. Because the liability of hunters is limited to the fixed hunting license surcharge, farmers bear the full brunt of the these uncertainties. The flaws in the current program not only affect farmers' welfare, but also the welfare of goose hunters and viewers throughout the flyway [Rollins; Keith; Bishop and Heberlein; GAO; Kuentzel and Heberlein]. Wildlife managers and recreational users would like to see the flock expanded further, but are reluctant to permit more rapid growth, largely because of the "farmer problem" at Horicon.

A crop damage abatement and compensation program based on this model would look markedly different than the current program. Farmers and the state would sign contracts for compensation, where the amount would be conditional on the state of the world that ultimately occurs each fall. The conditions, possibly including weather variables, goose numbers at Horicon over the fall and spring months, and final crop yields on the farm to which each contract applies, would be observable by both the DNR and farmers. There is no obvious economic rationale for linking the goose damage program to comparable programs for deer and bear. Compensation would be funded by a damage surcharge on goose hunting permits. The surcharge would vary depending on the amount of goose damage so that uncertainty regarding goose damage would be shared between the state and farmers.

The current study is too abstract to offer ultimate answers to the Horicon problem. Mutually observable monitors to serve as determiners of compensation levels, potential susceptibility to damage of various crops and of farms in various locations relative to the marsh, costs of farmers' on-farm abatement activities, potential costs of compensation for various levels of damage, and other such subjects will need to be addressed through biological and economic research before a fully developed alternative program can be proposed. Other questions, such as the share of total damages to be compensated, will need to be raised in a political context. Repeated [Malueg]and dual agency [Eswaran and

Kotwal] models can shed light on the longer term interaction between DNR dispersal policy, q, on-farm abatement, and recreational benefits.

The present study does provide principles to address the problem from a promising new vantage point. The Canada goose population that stops at Horicon Marsh is a valuable asset with substantial further potential. Through further research and further policy development, based on principles developed here, it may be possible to restructure the abatement-compensation program to relieve tensions with farmers and more effectively manage the area's wildlife and agricultural resources.

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