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Abstract: Within hunting, wildlife populations are estimated to be too high in many countries which is assumed to be due to the market failure, that each hunter harvests too little compared to what the regulator wants. This may be due to the existing regulation which, among other things, requires knowledge of the individual harvest. However, information about the individual harvest may be costly to obtain. Thus, we may have to look for alternatives to the existing system. This paper proposes a population tax/subsidy as an alternative which is the difference between the actual and optimal population multiplied by an individual, variable tax rate. The variable tax rate is, among other things, based on the difference in marginal value of the population between the hunter and the regulator. The paper shows that the population tax/subsidy secures a first-best optimum. Thus, the population tax is a good alternative to the existing regulation.

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1. Introduction

In France, as well as in many other European countries, big game (e.g. roe deer, red deer, wild boar) cause damage to forests and therefore cause conflicts between hunters and forest owners (Alphandéry and Fortier 2007, Poinsot 2008, Rakotoarison et al. 2009). Hunters prefer large populations of game, while forest owners experience economic loss due to damage to forest stands (reduced timber quality or replanting costs), or costs of averting measures (e.g. fencing and use of repellents) in areas with large populations. Furthermore, the wildlife manager (regulator) has to consider potential positive and negative effects of game populations on ecosystem services which are not directly related to hunting values or forest production. This may include positive effects of game populations on the recreation value of forest for non-hunters, as well as negative effects of game populations on biodiversity and sustainable forest management. For example, large game populations may impede the natural regeneration of forest stands and reduce species diversity due to the selective browsing of tree species. In addition, large big game may damage crops on adjacent agricultural land, damage vehicles due to collisions, while large wild boar populations impose sanitary risks (Ropars-Collet LeGoffe 2009b). During the past three decades, most big game populations have probably increased significantly (Poinsot 2008). In France, from 1985 to 2008, the harvest of roe deer increased from 70,000 to 470,000, while the harvest of wild boar increased from 65,000 to 568,000 (INSEE 2011). This may indicate increasing game populations. Simultaneously, the number of hunters who have validated their hunting license in France reduced from 2.0 to 1.3 million in the period 1982 – 2006 (Bédarida and François 2008). Today, the harvest of game is considered to be too low from the point of view of optimal resource exploitation. This is basically due to the presence of externalities, i.e. hunters do not bear all the damage costs associated with large game populations (Ropars-Collet and LeGoffe 2009a).

The hunting right belongs to the property owner. However, the *département*[1] government can decide to transfer the hunting right from small properties to an approved municipality hunting association (ACCA=l'Association Communales de Chasse Agréée). This is the case in one third of the *départements*. Small properties are defined as properties with an area below a certain threshold (30-60 hectares) which is determined by the *département* government. In *département* where the transfer of hunting rights is not compulsory for small properties, the creation of an ACCA is optional. The creation of an ACCA requires the participation of at least 60 per cent of the hunting right owners in a municipality and that at least 60 per

[1] *Départements* are administrative divisions between regions and municipalities. There are 96 *départements* in France (exluding the overseas *départements*)

cent of the land is included in the ACCA agreement[2]. In municipalities where hunting right owners decide to establish an ACCA, a property owner can block hunting on her land based on philosophical reasons. In such cases, the property owners are not allowed to hunt on their own land. Out of the 36,571 municipalities in metropolitan (i.e. excluding overseas municipalities) France, 10,100 municipalities have an ACCA (Fédération Nationale des Chasseurs 2011)

When the hunting rights are transferred to communal associations, game management decisions are not made by the forest owner who bears the costs of large game populations.[3] When the forest owner keeps the hunting right, she can balance the cost and benefit from large game populations by hunting herself, or by making contracts with hunters. However, as mentioned above, big game populations also impose externalities which have public good characteristics (vehicle collisions with big game, and the negative impact on species diversity in natural-managed forest). In the current regulation, the forest owner has no incentive to internalize these externalities by making contracts with hunters, which implies that the forest owner will accept a game population which is higher than the social optimal level.

With respect to regulation and management of hunting in France, the current legislation, to some degree, reflects the situation in the 1960-70s when the number of hunters was increasing and there were concerns about a decline in game species populations (Alphandéry and Fortier 2007, LeGoffe and Vollet 2008). Hunting plans were introduced by law in 1963 and were implemented in all French regions during the 1970s. The hunting plans introduced a quota system which restricted the harvest of big game such as stags, roe deer, fallow deer, mouflon and chamois. Hunting plans were accompanied by other measures which were designed to enhance reproductive conditions for the hunted wildlife (setting aside reserves where hunting was not allowed),[4] while rules for compensation for damages caused by game were also implemented during the same period (Alphandéry and Fortier 2007,p.45). Since 1970s, the hunting plans have been a major element in the French regulation of the hunting of big game (LeGoffe and Vollet 2008, p7). Subsequent revisions to the regulations have emphasized that the hunting plan should balance interests (agricultural versus forestry) including a specification of the minimum harvest levels (Charlez 2008).

If the owner of a hunting right (landowner, contractor, or ACCA) wants to execute this, the hunting right owner is required to have a hunting plan for the area. The hunting plan is based on potential information about the game population in the area and previous incidences of damages caused by the game.

[2] In Moselle and Alsace, hunting is managed by the communes (municipalities).
[3] However, the landowner can also be a member of a communal hunting organization and thereby influence the decisions made regarding the management of game.
[4] 10 per cent of land managed by an ACCA has to be set aside as reserves where hunting is prohibitted.

Furthermore, the plan is coordinated with a *département* level hunting plan, in which the minimum and maximum harvest for the *département* is determined for the coming hunting season. The duration of the plan is three years for big game. The plan states who is allowed to hunt on the territory specified in the plan and the maximum and minimum harvest for each relevant species and may also include restrictions on the sex and age of the eligible game. The hunting plan is the basis for an initial allocation of bracelets to hunters in the beginning of the hunting season. A bracelet is a strap which has to be attached to the game immediately after it has been killed. Transportation of the game without a bracelet is subject to penalty. Hunters pay for the bracelets, the sale of which contributes to funding the compensation of landowners (forest or agricultural land) who have experienced damage caused by game. This fund is managed by the *département* association of hunters (Fédérations Départementales des Chasseurs). The price of the bracelet is set by the *département* administration within a national upper limit and depends on the damage caused by the big game. The individual harvests are directly observable as a bracelet, which is sold by the *department,* is attached to all big game which is killed.

Farmers are eligible for compensation for wildlife damage to crops, while forest owners are only eligible for compensation in certain situations. Forest owners are compensated for damage to forest stands if the owner does not have any control over the hunting, e.g. when the hunting rights have been transferred to the communal hunting association (Charlez 2008, p.61). Alternatively, forest owners can ask for compensation for protection measures. In other situations, in which the forest owner has sold the hunting right voluntarily, it is only possible for the hunting right holder to obtain compensation by claiming the civil code if the minimum number of animals killed, stated in the hunting plan, has not been achieved (Charlez 2008, p.63). Alternatively, the forest owner can, in principle, include compensation measures through the hunting lease contract. However, this would only concern the damage imposed on the forest owner and not other externalities caused by game populations (e.g. loss of biodiversity). Note also that the compensation paid by the hunters through the bracelet system is not an internalization of the damage costs. The hunting fee is pooled in a regional fund and therefore the individual hunter does not pay significantly less compensation if she harvests more animals thereby reducing the game population locally.

If the minimum harvest is not achieved in a season, the beneficiaries of the hunting right may have to comply with different additional obligations in the following hunting season, e.g. keeping a hunting diary. Assessments have shown that, in most departments, the aggregate harvest level is lower than the aggregate minimum harvest levels determined by the hunting plans.

To sum up, the current regulations of big game hunting in France are complex. They involve a tax on the individual hunter’s harvest (the payment of bracelets), a levy on hunting licenses, schemes for compensating land owners, and detailed administrative regulation of the number of animals shot. However, the regulation has been unable to ensure an optimal big game population in France (Poinsot 2008, p41).

Therefore, we propose a simplification of the existing system for the regulation of hunting. It is assumed that the purpose of the regulation is to achieve economic efficiency[5]. Instead of the existing system which is based on, among others, hunting plans and monitoring and taxing the harvest of each individual hunter, we propose a tax/subsidy on the game population. Thus, the individual harvest is not used as a tax/subsidy variable. The individual harvest is measured in the existing system. However, without the bracelet system, the individual harvest is unobservable. The starting point for our tax on game population is that measuring the individual harvest involves high costs precisely because of the bracelet system. Instead of using the individual harvest as a tax variable, we purpose the use of the population size, which should reduce the measurement costs. The market failure which we address arises because hunters and regulators value the game population differently. For the regulators, a larger game population entails a lower benefit than it does for hunters because of, e.g. the damage caused by the browsing of trees. If the population is larger than the optimal/target population, a tax is imposed, which is equal to the difference in population multiplied by a variable tax rate that varies between hunters. Provided that the population is lower than the target population, a subsidy is given which is equal to the difference in populations multiplied by an individual, variable subsidy rate. The individual variable tax/subsidy reflects the difference in marginal net benefits between regulators and hunters. Such a tax secures a first-best optimum.

In this paper, we analyze a break-even tax system. Thus we are interested in a tax system where the total tax payment is zero. Therefore, we may exclude the simple solution of a subsidy for hunting. A subsidy for hunting does not imply break-even. An alternative to the population tax could be a two-part tariff (see Turner, 1996). The starting point for most two-part tariffs (a fixed tax and a subsidy per unit) is that the total tax payment is equal to zero. Then we could impose a fixed tax and a subsidy per unit harvest. The subsidy could be the difference in net benefits between the regulator and hunter. In order to break even, the fixed tax could be the total subsidy shared by the number of hunters. However, such a system does not secure a first-best optimum. Some hunters, who have a positive net benefit, are excluded from hunting because of the fixed tax. If the fixed tax is larger than the hunter’s net benefit, the hunter will not participate even though he has a positive rent. In general, the optimal two-part tariff involves a subsidy that is smaller than the difference in rents and a fixed tax that is smaller than the above-mentioned fixed tax.

[5] Other objectives than economic efficiency may determine the choice of hunting regulation, e.g. biological objectives or equity concerns. For example, the land owners’ right to compensation for damages was originally introduced as a compensation to land owners for transferring the hunting rights to communal organizations.

Thereby, the welfare gain of correcting differences in rents is balanced against the welfare loss of excluding hunters due to the fixed tax. Thus, a two-part tariff only secures a second-best optimum. The advantage of our population tax is that a first-best optimum is secured.

The inspiration for our population tax is taken from the literature on non-point pollution. More specifically, we use the ambient tax in Segerson (1988). With non-point pollution, individual pollution cannot be observed, but the aggregate pollution for several agents can be measured. In our paper, the exact individual harvest is expensive to observe, but the population size can be measured. The translation of the non-point pollution mechanism to hunting is important due to the fact that the optimization of hunting involves a resource restriction. This is not the case for pollution.

Within fisheries economics, a number of contributions have attempted to translate a non-point pollution mechanism to resource economics (Jensen and Vestergaard 2001, Jensen and Vestergaard 2006, Hansen et al 2006, and Jensen and Kronbak 2009). The main problem within fisheries is that the individual harvest is unobservable due to illegal landings and discard. However, the population size, and thereby the aggregate harvest, is assumed to be measurable. However, one difference arises between hunting and fisheries. Within fisheries, the market failure arises due to a restriction that is not incorporated by individual fishermen. For hunting, the main market failure is due to a difference in net benefits between the regulator and hunters. Second, it is easier to measure stocks for hunting than for fisheries. This makes stock taxes easier to apply for hunting. Thus, the translation of a non-point pollution mechanism to hunting is an important contribution to the literature.

Several studies have analyzed the welfare economic optimal management of hunting in the case where wild animals are both valuable and a nuisance. Zivin et al. (2000) analyze hunting and trapping regimes in the regulation of feral pigs in California and apply a bio-economic model. A similar approach has been applied by Ropars-Collet and Le Goffe (2009a,b) in their analysis of big game in France. Rakotoarison et al. (2009) analyze the roe deer population dynamics and damage costs in a simulation model which represents a region in the south west of France. Skonhoft (2005) and Skonhoft and Olaussen (2005) have analyzed the optimal management of moose in Norway taking into account hunting benefit, as well as browsing damage, by applying a spatial model which explicitly includes migration behavior . However, none of these studies explicitly address the implementation of an optimal management regime. Horan and Bulte (2004), Rondeau and Bulte (2005), and Bulte and Rondeau (2007) analyze measures of wildlife conservation with the presence of hunting in a developing country context, i.e. with imperfect property rights. The measures analyzed include trade measures applied by the international community and compensation paid to peasants for damage caused by wildlife conservation.

The paper is organized as follows. Section 2 analyzes the proposed population tax, while the tax is discussed in section 3. In section 4, the paper is concluded.

2. The mechanism

Within hunting, the individual harvest is currently measured exactly. Each hunter registers the harvest and reports it to the regulator. The reported harvest is, then, used as the basis for collecting a tax from every hunter. However, this system is expensive. It is costly for the regulator to register the exact harvest for each individual hunter and to impose the tax. Therefore, we decided to search for an alternative to the current system. The starting point for this alternative is that the individual harvest is unobservable. Thus, a moral hazard problem arises and, therefore, we use the population size as the tax variable. As mentioned in the introduction, amarket failure arises because hunters do not correctly estimate the benefits of the population. We assume that the hunters value the benefits of the population more than the regulator. If the regulator's marginal benefit is less than the hunters' marginal benefit, we have to correct a market failure. We suggest a population tax as a mechanism to solve this market failure. Note that in connection with the model, we adopt a single-species assumption.

We consider a model which includes a regulator and hunters. Thus, we analyze a situation in which hunting rights have been transferred to an approved municipality hunting association. Therefore, we do not need to model the forest owner. However, the analysis can be easily generalized to include the forest owner. To see this, assume that the regulator is interested in the greatest possible welfare, while the forest owner is interested in obtaining the largest possible profit from timber production and the sale of hunting rights to hunters. The regulator could now impose a population tax which is equal to the difference between welfare and profit. This would give the forest owner the correct incentive and we could model the relation between the forest owner and the hunters. However, we study the relation between the regulator and hunter and, thereby, assume that the forest owner does not have the property right. The hunter is interested in the greatest possible private net benefit. As mentioned above, there is a difference between the net benefit of the population for the regulator and the hunter due to, for example, biodiversity and the damage to timber production caused by the game population. This fact makes regulation necessary. We consider a tax/subsidy solution to correct the market failure problem. The tax mechanism for individual *i* is specified as:

$$T_i(x) = t_i(x - x^*) \tag{1}$$

where:

x is the game population size.

x^* is the target (optimal) game population size set by the regulator.

t_i is an individual tax/subsidy variable.[6]

$T_i(x)$ is the total individual tax/subsidy.

Note that t_i can vary between hunters. This can be considered as the most general case. A special case is then the situation where t_i is constant over a group of hunters. This case is captured by the general case where t_i varies over individuals.

The aim in the following analysis is to find the optimal t_i that ensures that $x = x^*$. Thus, in optimum, the tax is at break-even, i.e. no tax is paid. Therefore, we want to find the t_i that means that the actual population is equal to the target population. If $x < x^*$ (the population is less than the optimal population) $T_i(x) < 0$. Thus, individual hunters receive a subsidy. If the population is larger than the optimal population ($x > x^*$), $T_i(x) > 0$ and a tax is imposed on individual hunters.

The timing of the mechanism is shown in Figure 1.

t=0 Regulator announces the tax formula and targets stock size

Hunting season

t = 1. regulator observes population and collects the tax

[6] We use the concept target population because the mechanism also works if x^* is set according to biological criteria. However, in the following analysis, we assume that x^* is set according to economic criteria.

At the beginning of a hunting season, the regulator announces the target population (x^*) and the individual tax/subsidy variable (t_i). Then the hunter extracts the resource during the hunting season. At the end of the hunting season, the population size is measured and the total tax/subsidy ($T_i(x)$) is calculated and paid.

The individual hunter maximizes net benefits minus tax costs subject to a steady-state resource restriction. We assume Cournot-Nash expectations. Thus, when maximizing (2) subject to (3), individual hunters take the harvest of others as given. The objective of a hunter may be written as:

$$\underset{h_i}{Max}[B_i(h_i,x)-c_i(h_i,x)-T_i(x)] \qquad \text{for } i= 1, \ldots N \qquad (2)$$

s.t.

$$F(x)-\sum_{i=1}^{n} h_i = 0 \qquad (3)$$

where h_i is the harvest of an individual hunter and $F(x)$ is the natural growth. $B_i(h_i,x)$ is the gross benefit associated with hunting. We assume that $\frac{\partial B_i}{\partial x} > 0$ and $\frac{\partial^2 B_i}{\partial x^2} < 0$. Thus, a larger population size implies a larger gross benefit, but at a decreasing rate. In addition, it is assumed that $B_i(h_i, 0) < c_i(h_I, 0)$. With this assumption, we reach an interior solution and extinction is not optimal.

Furthermore, we assume that $\frac{\partial B_i}{\partial h_i} > 0$ and $\frac{\partial^2 B_i}{\partial h_i^2} < 0$, i.e. the hunters receive utility from shooting animals and/or selling the harvest. A larger harvest implies a higher gross benefit, but at a decreasing rate.

$c_i(h_i,x)$ is the cost function of hunter i. We assume that $\frac{\partial c_i}{\partial x} < 0$ and that $\frac{\partial c_i}{\partial h_i} > 0$. Thus a larger population implies a lower cost, while a larger harvest implies a higher cost. We also assume that

$\frac{\partial^2 c_i}{\partial x^2} > 0$ and $\frac{\partial^2 c_i}{\partial h_i^2} > 0$.[7] This implies that costs are increasing in h_i at an increasing rate and decreasing in x at an increasing rate.

(2) is the same as maximizing the long-run economic yield. Normally, we would maximize the present value of current and future net benefits (see, e.g. Zivin et al, 2000, Ropaes-Collet and Le Goffe, 2009 a,b). This would imply the incorporation of discounting. However, we exclude discounting in order to keep the analysis simple, but it is straightforward to generalize the analysis to include discounting.[8]

Note that in (2) h_i is the control variable, while x is the state variable. These labels are normally used within a dynamic formulation. Thus, within a dynamic formulation, an optimality condition, with respect to *x,* is also included. When moving from a dynamic to a static formulation, as in this paper, we therefore also need a first-order condition for x. However, in the following analysis, we substitute x awayand, therefore, only let the maximization in (2) occur with respect to h_i. However, an alternative formulation would be to maximize with respect to both h_i and x in (2).

In (3) *F(x)* is the natural growth. We assume that $\frac{\partial F(x)}{\partial x} > 0$ for $x < x_{MSY}$ and $\frac{\partial F(x)}{\partial x} < 0$ for $x > x_{MSY}$, where x_{MSY} is the population size which corresponds to the maximum sustainable yield. It is also assumed that $\frac{\partial^2 F(x)}{\partial x^2} < 0$. In addition, it is assumed that we produce optimally at the point where $\frac{\partial F(x)}{\partial x} < 0$ because $\frac{\partial c_i}{\partial x} < 0$. Thus, because the marginal stock costs are negative, it follows that $\frac{\partial F(x)}{\partial x} < 0$. (3) states that the natural growth is equal to the harvest. Thus, we are interested in a steady-state equilibrium. Normally, we would have that the change in population size between the time periods to be equal to the natural growth minus the harvest. This is the case when we study adjustments towards equilibrium. Note also that the steady-state analysis generalizes to studies of adjustments towards equilibrium.

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[7] See Neher (1990) for a justification of the assumptions behind the derivatives.

[8] Skonhoft and Olaussen (2005) discuss the consequences of ignoring discounting.

Because $\frac{\partial F(x)}{\partial x} < 0$ in optimum we may solve the restriction ((3)) to yield:

$$x = x(h_i, h_{-i}) \tag{4}$$

where h_i is the harvest for agent *i* and $h_i = \sum_{j \neq i} h_j$ is the harvest for all agents other than *i*. From (4), we may define $\frac{\partial x}{\partial h_i}$ as the biological response function. This captures how the harvest affects the steady-state population. We assume that $\frac{\partial x}{\partial h_i} < 0$. Thus, an increased harvest implies a reduction in the game population

Substituting (4) into (2) yields:

$$\underset{h_i}{Max}[B_i(h_i, x(h_i, h_{-i})) - c_i(h_i, x(h_i, h_{-i}) - T_i(x(h_i, h_{-i}))] \tag{5}$$

Note that $T_i(x(h_i, h_{-i})$ varies between individuals and that in (5) we maximize with respect to h_i. We have substituted *x* away. The first-order condition with a Cournot-Nash assumption is:

$$\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i} + (\frac{\partial B_i}{\partial x} - \frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i} - t_i \frac{\partial x}{\partial h_i} = 0 \tag{6}$$

The assumptions about the second-order derivatives imply that the second-order condition is fulfilled.

Note that the shadow price (user cost) of the resource restriction equals $(\frac{\partial B_i}{\partial x} - \frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}$. Thus, $(\frac{\partial B_i}{\partial x} - \frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}$ measures the user cost of the resource population as perceived by the hunter.

According to (6), the marginal private net benefits are set equal to zero. The marginal private net benefits consist of the marginal gross benefit ($\frac{\partial B_i}{\partial h_i}$), the marginal private costs ($\frac{\partial c_i}{\partial h_i}$), the marginal tax costs ($t_i \frac{\partial x}{\partial h_i}$) and the marginal user cost of the game population.

For the regulator, four types of net benefit occur. First, timber production gives a net benefit. Here, a large population of animals implies lower timber production. Second, a game population also has recreational value for forest visitors who are not hunters. This recreational value increases with the population size. Third, the regulator receives a benefit from the biodiversity in the forest. However, biodiversity decreases with a large population size[9]. Fourth, the hunter's net benefit (benefits minus the cost of hunting) is also a benefit for the regulator. Now a large population implies a higher net benefit. Summing up all the benefits, the regulator has a benefit function $D_i(x, h_i)$, where h_i is hunter i´s individual harvest. We assume that there are *n* hunters. It is assumed that for large *x* $\frac{\partial D_i}{\partial x} < 0$ while the marginal benefit of population size is positive for small *x*. This reflects that for a large population size, there is a large marginal loss in biodiversity and timber production due to increasing population size, while the marginal value of hunting and recreation is low. However, for small *x,* the marginal benefits of hunting and the recreational use of forests are high while the marginal loss in biodiversity and timber production is low. Regulators are interested in the greatest possible welfare from biodiversity, timber extraction, recreation and hunter´s value extraction. We assume that $\frac{\partial D_i}{\partial h_i} > 0$, i.e positive marginal benefit of hunting which is part of the welfare generated by hunting. In addition, we assume that $\frac{\partial^2 D_i}{\partial h_i^2} < 0$ and $\frac{\partial^2 D_i}{\partial x^2} < 0$. Thus, $D_i(h_i, x)$ is increasing in h_i at a decreasing rate and decreasing in *x* at a decreasing rate. We assume that for all *x* $\frac{\partial D_i}{\partial x} < \frac{\partial B_i}{\partial x}$. Thus, the hunter values population size more than regulator. Thus, the population will be too large with unregulated hunting. This is a market failure which the population tax in this paper is designed to solve.

The regulator maximizes:

$$\underset{h_i, x}{Max} E[\sum_{i=1}^{n}(D_i(x,h_i) - c_i(h_i,x)] \tag{7}$$

[9] Note that big game may also contribute positively to non-hunters' recreational value of forest and that big game is also an element that contributes to biodiversity itself.

s.t.

$$F(x) - E[\sum_{i=1}^{n} h_i] = 0 \tag{8}$$

where *E* is an expectation operator which is included because the individual harvest is not exactly measured by the regulator under the population tax. Note that the tax revenue is not included in the regulator's maximization problem. Thus, we do not adopt a double-dividend assumption in this paper.

Because $\frac{\partial c_i}{\partial x} < 0$ we assume that $\frac{\partial F(x)}{\partial x} < 0$ in optimum. Therefore, (8) may be solved to yield:

$$x = x(E(h_i), E(h_{-i})) \tag{9}$$

Where *E(h$_i$)* is the expected harvest of hunter *i* and $E(h_{-i}) = E(\sum_{j \neq i} h_j)$ is the expected harvest for all agents other than *i*.

(9) may be substituted into (7) which gives:

$$\underset{h_i}{Max} E[\sum_{i=1}^{n} (D_i(h_i, x(h_i, h_{-i}) - c_i(h_i, x(h_i, h_{-i})))] \tag{10}$$

The first-order condition may be written as:

$$E[\frac{\partial D_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i}] + E[(\frac{\partial D_i}{\partial x} - \frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}] + E[\sum_{j \neq i} (\frac{\partial D_j}{\partial x} - \frac{\partial c_j}{\partial x})\frac{\partial x}{\partial h_i}] = 0 \tag{11}$$

The assumption about the second-order derivatives implies that the second-order condition is fulfilled. Note that (11) entails huge information requirements. The regulator must know the benefit and cost functions of all agents and know that all agents maximize net benefits. We discuss these information requirements in section 4.

The shadow price of the resource restriction (user cost) is equal to: $E[(\frac{\partial D_i}{\partial x}-\frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}]+E[\sum_{j\neq i}(\frac{\partial D_j}{\partial x}-\frac{\partial c_j}{\partial x})\frac{\partial x}{\partial h_i}]$. Thus, $E[(\frac{\partial D_i}{\partial x}-\frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}]+E[\sum_{j\neq i}(\frac{\partial D_j}{\partial x}-\frac{\partial c_j}{\partial x})\frac{\partial x}{\partial h_i}]$ is the expected marginal user cost of harvesting one more unit. According to (11), the expected marginal social net benefits are set equal to zero. The expected marginal net benefits are equal to the marginal gross benefits ($E[\frac{\partial D_i}{\partial h_i}]$ minus the expected production costs ($E[\frac{\partial c_i}{\partial h_i}]$) and the user cost of the population of animals.

When comparing (11) with (6), we see that hunting results in two market failures. First, there is a difference in the marginal net benefits of harvesting. Second, there is a stock externality problem (difference in user costs), which is illustrated by the term $E[\sum_{j\neq i}(\frac{\partial D_j}{\partial x}-\frac{\partial c_j}{\partial x})\frac{\partial x}{\partial h_i}]$ that is not included in (6). The term captures the fact that each hunter does not take into account the effect harvesting has on other hunters due to the change in the population size.

By setting (6) equal to (11), we reach the following expression for the optimal marginal tax:

$$\frac{\frac{\partial B_i}{\partial h_i}-\frac{\partial c_i}{\partial h_i}-E[\frac{\partial D_i}{\partial h_i}-\frac{\partial c_i}{\partial h_i}]+(\frac{\partial B_i}{\partial x}-\frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}}{\frac{\partial x}{\partial h_i}}-$$

$$\frac{E[(\frac{\partial D_i}{\partial x}-\frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}]-E[\sum_{j\neq i}(\frac{\partial D_j}{\partial x}-\frac{\partial c_j}{\partial x})\frac{\partial x}{\partial h_i}]}{\frac{\partial x}{\partial h_i}}=t_i \quad (12)$$

From (12), we see that the marginal tax consists of two elements. First, the difference in marginal expected benefits (excluding the user cost) between the hunter and the regulator is included. This is reflected in $\frac{\partial B_i}{\partial h_i}-\frac{\partial c_i}{\partial h_i}-E[\frac{\partial D_i}{\partial h_i}-\frac{\partial c_i}{\partial h_i}]$ and this term corrects part of the market failure associated with hunting. Second, the difference in the expected user cost for the hunter and regulator is included ($(\frac{\partial B_i}{\partial x}-\frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}-E[(\frac{\partial D_i}{\partial x}-\frac{\partial c_i}{\partial x})\frac{\partial x}{\partial h_i}]-E[\sum_{j\neq i}(\frac{\partial D_j}{\partial x}-\frac{\partial c_j}{\partial x})\frac{\partial x}{\partial h_i}]$. Because of these two terms, each hunter pays the full marginal damage which is caused by harvesting. Thus, incentives to free-ride are excluded. The damage may vary between individuals. As mentioned above, a special case would be to make the tax identical for a group of hunters.

3. Discussion

Some aspects of the proposed incentive scheme need to be discussed further. Hunters will be opposed to a tax since part of their net benefit is exhausted. This conclusion applies to the mechanism in this paper if the actual population size is above the optimal population size. Therefore, it can be argued that population taxes are impossible to implement for hunting. However, with our tax, the tax payment is zero because the population is equal to the target population, and, therefore, the total tax is zero. In addition, one could propose a combination of individual transferable quotas and taxes to secure the fair distribution of the net benefits between regulators and hunters if quotas are grandfathered away. Thus, by selecting the share of taxes and quotas, we select the share of rent to regulators and hunters. However, introducing individual quotas necessitates exact information about individual harvests. Thus, we are back to the information requirements of the existing system. Another solution would be to pay back at least a part of the collected tax revenue to hunters as a lump-sum transfer if the actual population is above the optimal population. Furthermore, it can be argued that the tax arrived at in this paper is no different from the present harvest tax. An optimal harvest tax with economic objectives is the difference in net benefits, as it is for the tax in this paper. However, with regard to harvest taxes, an important difference arises. In this paper, population size and not the harvest, is the tax variable.

A problem is that in practice, most hunting activities harvest multiple species. Thus, the single-species assumption in this paper makes the population tax of little value. However, the analysis generalizes to a multi-species setting. In this case, welfare for owners and rents for hunters are defined over several species and multiple restrictions are included. However, the multi-species analysis becomes quite complicated because species interaction must be taken into consideration. However, we could have multi-species taxes in theory. An additional problem arises in connection with collusion among hunters. Hunters could collude in order to only pay the population tax once. However, compared to fisheries and pollution, it is reasonably easy for forest owners to measure the number of participants. If the number of participants is observable, collusion is not possible, and thus, the problem of collusion is of minor importance for hunting

Another criticism of the mechanism proposed here is that it does not secure budget-balance. By budget-balance we mean that the welfare gain of moving to the optimal harvest is transferred back to the hunters. This criticism is part of the motivation for the work of Xepapadeas (1991) and Govinsdasmy et al (1994) on non-point pollution. Xepapadeas (1991) proposes a random penalty mechanism to solve non-point pollution problems, while Govinsdasmy et al (1994) suggest an environmental ranking tournament. Even though it is relevant to discuss the environmental ranking tournament and random penalty mechanism for hunting, a fairly simple solution to the budget-balance problem would be to pay back the social benefit from falling in line with the optimal harvest to hunters, which would ensure budget-balance.

Furthermore, the information requirements for the proposed tax mechanism can be discussed. This point is part of the motivation for the work by Hansen (1999) and Hansen (2001). Within hunting, economic taxes could be criticized for requiring too much information. For example, the mechanism in this paper implies that the individual benefit and cost functions must be known. However, this also represents a challenge for the existing regulation, because any attempt to regulate in an optimal fashion depends on reliable data regarding costs and benefits. For example, when setting an optimal individual quota, regulators also depend on reliable cost and benefit data. A question that arises is how reliable cost and benefit data can be collected if hunters know they are being used to calculate a population tax. A solution to this problem would be to collect the data by participating in randomly selected hunting trips. Another solution would be to collect cost and benefit data through revealed or stated preference studies. For example, Ropars-Collet and Le Goffe (2009a) estimate hunters' marginal implicit prices for game hunting in eastern French forests using the hedonic pricing method on a sample of hunting lease prices. It is also possible to reduce the information requirements by adopting simplifying assumptions. For example, we could work with groups of homogenous hunters. Another solution to the information requirement problem would be to offer various combinations of individual taxes and target population sizes.

We could, then, let hunters select the tax and target population size that they prefer. Thus, hunters would self-select into groups just as for a club good. Furthermore, in practice, the information demands are no greater than if the ambition is to regulate in an optimal fashion using the current tax or mandatory regulations on harvest. Note also that the increased information requirements are due to the fact that more realistic assumptions about the information structure are allowed. In other words, the paper is conducted within what Russell (1994) calls complex regulation. Under complex regulation, more realistic discussions of regulatory regimes are permitted by dropping some of the simplifying assumptions which are traditionally used. The price of more realistic assumptions is an increase in complexity. The issue of complex regulation arises in another way. The regulatory structure proposed here is complex, since it combines the target population and taxes. However, it must be noted that the present regulatory structure is at least as complex.

The discussion of information problems is related to the analysis by Cabe and Herriges (1992), who mention two points in connection with non-point pollution. First, the tax scheme will only work if hunters think that they have a significant influence on the game population size. Thus, hunters must react to the population tax by taking their effect on the population into account to some degree. If hunters do not react in this way, the tax becomes ineffective. Hunters would interpret it as a lump-sum tax, which does not influence marginal incentives to harvest. This is the same as saying that the tax works best in small groups. In small groups, hunters believe that they can influence the population size. Note also that the tax will work if biological criteria are used to determine the target population. All that is required is that the marginal value of the harvest is determined. Second, the mechanism requires a reliable population estimate and an estimate of the natural growth. Within hunting it has proven difficult to estimate populations. Furthermore, game populations and growth information are based on harvest data, and because harvest is imprecisely measured, it may be difficult to obtain population and growth estimates. However, the mechanism also works if we only have a rough indicator of the population size. In this case, the regulator announces a target population size and individual variable tax rate based on expected values. Hunters react to this and a second-best optimum is achieved. Note that under the current regulation, forest owners and farmers are, under certain conditions, compensated for their private costs resulting from damage caused by game. The compensation is based on an assessment of the damages. This assessment could be considered as an indicator of the size of the game population. Note also that the paper does not attempt to solve the problems mentioned by Cabe and Herriges (1992). However, it can be argued that these problems are not as significant in hunting as they are in fisheries and non-point pollution.

4. Conclusion

In France, the current regulation of hunting is very complex. It involves a tax on the individual hunter's harvest (payment of bracelets), a levy on hunting licenses, schemes for compensating land owners, and detailed administrative regulation of the number of animals harvested. We propose a simplification of this regulation. The starting point for the analysis in this paper is that the individual harvest is unobservable without the bracelets. Thus, the individual harvest cannot be used as a tax/subsidy variable. The market failure that is analyzed in this paper is that hunters and regulators value the game population differently. The marginal value of large population sizes is greater for hunters than it is for the regulator. We propose making the population the tax/subsidy variable. If the actual population is above the optimal population, each hunter pays a tax which is equal to the difference in populations multiplied by a tax that varies between individual hunters. Provided the actual population is below the optimal population, each hunter receives a subsidy which reflects the difference in population multiplied by an individual variable subsidy rate. The variable tax/subsidy reflects the difference in the marginal valuation of population size between the regulator and the hunter and the differences in user costs of populations between the two actors. This tax scheme will secure a first-best optimum. Note also that the population tax works if there are problems with measuring the population size. If we can fix an expected population size, the mechanism will be able to ensure it. A measure of the population could be obtained in the same way as in the existing hunting plans. Here recommendations for the minimum and maximum harvest are based on the expected population size. However, several problems arise with the tax/subsidy mechanism. These include the lack of a budget balance, large information requirements, problems with measuring the population size, multi-species hunting and collusion among hunters. Important topics for future research include the development of mechanisms that can solve these problems. For example, it would be of interest to develop a mechanism that secures the budget-balance and raises the minimum information requirements.

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