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# The regulation of hunting: A game population based tax on hunters

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***Abstract*** *– This paper examines a tax/subsidy on hunters based on game population. The tax/subsidy is the difference between actual and optimal population multiplied by an individual, variable tax rate. The tax rate is, among other things, based on the difference between the marginal value of the game population to the hunter and the regulator and differences in user costs of the population. The paper shows that the population tax/subsidy secures a first-best optimum.*

***Keywords:*** *Hunting, population tax, regulation, forest, externality*

## La régulation de la chasse : Une taxe basée sur la population de gibier payée par des chasseurs

**Résumé –** Cet article examine une taxe/subvention basée sur la population de gibier à destination des chasseurs. La taxe/subvention est la différence entre la population observée et optimale multipliée par un taux de taxation individuel et variable. Le taux de taxe est, entre autres choses, basé sur la différence entre la valeur marginale de la population de gibier pour le chasseur et pour le régulateur et sur les différences dans la valeur virtuelle d'une unité du stock de gibier. L'article montre que la taxe/subvention basée sur les populations de gibier assure un optimum de premier rang.

**Mots-clés :** Chasse, taxe, régulation, forêt, externalité

**JEL Classification**: Q23, Q28, D62

## 1. Introduction

In many European countries, big game (*e.g.* roe deer, red deer, wild boar) cause damage to forests and agricultural crops and, therefore, cause conflicts between hunters and land owners (Alphandéry and Fortier, 2007; Poinsot, 2008; Rakotoarison *et al.*, 2009). Hunters prefer large populations of game while land owners experience economic loss due to damage to forest stands (reduced timber quality or replanting costs) and agricultural crops, or costs of averting measures (*e.g.* fencing and use of repellents) in areas with large populations. Furthermore, the manager (regulator) has to consider the potential positive and negative effects of game populations on ecosystem services which are not directly related to hunting values or production. This may include the positive effects of game populations on the recreational value to non-hunters, as well as the potential negative effects of game populations on biodiversity and sustainable 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 populations may damage vehicles due to collision, and large wild boar populations may impose sanitary risks (Ropars-Collet and Le Goffe, 2011). During the past three decades, most big game populations have probably increased significantly within Europe (Poinsot, 2008). For example, in France, from 1980 to 2008, the harvest of roe deer increased from 70,000 to 488,000, and that of wild boar increased from 65,000 to 568,000 (ONCFS, 2013). This may be an indication of increasing game populations. 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 Le Goffe, 2011; Le Goffe, 2012).

In most European countries, the hunting right belongs to the property owner. However, there are also situations where the property rights are transferred to the government. In France, the *département*[1] government can decide to transfer the hunting right from small properties to an approved municipality hunting association (ACCA = *Association Communales de Chasse Agréée*). In Europe, the current regulation of big game is complex and France illustrates this. Here regulation involves a tax on the individual hunter's harvest, a levy on hunting licenses, schemes for compensating landowners, and detailed administrative regulation of the number of animals bagged. However, the regulation has been unable to ensure an optimal big game population in France (Poinsot, 2008).

In this paper, we analyze a tax/subsidy on the game population. Thus, the individual harvest is not used as a tax/subsidy variable. The market failures which we address arise because hunters do not include a resource

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

restriction and 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 browsing of trees and wild boars rooting and grubbing on agricultural fields. We assume that the market failure associated with the negative externalities from the population is dominating the market failure of hunters not considering the resource restriction. Therefore, 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 tax rate that varies between hunters. If the population is lower than the target population, a subsidy is paid that equals the difference in populations multiplied by an individual subsidy rate. The individual variable tax/subsidy reflects the difference in marginal net benefits and marginal user costs of game population between the regulator and hunters at the social optimal game population. The advantage of this tax/subsidy mechanism is that at the optimal population hunters will neither pay a tax nor receive a subsidy. For example, in the case where the unregulated population is too high, which is the focus of this paper, the hunters will pay a tax if the population is higher than the social optimal target population. The hunters will have incentives to reduce the population to the target size in order to avoid paying a tax that is higher than the negative of their marginal net benefit of the population size. If the population gets smaller than the target size, hunters' marginal net benefit of population size will be higher than the subsidy rate and the hunters will, therefore, not continue to reduce the population to obtain a subsidy. The proposed tax/subsidy mechanism applies also to the case where the market failure associated with hunters ignoring the resource restriction is dominating the negative externalities of the population. In this case, the tax/subsidy rate changes sign and hunters pay a tax if the actual population is smaller than the target population.

The inspiration for our tax on hunters based on population is 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 not observed, but the population size is 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 non-pollution.

Within fisheries economics, a number of contributions have attempted to translate a non-point pollution mechanism to resource economics (Jensen and Vestergaard, 2002; Jensen and Vestergaard, 2007; Hansen *et al.,* 2006; Jensen and Kronbak, 2009). The main problem within fisheries is that due to illegal landings and discard the individual harvest is unobservable. The population size is assumed to be measurable. However, there are differences between hunting and fisheries. Within fisheries, the market failure arises due to a resource 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. Within hunting, the population could be measured by the damage that animals impose on the environment. This makes taxes based on game population 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 regulation of feral pigs in California and apply a bio-economic model. A similar approach has been applied by Ropars-Collet and Le Goffe (2009; 2011) 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 southwestern 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. Basically, our analysis applies a bio-economic model framework similar to those used in the above mentioned studies. However, our model is not spatial since including migration would not change the main conclusions. Contrary to the previous studies, we explicitly address the implementation of an optimal management regime. The regulation of hunting has been analyzed in a developing country context (*i.e.* with imperfect property rights) by Horan and Bulte (2004), Rondeau and Bulte (2007), and Bulte and Rondeau (2007). The regulation analyzed includes trade measures applied by the international community and compensation paid to peasants for damage caused by wildlife conservation. These studies are different from our study. The need for regulation in the French case is primarily due to damage caused by large game populations (loss of biodiversity, damage to agricultural crops, and vehicle-game collision). This damage has public good characteristics since the hunters do not pay the damage costs. The market failures associated with hunting and the regulation in France are analyzed by Le Goffe (2012) and Ropars-Collet and Le Goffe (2011) who estimate the population tax necessary to attain the welfare economic optimal hunting level given different assumptions about market failures. More specifically, Le Goffe (2012) and Ropars-Collet and Le Goffe (2011) analyze the case where hunters do not consider the resource restriction (tragedy of commons), the case where hunters co-operate to maximize their net benefit, and the social optimal case that takes into account the resource restriction and negative externalities of the population. The present paper's main contribution to this literature is that it formally analyzes the implementation of a population tax when accounting for both resource restriction and negative population externalities, applying the non-point pollution framework introduced by Segerson (1988).

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

## 2. The mechanism

### 2.1. The tax

We propose a tax mechanism that does not require measurement of the hunters' individual harvest. This gives rise to a moral hazard problem. Thus, we use the population size as the tax variable. Moral hazard arises when an endogenous variable is unobservable (see, *e.g.* Laffont and Tirole, 1993), a clear example of which is the individual harvest. As mentioned, our main market failure arises because hunters do not correctly estimate the benefits of the population. We assume that the hunters value the benefits of a large game 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 the mechanism to solve this market failure and consider a model that includes a regulator and hunters. This corresponds to the situation in France where hunting rights have been transferred to an approved municipality hunting association. Therefore, we do not need to model the landowners, although the analysis can easily be generalized to include them. To see this, assume that the regulator is interested in the largest possible welfare, while the landowner (forest owner or farmer) is interested in obtaining the largest possible profit from timber and crop production and the sale of hunting rights to hunters. The regulator could now impose a tax on landowners based on the game population that is equal to the difference between welfare and profit. This would give the owner correct incentives and we could model the relation between owner and hunters. However, we study the relation between the regulator and hunters and, thereby, assume that the owner does not hold the property right. The hunter is interested in the largest possible private net benefit. As mentioned above, there is a difference between the net benefit of the population to the regulator and that to the hunter due to, *e.g.* the damage from the game population to timber and agricultural crop, biodiversity in forests and game-vehicle collision. This fact makes regulation necessary. We consider a tax/subsidy solution to correct the market failure. We assume that there are $n$ hunters and the tax mechanism for individual $i$ is specified as:

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

where:

$x$ is the game population size.

$x^*$ is the target (optimal) game population size set by the regulator[2].

$t_i$ is an individual tax/subsidy variable.

$T_i(x)$ 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.

Note that the tax mechanism requires that population size can be measured. This could be done by observing the damage that animals impose on the vegetation, *e.g.* trees and crops. Within the current system, the individual harvest constitutes part of the basis for measuring the population. Thus, with our tax, a tool for measuring the population is lost because we do not measure the individual harvest. However, an estimate of the population size can be obtained by observing damage to trees or crop.[3] Note that with this procedure we only reach a rough estimate of population size. A population size which is different from the expected population size indicates inefficiency. While incorrect expectations are a topic for a separate paper, correct measurement of stock size is an important assumption in the present model. 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 smaller 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. In a situation where the unregulated population would be smaller than the target population, the tax rate $t_i$ in (1) would be negative, implying that hunters would pay a tax.

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.

## 2.2. The individual hunter

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 hunter *i* may be written as:

[2] 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.

[3] For deer we may estimate population size by observing damage on trees. This is not the case for wild boars. Here population size can be estimated by observing damage to crops.

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

s.t.

$$F(x) - h = 0 \tag{3}$$

where $h_i$ is the harvest of an individual hunter, $h$ is aggregate harvest and $F(x)$ is the natural population 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. 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.

The cost function captures the hunters' cost of harvesting. Thus, costs arise in connection with the intensity of the hunting activities (*e.g.* transport, equipment and time costs). 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 $\frac{\partial^2 c_i}{\partial h_i^2} > 0$[4]. This implies that costs are increasing in $h_i$ at an increasing rate and decreasing in $x$ at an increasing rate. From the assumptions about the cost and benefit functions and the additional condition that $B_i(h_i, 0) < c_i(h_i, 0)$ an interior solution is reached and extinction is not optimal.

(2) is the same as maximizing the long-run economic yield. Note that in (2) $h_i$ is the control variable, while $x$ is the state variable. However, in the following analysis, we substitute $x$ away and, therefore, only let the maximization in (2) occur with respect to $h_i$. An alternative formulation would be to maximize with respect to both $h_i$ and $x$ in (2).

In (3) $F(x)$ is the natural population 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 that corresponds to the maximum sustainable yield. It is also assumed that $\frac{\partial^2 F(x)}{\partial x^2} < 0$. We assume that each individual hunter harvests at a point where $\frac{\partial F(x)}{\partial x} < 0$.[5] (3) states that the natural growth is equal to the harvest. Thus, we are interested in a steady-state equilibrium. We may solve the restriction (3) yielding:

$$x = M(h) \tag{4}$$

[4] See Neher (1990) for a justification of the assumptions behind the derivatives.
[5] This holds under reasonable conditions imposed on the cost function (see Jensen and Vestergaard, 2002).

From (4), we may define $\frac{\partial M}{\partial h}i$ as the biological response function. As mentioned above, it is assumed that $\frac{\partial F(x)}{\partial x} < 0$ in the private optimum. This implies that $\frac{\partial M}{\partial h} < 0$. Thus, an increased harvest implies a reduction in the game population.

Substituting (4) into (2) yields:

$$Max[B_i(h_i(M(h)) - (c_i(h_i(M(h)) - T_i(M(h))] \qquad (5)$$

Note that $T_i(M(h))$ varies between individuals and that in (5) we maximize with respect to $h_i$. Since we have substituted $x$ away, the first-order condition with a Cournot-Nash assumption $\left(\frac{\partial h}{\partial h_i} = 1\right)$ is:

$$\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i} + \left(\frac{\partial B_i}{\partial M} - \frac{\partial c_i}{\partial M}\right)\frac{\partial M}{\partial h} - t_i\frac{\partial M}{\partial h} = 0 \qquad (6)$$

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 as perceived by hunter $i$ equals $\left(\frac{\partial B_i}{\partial M} - \frac{\partial c_i}{\partial M}\right)\frac{\partial M}{\partial h}$. According to (6), the marginal private net benefits are set equal to zero. The marginal private net benefits consist of the marginal gross benefit $\left(\frac{\partial B_i}{\partial h_i}\right)$, the marginal private costs $\left(\frac{\partial c_i}{\partial h_i}\right)$, the marginal tax costs $\left(t_i\frac{\partial M}{\partial h}\right)$, and the marginal user cost of the game population.

### 2.3. Regulator

For the regulator four types of net benefit occur. First, timber and agricultural production give a net benefit. Here a larger population size implies a lower benefit. Second, a game population also has a recreational value to visitors who are not hunters. Thus, recreational value increases with the population size. Third, the regulator receives a direct benefit from the protection of natural mixed forests against selective browsing by the deer population[6]. This

[6] For example, one of the threats to natural forests and ecosystems in Les Vosges is a conversion from mixed tree species forest into mono-species forests due to selective browsing of seedlings of all other tree species than Norway spruce by roe deer. This is not necessarily considered a loss by forest owners as Norway spruce is a relatively profitable species in terms of timber production. However, from a biodiversity point of view Norway spruce is considered less attractive and may not be compatible with preservation objectives in, *e.g.* Natura 2000 areas.

benefit decreases as population size increases. Fourth, the hunters´ net benefit (2) is a benefit to the regulator. Here a larger population implies a higher benefit.[7] We assume that there are $n$ hunters and summing up all benefits, the regulator's benefit function may be written as $D(h_1, \ldots, h_n, x) = d(h_1, \ldots, h_n, x) + \sum_{i=1}^{n} (B_i(x, h_i) - c_i(x, h_i))$. Note that the benefit function consists of two terms and these terms are basically a static version of present value of net benefit in Ropars-Collet and Le Goffe (2011). The second term is $\sum_{i=1}^{n} (B_i(x, h_i) - c_i(x, h_i))$ which is the sum of hunters´ net benefits. The first term is $d(h_1, \ldots, h_n, x)$ and captures net benefit of other agents than the hunters. Thus, $d(h_1, \ldots, h_n, x)$ captures the production benefit, the recreational value and the direct benefit to the regulator.[8] It is assumed that for large x, $\frac{\partial d}{\partial x} < 0$, while $\frac{\partial d}{\partial x} > 0$ for small $x$. This reflects that for a large population size there is a large marginal loss in direct value and timber and crop production due to increasing population size, while the marginal value of recreation is low. However, for a small $x$ the marginal benefit of recreation is high while the marginal loss in production value and biodiversity is low. In addition, we assume that $\frac{\partial d}{\partial h_i} < 0$. Thus, a larger harvest implies a lower marginal benefit for other actors than the hunter. With respect to second-order derivatives we assume that $\frac{\partial^2 d}{\partial x^2} > 0$ when the stock size is large while $\frac{\partial^2 d}{\partial x^2} < 0$ when $x$ is small. In addition, we assume that $\frac{\partial^2 d}{\partial h_i^2} < 0$. Together with the assumptions about the second-order derivatives of the hunter's benefit and cost functions, these conditions imply that the second-order condition is fulfilled. Note that hunters value population size more than regulator. This is given that the market failure of different marginal values between hunter and regulator is dominating the market failure associated with hunters ignoring the resource restriction. Therefore, the population size 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 the welfare of all agents:

$$\underset{h_1,\ldots,h_n,x}{Max} \; E[d(x, h_1, \ldots, h_n) + \sum_{i=1}^{n} (B_i(h_i, x) - c_i(h_i, x))] \tag{7}$$

s.t.

$$F(x) - E[h] = 0 \tag{8}$$

[7] It could be of interest to consider explicitly all four categories of benefits in the problem. This constitutes an important area for future research.

[8] Harvest is included in $d(x, h_1, \ldots, h_n)$ because it is assumed that hunting influences the utility of other visitors than hunters in the forests.

where $E$ is an expectation operator which is included because the individual harvest is not exactly measured by the regulator under the tax on hunters based on population. Thus, regulator is uncertain about the individual harvest and this is captured by the expectation operator. Contrary, individual hunters know their harvest and, therefore, the expectation operator is not used in (2) and (3).

We assume that $\frac{\partial F(x)}{\partial x} < 0$ in the social optimum.[9] Therefore, (8) may be solved to yield:

$$x = K(E\{h\}) \tag{9}$$

where $E\{h\}$ is expected aggregate harvest.

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

$$MaxE\left[d\left(K(h), h_1, \ldots, h_n\right) + \sum\nolimits_{i=1}^{n} \left(B_i(h_i, K(h)) - c_i\left(h_i, K(h)\right)\right)\right] \tag{10}$$

The first-order condition for hunter $i$ with $\frac{\partial h}{\partial h_i} = 1$ may be written as:

$$E\left[\frac{\partial d}{\partial h_i} + \frac{\partial d}{\partial K}\frac{\partial K}{\partial h}\right] + E\left[\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i}\right] + E\left[\left(\frac{\partial B_i}{\partial K} - \frac{\partial c_i}{\partial K}\right)\frac{\partial K}{\partial h}\right] + E\left[\sum\nolimits_{j\neq i}\left(\frac{\partial B_j}{\partial K} - \frac{\partial c_j}{\partial K}\right)\frac{\partial K}{\partial h}\right] = 0 \tag{11}$$

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. This is clearly a major limitation in the present paper and lack of information about cost and benefit functions may cause the mechanism to break down.

The shadow price of the resource restriction as perceived by regulator (user cost) is equal to $E[\frac{\partial d}{\partial K}\frac{\partial K}{\partial h} + (\frac{\partial B_i}{\partial K} - \frac{\partial c_i}{\partial K})\frac{\partial K}{\partial h} + \sum_{j\neq i}(\frac{\partial B_j}{\partial K} - \frac{\partial c_j}{\partial K})\frac{\partial K}{\partial h}]$ *i.e.* 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 expected marginal net benefits $E[\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i}]$ to hunter $i$, the expected damage of the population of animals ($E[\frac{\partial d}{\partial h_i}]$), and the expected marginal user costs. When comparing (11) with

[9] This holds under reasonable conditions about $c_i(h_i,x)$ and $d(x, h_1,\ldots,h_n)$.

(6), we see that hunting results in two market failures. First, other users have a benefit arising as a consequence of hunting $[\frac{\partial d}{\partial h_i} + \frac{\partial d}{\partial K}\frac{\partial K}{\partial h}]$. Second, there is a stock externality problem (difference in user costs), which is illustrated by the term $E[\sum_{j \neq i}(\frac{\partial B_j}{\partial K} - \frac{\partial c_j}{\partial K})\frac{\partial K}{\partial h}]$ 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 population size.

### 2.4. The optimal tax

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

$$t_i = \frac{\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i} - E\left[\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i}\right] + \left(\frac{\partial B_i}{\partial M} - \frac{\partial c_i}{\partial M}\right)\frac{\partial M}{\partial h}}{\frac{\partial M}{\partial h}} - \frac{E\left[\left(\frac{\partial B_i}{\partial K} - \frac{\partial c_i}{\partial K}\right)\frac{\partial K}{\partial h}\right] + E\left[\frac{\partial d}{\partial h_i} + \frac{\partial d \partial K}{\partial K \partial h}\right] + E\left[\sum_{j \neq i}\left(\frac{\partial B_j}{\partial K} - \frac{\partial c_j}{\partial K}\right)\frac{\partial K}{\partial h}\right]}{\frac{\partial M}{\partial h}} \quad (12)$$

From (12), we see that the marginal tax consists of three elements. First, the regulator's expectations with respect to harvest may differ from the hunter's individual harvest. $\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i} - E[\frac{\partial B_i}{\partial h_i} - \frac{\partial c_i}{\partial h_i}] + (\frac{\partial B_i}{\partial M} - \frac{\partial c_i}{\partial M})\frac{\partial M}{\partial h} - E[(\frac{\partial B_i}{\partial K} - \frac{\partial c_i}{\partial K})\frac{\partial K}{\partial h}]$ captures this element. Second, other users may have an expected pay-off from the population $(E[\frac{\partial d}{\partial h_i} + \frac{\partial d}{\partial K}\frac{\partial K}{\partial h}])$. Third, the expected net benefits of other users are included. This effect on the tax is reflected in $E[\sum_{j \neq i}(\frac{\partial B_i}{\partial K} - \frac{\partial c_i}{\partial K})\frac{\partial K}{\partial h}]$. Because of these three terms, each hunter pays the full marginal damage caused by harvesting. Thus, incentives to free-riding are excluded. In the French case, where the unregulated population is considered too high, the expected user costs will be higher than the negative marginal benefit of population size (the marginal damage cost when the population is large) and the tax rate, $t_i$, will be positive. The expression in (12) is an individual, variable tax rate. Thus, the tax rate may differ between hunters because they may be heterogeneous. Note that the tax secures that $x = x^*$. Thus, the total tax payment is zero in equilibrium.

## 3. Discussion

Some aspects of the incentive scheme proposed here should be further discussed. We proposed a tax/subsidy scheme as in Segerson (1988) where a tax is paid if the population is higher than the social optimal population and a subsidy is given if the population is lower than this target. The focus of the paper is on the situation where the unregulated population is higher than the optimal population. In this situation we could set the subsidy to zero if the population is smaller than the target. The hunters would still have incentives for hunting until the target population is reached. This would be a tax mechanism with a lower population threshold for paying the tax. However, we decided to use the more general definition of the mechanism. This ensures that our results generalize to the situation where the population with unregulated hunting is lower than the optimal population. In this case, the tax rate is negative, implying that a tax is paid if the population is lower than optimal population and hunters will, therefore, have incentives to reduce their harvest.

Within hunting, the individual harvest is currently measured exactly. Each hunter registers the harvest and reports it to the regulator. However, regulation which is based on the individual harvest is costly due to two issues. First, a tax on the individual harvest requires extensive administration and, therefore, a social cost is incurred with this system. The enforcement of the existing system implies monitoring of each individual hunters´harvest. Due to extensive spatial and temporal scale of hunting, effective monitoring is costly. This would not be the case if the game population is measured by the damage done to forest or agriculture crops. For example, Morellet *et al*. (2001, 2007) and Acevedo *et al*. (2008) find that the measurement of browsing is a reliable indicator of the size of the game population. Second, many instruments are used in actual regulation in Europe. This makes administration of the regulation difficult. Therefore, the advantage of the tax/subsidy mechanism analyzed in this paper is that it is simpler than the existing regulation.

However, hunters will be opposed to taxes 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 size. Therefore, it can be argued that population taxes are impossible to implement for hunting. However, with our tax the 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 a 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, by introducing individual quotas we make exact information about individual harvest necessary. Thus, we are back at the information requirements of the existing system. Furthermore, it can be argued that the tax arrived at in this paper is not different from the present harvest tax. An optimal harvest tax with economic objectives is the difference in net benefits, as for the tax in this paper. However, with regard to harvest taxes an important difference arises. In this paper, it is population size, not harvest, that is the tax variable. This makes monitoring of individual harvest unnecessary.

A problem is that in practice most hunting activities involve harvest of multiple species. However, the analysis generalizes to a multi-species setting. In such a setting we can impose a tax on the species that cause damage. Species that do not cause damage are not taxed. The usefulness of the population tax also depends on the type of the species. With regulation of wild boars it will be relatively more appropriate to estimate a population index based on the damage to agricultural crops, as a system for assessing such damage is already implemented. Wild boars mainly cause damage to agricultural crops. On the other hand, there is currently no framework implemented to assess the damage from deer to forest regeneration. An assumption behind our population tax is that hunters have Cournot-Nash expectations. In France, part of the hunting is regulated by local communities. Therefore, it cannot be excluded that collusion arises. In this case the population tax performs poorly. In addition, even though hunters may have Cournot-Nash expectations in the beginning of the hunting season, this may change during the season. However, it is reasonably easy to fix a population tax under the assumption that hunters collude (see Hansen and Romstad, 2007). Thus, the collusion problem for hunting in France may be solved.

Another criticism of the mechanism proposed here is that it does not secure budget-balance. By budget-balance we mean that the welfare gain from moving to the optimal harvest is transferred back to the hunters. This criticism is part of the motivation for the work by 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 is to pay back the social benefit from falling in line with the optimal harvest to hunters. In this manner, budget-balance can be secured.

Furthermore, the information requirements of the proposed tax mechanism could be discussed. This point is also part of the motivation for Xepapadeas (1991) and Govinsdasmy *et al*. (1994). Within hunting economic taxes could be criticized for posing too many information requirements. The information requirements in this paper can be seen from the fact that the mechanism requires that individual benefit and cost functions must be known. If the regulator does not have information about cost and benefit functions, the mechanism will break down and this constitutes a major limitation for our mechanism. However, it also represents a challenge to the existing regulation, because any attempt to regulate in an optimal fashion depends on reliable cost and benefit data. For example, in setting an optimal individual quota, regulators are dependent on reliable cost and benefit data. The question arises how reliable cost and benefit data can be collected if hunters knew that data were used to calculate a population tax. A solution could be to collect cost and benefit data by revealed or stated preference studies. For example, Ropars-Collet and Le Goffe (2009) estimate hunters' marginal implicit prices for game hunting in eastern French forests, using the hedonic price 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. This would reduce the information requirements. Another solution to the information requirement problem is to offer various combinations of individual taxes and target population sizes. We can, then, let hunters select the tax and target population size that they prefer. Thus, we let hunters self-select into groups just as for a club good. Furthermore, in practice the information requirements are not larger than for the information needed when 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 cost 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 allowed by dropping some simplifications traditionally used. The increase in realism causes increased complexity. The issue of complex regulation arises in another way. The regulatory structure proposed here is complex, since it combines target population and taxes. However, the present regulatory structure is at least as complex. An alternative approach based on a co-operation between the different local users of the land (*e.g.* farmers and hunters) which does not raise large information requirements has been suggested by Le Goffe (2012). However, as also noted by Le Goffe (2012), this would be most appropriate when externalities are local in nature. Cooperation solutions will be less relevant when considering damages associated with collision with vehicles, loss of biodiversity, and sanitary risks.

The discussion of information problems are 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 perceive they have a significant influence on the game population size. Thus, hunters must react to the population tax by taking some account of their effect on the population. If hunters do not react in this way, the tax would be 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 they 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 harvest is determined. Second, the mechanism requires a reliable game population estimate and an estimate of the natural growth. Within hunting it has proven difficult to estimate populations. Furthermore, game populations and growth information is based on harvest data and because such data are imprecise it may be difficult to obtain population and growth estimates. However, the mechanism also works if we have only a rough indicator of population size. In this case 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 received. Despite this, estimation of stock size constitutes a major limitation in the present paper. Note that with the current regulation forest owners and farmers are, under certain conditions, compensated for their private costs of game population damages. The compensation is based on an assessment of the damages. This assessment could be considered as an indicator of the game population size. Note also that the paper does not attempt to solve the problems mentioned by Cabe and Herriges (1992) but it could be argued that these problems are not as significant within hunting as within fisheries and non-point pollution.

Note that it is possible that the optimal number of hunters is not reached. Thus, we need to find the optimum $n$ and a solution to this problem is a lump-sum transfer from society to hunters (see Horan *et al.*, 1998; Hansen *et al.*, 2006). The basic idea is that the optimal group of participating hunters is the group that maximizes total net benefits. The participation condition for hunter $i$ in optimum is that the sum of net benefit losses experienced by all other active hunters (after having adjusted their harvest level to new marginal optimality conditions) if hunter $i$ were to exit, is larger than hunter $i$'s benefit loss incurred by exiting. We let $A$ denote the sum of benefit losses experienced by the remaining hunters if hunter $i$ were to exit. The basic idea is to design the lump-sum element of the tax so that the total tax payment for hunter $i$ equals $A$. If this is possible, the optimal number of hunters is ensured because the marginal non-participating hunter would face a lump-sum subsidy which is smaller than the total benefits she would lose if she started hunting, while the marginal participating hunter would have a smaller net benefit loss from hunting than $A$ and would, therefore, continue hunting. Hansen *et al.* (2006) have considered such a lump-sum transfer for fisheries. In addition to the above tax (12), the authors include self-reporting regarding harvest. By proper selection of a penalty function for incorrect self-reporting, correct revelation of the harvest can be secured. The optimal lump-sum transfer can then be approximated by the aggregated net benefit evaluated in the self-reporting of all hunters other than hunter $i$. This transfer corresponds to the sum of the marginal net benefit losses to the remaining hunters if hunter $i$ were to exit. Though the generated entry and exit incentives are not optimal, they come close and correspond to a first-order approximation of the correct incentives. As $n$ (the number of hunters) increases, the approximation error decreases.

In our model, we assume that the regulator has full information on the cost and benefit of each individual hunter. In practice this is not realistic. Therefore, the implementation of policy would have to consider how to ensure participation and incentive compatibility. This is not the main focus of this paper. However, we have discussed above how hunters can select into groups and how to ensure optimal number of hunters.

## 4. Conclusion

In this paper, we focus on the market failure of hunters and regulators valuing the game population differently. The marginal value of large population size is larger for hunters than it is for the regulator. We propose making the population 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 rate that varies between individual hunters. If 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 rate reflects the difference in the marginal valuation of population size between the regulator and the hunter and the differences in user costs of population between the two actors. This tax scheme will secure a first-best optimum. There are two major limitations regarding our mechanism. First, the mechanism requires perfect information about individual cost and benefit functions. Second, the tax scheme requires that stock size can be measured. If these two conditions are not fulfilled, the mechanism will break down. Another problem with the tax is that the optimal number of hunters is not reached. However, the optimal number of hunters may be ensured by introducing a lump sum transfer. Several other problems arise with the tax/subsidy mechanism. These include the lack of a budget balance and large information requirements. 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 budget balance and reduces the minimum information requirements.

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