Preface

The work is done, and I have finished my first large work in the subject of economics.

I would like to thank my supervisor Anders Skonhoft for all of his effort. He has been of great help during the studies, both before the work of this thesis started, and during the work. It was you who introduced me to the subject of recourse economics, and it is thanks to you that I have been working on this interesting topic. We have had many nice, interesting and constructive talks. I do however still wonder what your smilies without a mouth means:-

The master thesis is a result of my own work, however there are some people that should be thanked for their contributions. I would like to thank my parents for proofreading, even though the mathematics was beyond comprehension. I would also like to thank Kim Marius Ilmo Bolin for some nice chats about the topic of the thesis during our days at Deichmanske bibliotek.

During my studies at NTNU I have gotten to know a lot of nice people at the Department of Economics. The department plays a huge role in making the student's work day pleasing. The cooperation with the lecturers has been good, but I would especially like to thank Anne Larsen Viken for her great support. She is a nice contact for the students and I appreciate the chats we have had.

The title of the master thesis is inspired by a song I listened to while working. It became my working title of this paper, but the title got stuck. For the title to have any real relation to the topic, I changed the tense of the verb 'cried' to 'cries'. Thus the it do not refer to the well-known fable and the moral of this. The title refers rather to the conflict that arises due to the carnivore stock in Norway, and that both parties of the conflict 'cries'.

Martin Isaksen

The Boy who Cries Wolf

An Analysis of Ex-post and Ex-ante Compensation Schemes for Carnivore Predation on Sheep in Norway

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March, 2014

ABSTRACT

This master thesis compares the Norwegian model for compensation of sheep lost due to predation with the social planner optimum. The Norwegian model is based on the concept of compensating the observed damage caused by carnivores. I also analyze an alternative compensation scheme where the compensation is paid in advance. The results of the analysis shows that the usual compensation scheme removes farmers' incentives to protect their herd. This do not occur in the alternative model. However it might be that this alternative model is difficult to use in Norway because of distribution and fairness. It is shown that the conservation agency can maintain protective effort through subsidies under the assumption that there are no moral hazard. But even with this correction, it seems like the Norwegian compensation scheme gives the sheep herders' increased profitability, and thus their sheep stock is larger than what is considered social optimal. By a numerical example it is shown that the loss from the compensation scheme, when protective effort is not subsidized, is greater the greater the effect of the protective effort. Thus it seems like the present Norwegian compensation scheme is costly in terms of transaction costs, but that the alternative approach might not be a perfect solution either.

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1 Introduction

1.1 Presentation of the Problem

The large predators lynx (*Lynx lynx*), wolf (*Canis lupus*), wolverine (*Gulo gulo*), brown bear (*Ursus arctos*) and golden eagle (*Aquila chrysaetos*) are some of the endangered species in the world today. All of them can be found in the Norwegian fauna. To maintain a biological diversity, the public policy has been to protect the carnivores so that their populations could reach a sustainable level. This commitment was made by signing the Bern Convention on the Conservation of European Wildlife and Natural Habitats in 1979. This was ratified in 1986 and has played an important part of the Norwegian conservation policy the latest years, cf. stortingsmelding 35 1996/97.[1] Due to these policies, we have seen a rise in the number of carnivores the latest decades. (Mortensen , 2008) However, such an increase in the carnivore stock comes at the cost of the farmers, since the carnivores tend to prey on their livestock. This thesis will examine the conflict that occurs between sheep herders and carnivores in Norway. The main question being how the farmers' incentives for protecting the herd will change during different compensation schemes, compared to the social optimum.

The compensation scheme used in Norway is based on a commonly used ex-post payment. The animals proven to be killed by the endangered carnivores are being compensated in full. As a contrast to this scheme, the Swedes have taken use of an ex-ante compensation scheme in the Sami reindeer (*Rangifer tarandus*) herding villages. Here farmers are paid in advance for the damage that the carnivores will cause during their lifetime. Zabel and Holm-Müller (2008) describes and analyses this Swedish compensation scheme. The two schemes have different economical outcomes, which will be analyzed in this paper. It will be focused on the incentives of such schemes, but I will also look on the effects the schemes will have on the sheep stock and the predation. Common problems of compensation schemes are moral hazard, transaction costs, and long time lags. But these might vary greatly between different schemes. In 2011 the Norwegian Ministry of the Environment selected a group to study the Norwegian PES (Payment for Environmental Services) structure, and to see if this could be improved. (Ekspertpanel , 2011) Much of this thesis will cover the economical aspects of this analysis.

The framework for the analysis will mainly be a static social planner framework compared with the herders' optimal decision. Zabel et al. (2010-I) compared such an ex-ante scheme with the common ex-post scheme. The results from this theoretical framework was that the herder would have no incentives to protect the herd stock from the carnivores under the full compensated ex-post scheme. This problem did not occur under the ex-ante

[1] http://www.regjeringen.no/nb/dep/md/dok/regpubl/stmeld/19961997/st-meld-nr-35_1996-97/5.html?id=191155\#E19E1

scheme. However it was shown that the ex-ante scheme comes with greater transfers from the conservation agency to the farmers.

1.2 Structure of the Paper

This thesis will start with a descriptive discussion of the carnivore conservation in Norway. This will be shown in section 2. Key aspects of this section is the notion about normal loss, and the general discussion of the two compensation schemes. The section refers to the previous analysis by Ekspertpanel (2011). In section 3 the ex-post scheme used in the carnivore conservation in Norway today will be discussed. This is studied in a static social planner framework, and will rely on the model used in Zabel et al. (2010-I). In section 4 there will be an analysis of an ex-ante compensation scheme similar to the Swedish ex-ante compensation model. There will be some short comments on the transfer size such a scheme will have in Norway compared to the ex-post scheme. A static framework is used in section 3 and 4, but I will examine a dynamic model in section 5 that utilizes some of the information we have learned from the previous sections. The dynamic model analyze the effects on the herd size in addition to the protective efforts. Some of the important functions will be specified in section 6, so that it is possible to examine how the model works in Norway with data inserted for the parameters. This will highlight some of the theoretical results from the dynamic model. The last section summarizes and concludes the paper. An appendix that draws some additional remarks is found in section 8.

References are made throughout the text, and a comprehensive list of these can be found in the end of the paper. There are some references to laws and regulations. These are named in the text, and marked with a footnote that shows a link to the official online listening of the laws on `www.lovdata.no`. Statistisk sentralbyrå (Statistics Norway, SSB), Rovdata (Section in the Norwegian Institute for Natural Research with responsibilities for analyzing the carnivores in Norway) and Norsk sau & geit (The Norwegian Organization for Sheep Herders, NSG) is important sources of statistics and data. Figures and tables has been made from such information. These data sources are listed next to the respective data figures. A list of figures and tables can be found after the table of contents.

2 Descriptive Discussion

2.1 Reintroducing Species

Sheep herding have long traditions in Norway, and with the sheep herding there have always been problems with the large predators. This gave the sheep herders a negative view of the of the carnivores. In 1845 a law was accepted, as a part of a national plan of making the predators go extinct (Bevanger , 2012). The law gave increased incentives in form of payments to farmers, so that they would hunt more predators. The law was not flawless, and lead to a lot of frauds (Bevanger , 2012), but it did also manage to drive the predators close to extinction. By the 1930's both the wolf, wolverine, lynx and brown bear populations were driven close to zero (Mortensen , 2008).

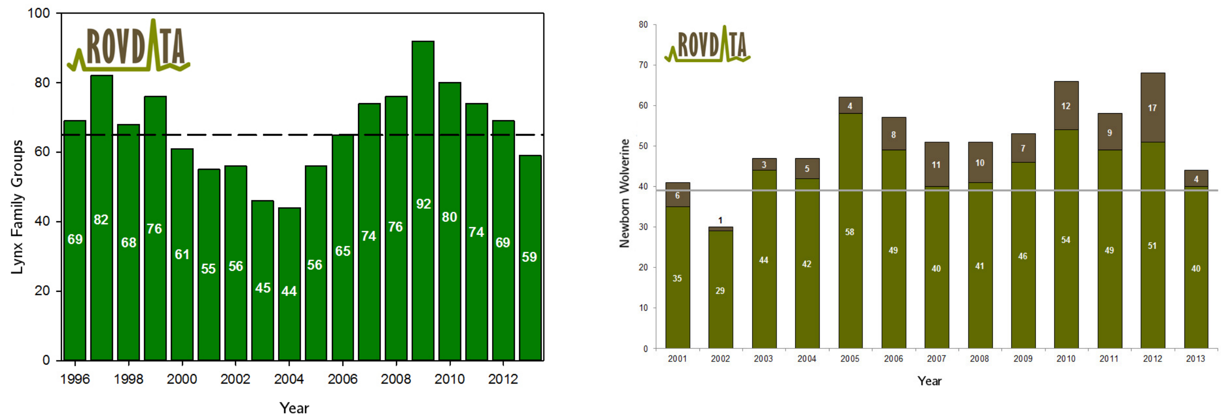

Figure 1: Lynx family groups (Brøseth and Tovmo , 2013-I) and wolverine yearlings (Brøseth and Tovmo , 2013-II), respectively. The target line represents the governing goal.

In recent times, the notion of biodiversity has gained more acceptance. The predators have a value to us, just for being predators. Some of them can have a value in controlling the population of wild prey, when this prey do some sort of damage like grazing damage or causes car accidents. They also have a tourist value. When you're visiting a forest, it brings some excitement to know that there are wild animals lurking about. But most important, the predators have an existence value. For some citizens it would make a difference to know that there exist a wolf or brown bear population. Just like we enjoy the thought of there being lions in the Serengeti. Because of this, new policies came forth in the mid 20th century. In 1959 we came to see the first compensation scheme for herd stock predation, and in the 70's some of the carnivores got protected from hunting by law. (Ekspertpanel , 2011) At that time the carnivore species were close to extinction, but the policy changes lead to a rise in their populations. The latest decades the populations of wolverine and lynx have risen to what we can call a sustainable population level. This level is considered to be 65 family groups of lynx, in which it was found 69 family groups in the Norwegian fauna in 2012 (Brøseth and Tovmo , 2013-I), and 39 newborns a year for wolverine, which was measured to be 58 in 2011 (Brøseth and Tovmo , 2013-II). This is shown in figure 1, used in these reports from Rovdata.

2.2 Herding Size and Farmer Composition

Sheep herding is a seasonal job. While there are various costs during the seasons, the revenue is mainly in the autumn when we have the shearing and the slaughtering. Because of this, the farmers must do other kinds of work on the side. This could either be other farm activities, or farmers can have other full time work, making farming the secondary activity. It is reasonable to assume that the herders with small herd size are the farmers that do not consider farming a primary job. Because of this work composition, it might be reasonable to include time constraints in the model.

Sheep herders release sheep on the grazing area in the summer. Since there are no physical boundaries in the grazing areas the different herders in an area is subject to the same predators and the sheep mixes. Thus the actions of one sheep herder influences the others. This is examined briefly in the appendix in 8.1. This has lead to some level of cooperation between the farmers that use the same grazing fields, so-called "gjeterlag" (herding groups). NSG, the organization for sheep and goat herders, is organized so that it is split up into different regional groups.[2] Because of this, and the distribution problem under the ex-ante scheme I will during the model consider this group of farmers instead of a single farmer.

Data from SSB shows that the number of sheep in total in Norway has been pretty much constant over the latest decade, however with probably a small decline, as shown in table 1. At the same time, it is clear that the number of herders in total decreases, shown by table 2. From this table we can also observe a tendency to large scale farmers increasing the sheep stock, and investments in sheep farming is increasing over the latest years. This might imply a tendency of high quit rate among low scale farmers, while farmers with initially larger sheep stock are experiencing increased profitability. The table 1 shows the number of sheep in the wintertime in Norway. Ekspertpanel (2011) states that about twice this amount is free-range grazing in the summer time, and thus exposed to the threat from predators.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Sheep	1 111 513	1 083 216	1 059 139	1 023 622	1 027 076	1 029 380	1 055 223	1 045 495	1 041 119	1 037 065

Table 1: The winterfed sheep stock size over the latest 10 years. Data Source: SSB

[2] The regional groups are divided on two levels. The local herding groups, and the county groups assisting the local groups in the region. More information on the herding groups can be found on www.nsg.no.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total	17 897	16 959	16 233	15 497	15 132	14 800	14 751	14 591	14 477	14 273
1-9	1 088	1 058	956	923	882	815	806	807	829	776
10-19	1 653	1 436	1 481	1 443	1 423	1 403	1 397	1 340	1 421	1 382
20-49	6 262	5 685	5 236	4 997	4 772	4 696	4 567	4 525	4 415	4 361
50-99	5 650	5 559	5 347	4 978	4 817	4 523	4 456	4 421	4 356	4 291
100-149	2 188	2 175	2 117	2 055	2 026	2 097	2 093	2 078	2 003	1 998
150-	1 056	1 046	1 096	1 101	1 212	1 266	1 432	1 420	1 453	1 465

Table 2: The number of sheep herders by the winterfed sheep stock size. Data Source: SSB

2.3 Predation Patterns and Protection

The conflict that occurs from a rising predator stock is obvious. A higher predator stock cet.par., the higher is the risk of sheep killed during the grazing, and the higher the cost to the herder. However, the predators are not dependent on preying on the sheep. The sheep herding is a periodic activity. In the winter, the animals are at the barn, the spring they get offspring, in the summertime the sheep stock are released for grazing in the forest, and in the autumn, the lamb is slaughtered where only some are kept for breeding. The timing of the events is depicted in figure 4. This means that the carnivores can not be dependent on sheep as food else than in the summer season, when the sheep is free-ranged and unattended. This is a season where the access to the usual food sources are higher than in the other seasons. Hence, Odden et al. (2002) argues that the sheep can be fully protected without having any damaging influence on the sustainability of the carnivore populations.

Lynx and wolverine is by far the carnivores that causes the most damage to the domesticated animals. This is easily shown by the data presented in figure 2. It is also a natural result of the fact that these predators are the most numerous of the carnivore species in the Norwegian wilderness. Odden et al. (2002) examines the sheep predation habits of radio-collared lynx in Norway. The analysis shows several patterns of the carnivore predation habits. First of all it was found that only 8% of the killed sheep were completely consumed, while 36% of the carcasses were not consumed at all. This shows that the carnivores are not dependent on domesticated animals as food, like argued, but that killings take place due to other reasons. In the same article Odden et al. (2002) presents findings on the frequency of multiple killings. That is when a carnivore kills again after the first killing. It showed that male lynx was more likely to engage in multiple killings than female lynx. Odden et al. (2002) states also that the case of continuous killings are more likely to happen to domesticated prey than to wild prey, since the domesticated prey do not flee when they get attacked.

As sheep killings are a high cost for the farmer, and sheep predation is not a necessity to the predators, it should be preferred to avoid these incidents. One of the main objectives is to provide some sort of protective effort so that killed sheep are quickly discovered, the

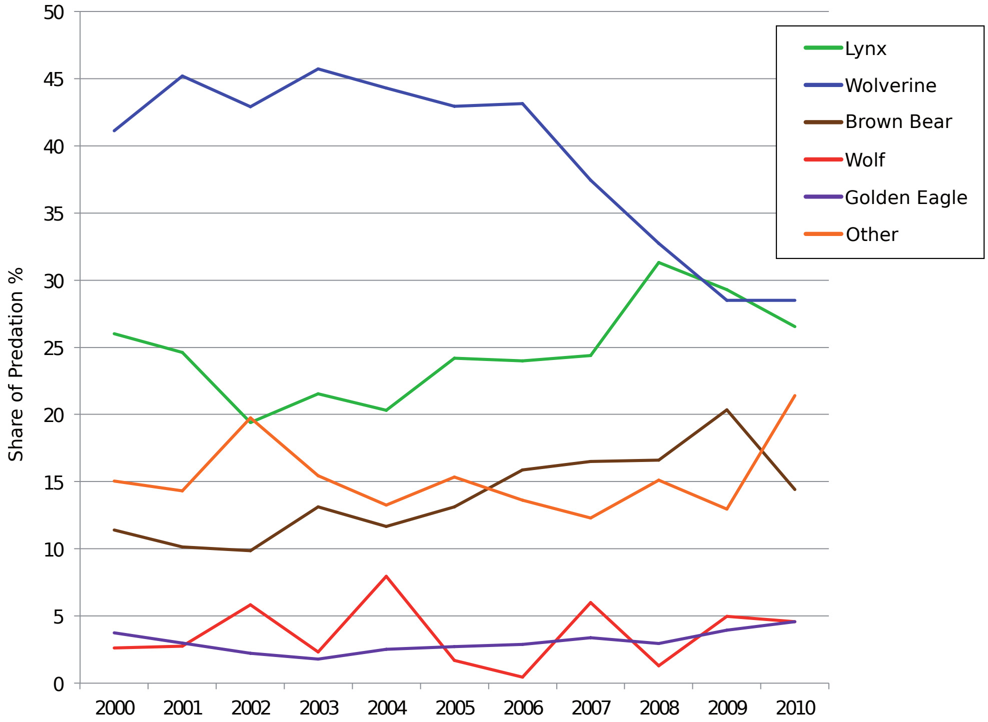

Figure 2: Predators share of total predation. (Ekspertpanel , 2011)

carnivore exposed, and taken out so that one can prevent the cases of multiple killings. One of the ways of doing so is simply being there. So one of the best protective effort is to patrol the grazing areas, so that carcasses are discovered quickly. In Norway this is done partially by the farmer, but a large part of the carcass findings are done by either tourists or a official patrolling supervisor (Ekspertpanel , 2011). There are however less conventional methods to protect the herd. One method of protection is to radio-collar the sheep, so that it easily can be seen if the sheep is not in activity, and thus it can be discovered if an animal is dead and its location without patrolling. Haugset et al. (2011) analyses how this can limit the predation on sheep. However they concludes that the effect on the predation might not be very high. Radio-collared predators might also help in the protection of the sheep. This can both help us to discover stray animals quickly, and helps us discover predation patterns like Odden et al. (2002).

Ekspertpanel (2011) also highlights other ways of protecting the herd. One of these could be to shorten the grazing period for the sheep. If the sheep is released for off-farm grazing at a later stage, or collected at an earlier stage in the autumn, it will be less time for the predators to kill sheep. The costs that follows this protection is due to in-field grazing. If they are collected earlier in the autumn the sheep might have a lower slaughter weight, and thus lead to a lower value per sheep. It might also be possible to limit predation by using herding dogs, carnivore-proof fencing, move the herd as stray animals are discovered, and use breeds of sheep that have a higher instinct of survival.

Hansen et al. (2013) analyzes the effect of the protective efforts used in Oppland county.

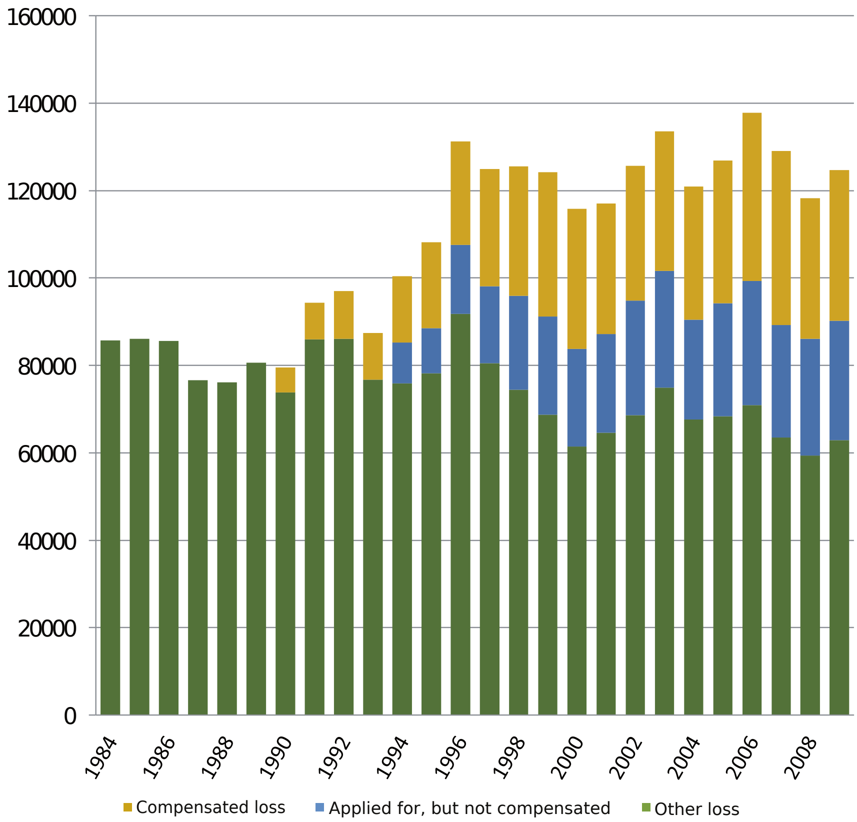

Figure 3: Yearly sheep loss split in shares of normal loss and predation loss. (Ekspertpanel , 2011)

They analyzes the most common ways of protecting the herd. The shortening of the grazing period is considered an effective way to reduce predation. The effect of patroling the grazing areas and radio-collaring of the sheep is however not considered to reduce the predation by much. But these protective tools are still good since they eases the cadaver verification, and thus might help to a general acceptance of the predators.

2.4 Normal Loss

About 125.000 sheep are lost yearly during the grazing season the latest years. However, a large share of this loss have other causes than carnivore predation. Only 30% of this loss is compensated because of predation. (Ekspertpanel , 2011) Other causes to sheep loss can both be accidents, diseases or loss to non-protected predators like the red fox (*Vulpes vulpes*). Most important sources of loss might be tick related diseases like borreliosis, intoxication from eating the plant *Narthecium ossifragum* when this is fungal infected, or viruses like louping ill. (Ekspertpanel , 2011)

One of the main problems with predation compensation is that it is hard to identify if a predator has killed the sheep, or if the cause of death is something completely different.

Many of the carcasses are even not found. This is a problem since the farmer only gets compensated in full for the carnivore damage. This is also one of the main reasons for the concept of normal loss. There are some areas in Norway that is not exposed to carnivores, except for the golden eagle, hence the loss in that area have to be due to other reasons than predation. This can help identifying the normal loss that should occur in other geographical locations as well, given that they have the same exposure to diseases, accidents and tick.

Not all carcasses are discovered, and for many of the discovered ones it is hard to identify the real cause of death. In an attempt of compensate for all the damage from carnivores, it is considered that the farmer can provide enough information to make it likely that the sheep has been killed by the protected species. The normal loss and historical predation values are used so that the compensation can be estimated. However this evaluation of the loss has also lead to difficulties between the farmers and the conservation agency. Statistics show that farmers apply for compensation due to predation for about 45% of all the sheep loss. (Ekspertpanel , 2011) Still only about 30% of the actual loss is compensated. This shows that there is a gap between what the farmers think they should be compensated, and what they actually do get compensated. Some of the gap might be explained from the fact that there are some problems of trust and transparency in the scheme. The farmer has nothing to loose from trying to get more sheep compensated than the actual carnivore loss. Hence there are incentives for farmers to report other accidents as carnivore killings. Some normal loss might be compensated through other insurances or the law *Forskrift om erstatning for tap av sau på beite*[3], but the full compensation is always better than a partly compensated sheep.

2.5 The Guidelines of the Norwegian Compensation Scheme

While there are a general acceptance of the predators presence in the wilderness, the local herder might not have the same view. It is clear that the society in general have some gains from a carnivore stock, this might not reflect the situation for the herders. Hence we have two different parties with conflicting interests. The society wants a carnivore stock, while the farmers wish to avoid predation. Coase (1960) states that under the absence of transaction costs, social optimal solution will occur regardless of who has the property rights. Thus we should - under the assumption that the farmers have the right to use the wilderness for grazing areas - introduce some sort of payment from the society to the farmers. This transaction should reflect the costs of the predators, so as we reach the optimal level of predators and the correct optimal predation in pareto terms. In the appendix in section 8.2 there is made an easy model on the Coase theorem applied to

[3]http://lovdata.no/for/sf/ld/xd-20040721-1129.html

the case of sheep versus predator conflict, in which I have taken the opposite stand on who has the property rights. This is however a pure theoretical example since it seems well-established in the Norwegian society that the farmers have got the property rights. Aanesland and Holm (2002) analyses the economical and legal aspects of the Norwegian sheep herding and the predation conflict. The importance that the property rights are well defined is underlined. Aanesland and Holm (2002) concludes after a legal discussion that the farmers who owns the grazing areas should be assigned the property rights. Thus the society should pay the farmers for the presence of the predators so that we can reach a pareto optimal solution. This is in general defining the need for a compensation scheme. The problem is however to find the best way to make the transaction from the society to the farmers.

One of the important aspects of the Norwegian compensation scheme is that the farmer should be fully compensated for the damages caused by the protected wildlife. This notion is well founded in the Norwegian society and included in the law, cf. *Lov om forvaltning av naturens mangfold §19*[4]. Here it is stated that the farmer should not only be compensated for the direct costs caused by damage from protected carnivores, but also the indirect costs that follow. Another important aspect of the Norwegian compensation scheme is that the actual loss should be compensated. Thus one wish to compensate the sheep proven to be killed. As this is a concept of ethics that is most likely not going to change, I will through this paper mainly consider the case where the farmer is fully compensated. I will however still comment on the cases where we don't have full compensation, to see how that would alter the situation in Norway.

Another important notion about the Norwegian guidelines for compensation is the law that puts some responsibilities on the farmer. *Forskrift om erstatning for tap og følgekostnader når husdyr blir drept eller skadet av rovvilt §4*[5] makes some conditions for a compensation to be made. The farmer must have done the best to avoid or limit the loss. Hence, the compensation can be shortened or cut out if the farmer do not ensure the herd stock's safety. This law is not very rigid though since there are no real way to measure the loss-reducing effort, and hence there are not much effort that have to be provided to be able to be compensated for loss. We might have some sort of moral hazard in this case, since the effort level used to protect the herd is hard to measure and to control. I will come back to this kind of moral hazard later in the discussion of the upcoming model in section 3.3.

Another thing that might be interesting to note about the problem to measure effort is that it is hard to find the compensation that the farmer should have. It was stated that the farmer should be compensated for both the direct and the indirect costs of

[4] http://www.lovdata.no/all/tl-20090619-100-003.html\#19

[5] http://www.lovdata.no/for/sf/md/td-19990702-0720-002.html\#4

predation. Since it is hard to measure the effort and the cost of the effort related to getting compensated, the farmer might in fact feel under-compensated due to problem measuring indirect costs.

The most important aspect of the Norwegian carnivore conservation is that hunting is limited by law. *Lov om jakt og fangst av vilt §9*[6] states that the Norwegian Directorate for Natural Management is the organ that can allow or prohibit hunting of wild species. Most of the large carnivores are protected by this law, either fully like the Brown Bear, Wolf and the Wolverine. While Lynx are just protected in the mating season. This protection of the species are limiting the options for the farmer, as they can not themselves lower the populations of carnivores. The carnivore population is still regulated by the conservation agency, but the farmers can not affect the population size. At least not by legal measures. There are some incidents of carnivore killings or poison traps, but they are rare. Lindberg et al. (2008) made a study on such poaching. During their research they confirmed two cases of wolf poaching in Norway. But they also concluded that the numbers might in fact be higher, since other radio-collared wolf went missing.

Because of the hunting regulations in Norway, it might seem like the carnivore stock should be considered fixed to the farmer. This will also be the main approach in this paper. Considering the Bern Convention, there exists a lowest number of carnivores that the conservation agency can set as well. So the carnivore stock might be considered fixed even from the conversation agency's perspective. It is not possible to have a lower carnivore stock that what is considered a sustainable population due to the international agreements, and thus there are some limitations to the hunting of predators.

Furthermore it is worth noting on the side that the farmers do not only get economic support for the damage by the predation. *Forskrift om produksjonstilskudd i jordbruket §7*[7] states that a grant can be given based on the size of the sheep stock. This is so that the agricultural activity is kept up despite competition from low-cost countries, and despite the fact that there are more profitable industries in Norway. I will not discuss the efficiency of such a production grant in this paper, but it might be good to have this in mind when it comes to some of the results in the models presented.

It may seem like the Norwegian compensation scheme is basically an ethical and political tool made to compensate damage to the farmers, rather than a tool for carnivore conservation. It might just be that the compensation is there to create some local support for the carnivore conservation, rather than actually manage the predator stock itself. In this thesis I will however start in the static model with the latter approach, the tool for carnivore conservation, since this approach is used in Zabel et al. (2010-I). The results from this model might show us why the compensation itself is no longer a tool for carnivore

[6] http://www.lovdata.no/all/tl-19810529-038-004.html\#9

[7] http://www.lovdata.no/for/sf/ld/td-20020322-0283-0.html\#7

conservation, and thus the dynamic model is altered a bit.

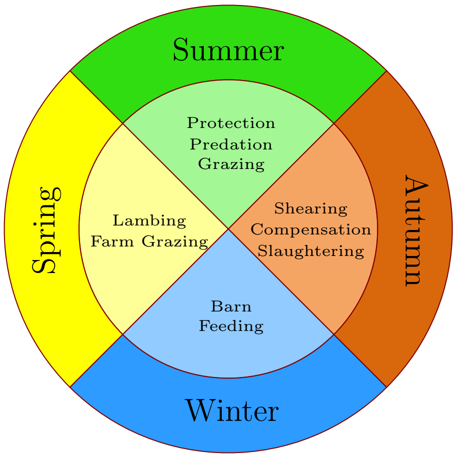

Figure 4: Time circle of ex-post compensation scheme

The sheep farming varies through the seasons, and thus the timing of the events might be of importance. The seasons goes like illustrated in figure 4. In the winter, there are no revenue, but costs due to keeping the sheep at the barn. In the spring, there are lambing and grazing in the close areas. In the summer, the sheep is released for grazing in the wilderness, and one could expect predation. In the autumn, the farmer gets revenue from sheep shearing, sale value from meat and from compensation due to dead animals.

2.5.1 Costs of the Norwegian Compensation Scheme

Zabel and Holm-Müller (2008) underlines that there are four important problems that might arise under the conventional compensation schemes. We might expect moral hazard, high transaction costs, time lags, and problems with trust and lack of transparent information. These problems can be found in the Norwegian compensation scheme. The problem of moral hazard will be analyzed in depth throughout the model, however we should take a look on the other issues in this section. Ekspertpanel (2011) describes the costs of the Norwegian model, and goes in detail into the transaction costs of the scheme. To get a structure of the costs, it should be looked on the transaction costs on the farmer's side and the conservation agency's side separately. The compensation scheme is supposed to cover all the direct and the following indirect costs of predation. That means that the farmer should be covered regardless if there are transaction costs on that side of the deal. However, that does not mean that these transaction costs are of no importance. They are still there, even if they are covered through the compensation.

The transaction costs on the farmers' side can be found through the increased workload that occurs due to applying for compensation and to locate killed animals for verification on predation. The search for the missing animals is however a cost that occurs even if one discovers that the sheep did not die to predators after all. What is being compensated as a part of the increased workload is based on statistics from Organisert beitebruk (The cooperation between NSG and the Ministry of Agriculture and Food, OBB) (Ekspertpanel , 2011).

Cadaver verification is also one of the large costs of the conservation agency. In about 5500 to 6000 cases of verification yearly, the expenditure is at about 9.3 million NOK. (Ekspertpanel , 2011) Compared to the to compensation paid each year, this is still a relatively low number. There are however some benefits of this work, as it helps to discover predators in the geographical area, and it helps with knowledge about the predators.

The processing of the applications is costly as well, however there are no clear data on how much resources that are spent on this. There is a deadline for the claims at the 1st of November and a deadline of processing at the end of the year. Thus the 2500 yearly claims generate a significant work load at the last two months of the year. (Ekspertpanel , 2011) The processing of the claims is resource-demanding since each claim is evaluated individually because of the lack of complete cadaver verification. There are also some resource usage for the complaints on the decisions. In Ekspertpanel (2011) it is stated that about 3.5 man-years is used for processing yearly in only Hedemark.

This processing is also a problem to the farmer, as it delays the time between the claim and the actual compensation. While the value of sheep meat is paying off in the autumn, the farmer has to wait until the beginning of the next year to get compensated for the predation loss. The processing time leads to some lagging in income, which is costly to the farmer.

The last con of the present scheme is that there is a lack of full information. There is no clear information on which animals are being killed, and while this makes the processing of claims more costly, it also raises the chance of errors. It can be that farmers are under-compensated, but farmers also can raise fraudulent claims. Most of the information provided by the farmers in claims are based on non-verifiable information. Such as information about accidents and diseases in the stock, together with size of other grants the farmer receives.

2.5.2 Farmers' Dissatisfaction with the Present Scheme

There are several reasons why farmers might be dissatisfied with the presence of predators even though they per definition are fully compensated. Some of these reasons are related to the costs of the scheme. Since claims are processed by the agency's judgment, there might be a mismatch between what the farmer think should be compensated and what is actually compensated. This mismatch is easily depicted by the data presented in figure 3.

Much of this problem might origin from the fact that it is hard to evaluate the normal loss.

The compensation scheme might also feel discriminating to farmers, since claims are individually processed. The agency might consider claims differently based on other discoveries of cadavers in the area or if there are any known diseases in the herd that year. Such variations in judgment might lead to conflicts.

While the farmer by definition is compensated for the indirect costs, it is not always that the compensation covers all the experienced costs. It might feel like a lot of unnecessary work to search for cadavers and raise claims. Also, since a lot of farmers only work part time with sheep herding, having other profitable work, their outside option, or evaluation of spare time value, might be higher than what is considered through the data from Organisert beitebruk (OBB). I will come back to the cost of outside option in the discussion of the model.

There might also be some emotional costs that can construct a stronger conflict. This is not related to the scheme, but to the predation in general. However it should be considered since one of the stated goals of the compensation scheme is to gain acceptance for carnivores in the Norwegian fauna. However when the farmer raises a small sheep stock, it might get emotionally connected to some of the animals, even though they do not live past the winter anyways. To see how the animals are ripped apart in the forest might be a saddening sight. Care for animal welfare might thus increase the level of conflict even though the farmers gets compensated completely.

2.6 The Swedish Ex-Ante Scheme

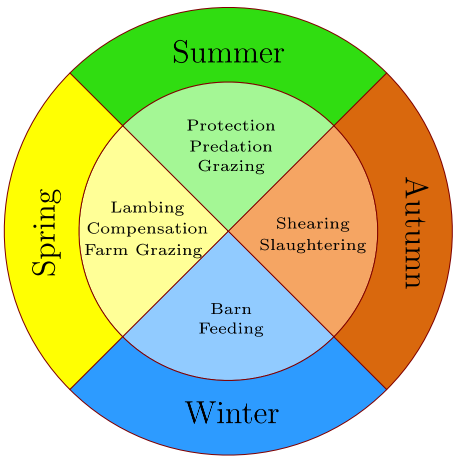

Figure 5: Time circle of ex-ante compensation scheme

The ex-ante scheme differs on two main areas. The first one is the timing of the compensation. By the name, it is easy to understand that ex-ante compensation is compensation that is paid prior to the damage. This changes the time circle from what we had in figure 4 to what we can see in figure 5. The compensation is rather paid out in the spring than in the autumn. This gives the farmers an opportunity to improve the situation by providing protective effort after the compensation has been made, thus lowering the predation. This is conditional on one important factor; that the compensation the following year does not decline if the predation rate declines due to the protection. The compensation has to be completely independent from the predation rate itself. This will be explained in detail in the model used in chapter 4.

The other important aspect of this compensation scheme is exactly that it is intended to have no relation to the predation. The compensation being made relies on the number of carnivores in the geographic area. Zabel and Holm-Müller (2008) states that the Swedish ex-ante compensation is determined from the expected monetary damage that a carnivore will cause during the lifetime. It is furthermore stated that the ex-ante compensation scheme do not give rise to moral hazard due to the fact that the payment does not depend on the livestock losses. This might seem like a simple assumption since the expected damage a carnivore causes during the lifetime, which is used in calculating the compensation, surely must depend on the predation. However for the modeling I will take this first position, and just commenting on some of the possible effects.

One obvious advantage of the ex-ante scheme is the removal of time lags. The ex-post scheme is costly to the farmers due to the timing of the payment. Thus the ex-ante scheme helps against this problem. Another important characteristic is that the farmers do not have to do a significant amount of paperwork to be able to get compensated. Today the number of applications for compensation is about 2.500 applications yearly. (Ekspertpanel , 2011) It is also important to consider the effects on the conservation agency as well. Ekspertpanel (2011) states that there is a significant work load on the agency employees that process the compensation the latest two months of the year. This is much related to the identification of cadavers and analysis of the individual cases where the cause of death is unclear or the sheep cadaver is not found. These are all problems that do not appear in the ex-ante scheme. Since the compensation is paid in advance, there are no time lags, but also no hurry to decide on sheep death cause.

The ex-ante compensation simplifies the work of the agency when it comes to processing the compensation, and the work load at the end of the year. However, the compensation scheme put some new requirements on the agency. If one should base compensation on the expected damage by carnivores in a geographic location, it is important to both monitor the number of carnivores and the predation rate. Thus the scheme depends an increased knowledge about the predator stock. Today this might not seem like a large problem, as the predators already are monitored closely in Norway by Rovdata, who publishes annual reports of each predator species and their stock and predation habits.

A problem with ex-ante scheme that arises is however the problem of distribution. In the analysis of the Swedish ex-ante scheme, Zabel et al. (2010-III) concludes that the distribution of the compensation works well. The Swedish reindeer herding is being done by the Sami people in northern parts of Sweden. They are organized in different Sami villages. The compensation scheme is set up so that the the payment is sent to the village. Zabel et al. (2010-III, p.4) states that *"From the villagers' perspective, the performance payment money thus is a common pool resource."* It is the village that optimizes the benefits from compensation and reindeer loss. The compensation is then distributed to the herder based on herd size. The distribution might however be more difficult when there are no such local society that organizes the herders.

Another problem with the distribution is that many of the predators stray and walk for longer distances. Thus, as carnivores know no borders, they might cross over to different geographical regions. As the compensation scheme is laid out so that the compensation is paid out for how many predators there are present in the geographical vicinity, this might be a problem. Both for the compensation itself, but also for the fairness and the acceptance among the farmers. The problem might be even higher for animals like the wolf, who strays between countries.

3 The Norwegian Ex-Post Compensation Scheme

3.1 The General Ex-post Compensation

The Norwegian compensation scheme is based on the notion about compensating the total damage caused to the sheep farmers. Together with this concept, it is believed that one has to observe the damage before it can be compensated, so that the compensation is fairly distributed. Since the total damage is compensated, the compensation value has to equal the value of the killed sheep. So if the value of a sheep is given by p, this should also the compensation value. The compensation per sheep will be given by q so that the model easily can be examined without full compensation. q must therefore take a value between zero and the sheep value, p.

The slaughter value of a sheep is assumed to be fixed to p. This is mainly just a simplification, but it can be reasoned why this also can be the case for farmers in Norway. From the descriptive section we can see that there are about 14.500 sheep farming companies in Norway, and many of them works in relatively small scale. On the other side, there are very few distribution chains of food in Norway. It is also so that the value of the sheep is influenced by the global prices, so even though we can see some organization between the farmers it is still reasonable to assume that a single sheep farmer must consider the price of meat and wool, in other words the ending value of the sheep, for given.

In Norway, the number of predators may be considered to be given to the farmers, since hunting the carnivores are to a large extent protected by law. However, farmers might violate the rules set, and try to lower the level of predators illegally. This can be done through either poaching or by poison traps. I will therefore look on such effort in addition to the effort that is used for legal protection. There are two main reasons for this approach. This way the model relates better to the model by Zabel et al. (2010-I), which is also analyzing the topic about ex-post and ex-ante compensation. But it also can be used to show how the institutional characteristics of the Norwegian sheep herding alters the model.

The local herder will have the costs $c(e)$ of the illegal effort provided. This function is not measuring the direct costs of the illegal effort, but only the expected loss of being caught. The direct loss from the protective effort, both legal and illegal, is measured through a time constraint. The farmer has also got a chance of protecting the livestock by legal means, this protection is denoted E. In total, the farmer can spend his time on either illegal protection e, legal protection E or on off-farm work o. The work not related to the farming yields a marginal payoff r. The farmer must choose on allocating the time use given the time limit of the period L. Hence the farmer faces the time constraint $L = e + E + o$. With this time constraint, the local herder faces the profit given by equation 1.

$$\Pi^{LH} = p\left(X - K(E, W(e))\right) + qK(E, W(e)) - c(e) + ro \tag{1}$$

The herd size is given by X, and will be the slaughter level without any predation. But to find the real slaughter, the number of sheep killed by carnivores given by $K(E, W(e))$ must be subtracted. It is assumed that the predation is declining in the legal protective effort, $K_E < 0$, and that it is increasing in the carnivore stock, $K_W > 0$. In this general model, it is assumed that the farmer may regulate the carnivore stock themselves, hence the carnivore stock is reduced by the illegal protective effort $W_e < 0$. The profit equation states that the revenue of the farmer is given by the value of a sheep times the level of the slaughter, described by the first part of equation 1. The farmer gains an additional revenue from the compensation due to the predation, described in the second part of equation 1. It is then subtracted for the risk cost of providing illegal protective effort, and added the revenue from off-farm work. Considering the time constraint, the profit equation can be rewritten into equation 2.

$$\Pi^{LH} = p\left(X - K(E, W(e))\right) + qK(E, W(e)) - c(e) + r(L - E - e) \tag{2}$$

This ex-post model is pretty much the same as used in Zabel et al. (2010-I). The only real difference is that this model takes the cost of criminal behavior into consideration. In Norway, this is another mean for the conservation agency to control the behavior of the farmers, and we should expect that it should be less poaching with this policy than in the model in Zabel et al. (2010-I). The cost of criminal behavior in this model might not be the best suited to make a social planner comparison, since the criminalization of the poaching should lead to us expecting that the society wants the predator stock to be given to the farmers. But it helps us to understand the variables the local herder has to take into consideration.

The local herder wants to maximize the profits with respect to the effort provided under the time constraint. The first order conditions to this problem is given by equation 3 and 4.

$$\frac{\partial \Pi^{LH}}{\partial E} = -pK_E + qK_E - r \lesseqqgtr 0 \quad ; \quad 0 \leq E \leq L \tag{3}$$

$$\frac{\partial \Pi^{LH}}{\partial e} = -pK_W W_e - c_e + qK_W W_e - r \lesseqqgtr 0 \quad ; \quad 0 \leq e \leq L \tag{4}$$

First of all it should be noted that we have some Khun-Tucker conditions to this problem. This is because the local herder can not spend a negative amount of time on any of the

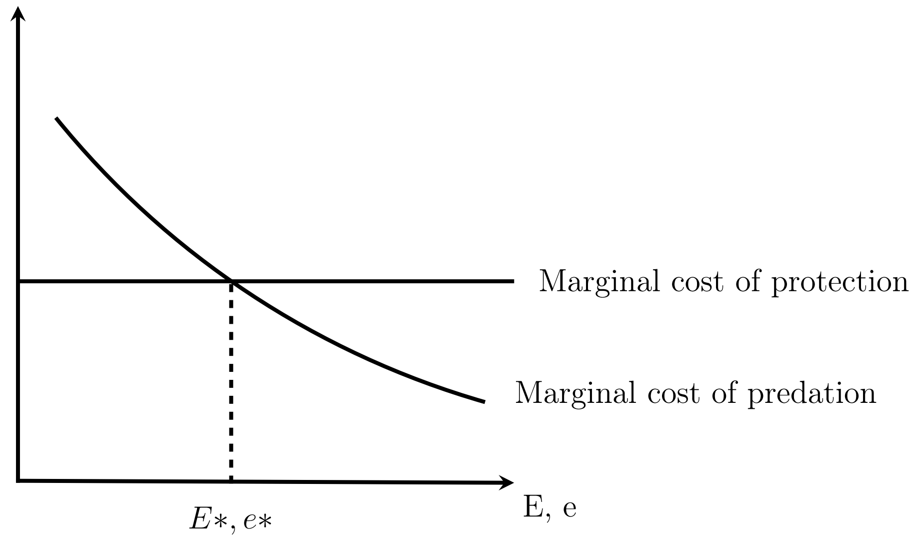

Figure 6: Marginal Predation Costs vs. Marginal Effort Costs

activities, $E \geq 0$, $e \geq 0$, $o \geq 0$. The last condition can be rewritten into $e + E \leq L$. As long as the solutions of the first order conditions satisfies these conditions, the equations 3 and 4 will hold as equalities. This will not be the case if there are no internal solution. If the first order solutions is less than zero, then there will be a lower corner solution to the problem. On the other hand we also have an upper limit, since the farmer can only spend limited time during the period, L. Thus the first order conditions also might be larger than zero, when the total effort at largest is equal to L.

An interesting thing to note about this maximization problem is that we do not have the usual revenue versus cost problem. The situation is rather that the farmer should replace one cost, the cost of predation, with an alternative cost, the cost of protection, as shown in figure 6. Hence as long the protection cost is cheaper on the margin than the predation cost, the farmer should increase protection. In figure 6 we can see that it is beneficial to protect the herd up to the point of E^*, e^*. From this point it is rather beneficial to accept the predation costs. I will look upon the cost of predation as the gain from protection, since protection is reducing the predation costs. Hence the reduced predation costs will be considered as the revenue part of the profit equation in this analysis.

The first order conditions are pretty much the same as the model in Zabel et al. (2010-I). The only difference is found in equation 4. Here the expected marginal cost of being punished for poaching is included in the condition. It is obvious that this term leads to less poaching than in the model by Zabel et al. (2010-I) with no such legal issues.

It should be noted that equations 3 and 4 can be rewritten into equations 5 and 6, with $Q = \frac{q}{p}$ being the compensation ratio. Thus $Q \in [0, 1]$ tells how large share of the loss is compensated. The results of the analysis of the first order conditions are the same, however it might enlighten the case to look on the compensation ratio instead of the compensation itself.

$$-p(1-Q)K_E \lesseqgtr r \quad ; \quad 0 \leq E \leq L \tag{5}$$

$$-p(1-Q)K_W W_e \lesseqgtr r + c_e \quad ; \quad 0 \leq e \leq L \tag{6}$$

3.1.1 Illegal Protective Effort

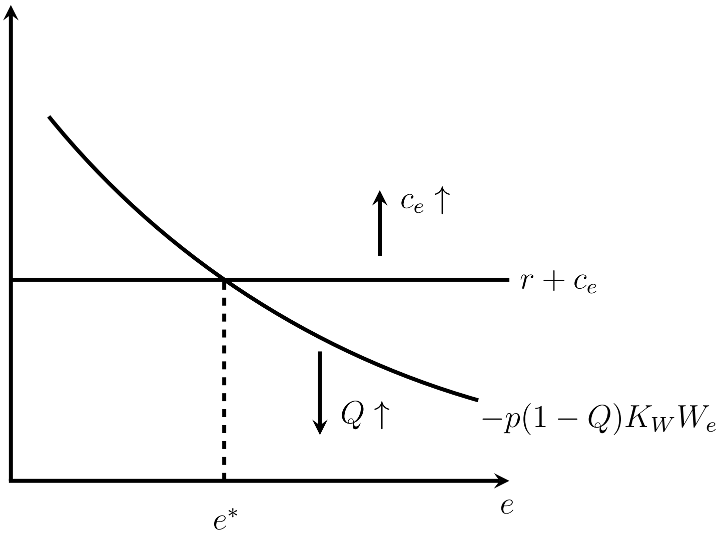

Figure 7: Illegal Protective Effort and the Effect of Policies

To evaluate the results it must be made some assumptions on the function specifications. It is reasonable to assume that the predation is increasing in the carnivore stock, $K_W < 0$, to either a diminishing or a constant rate, $K_{WW} \leq 0$. For simplicity it will be assumed that the predation is increasing at a constant rate. The carnivore stock is furthermore decreasing in the level of poaching, $W_e < 0$, at a diminishing rate $W_{ee} > 0$. With the risk cost function being increasing to either a increasing or constant rate, we have ensured that the profit function is concave in the variable e, and that the solution is a maximum. However it is not clear that the solution is given at the defined interval, $0 \leq e \leq L$. The figure 7 shows the decreasing marginal revenue of providing illegal protective effort, and the assumed to be constant marginal costs. It will be a possible solution to this problem given that the marginal costs initially are lower than the marginal gain from the poaching.

If there is full compensation $Q = 1$, it is clear from equation 6 that the terms on the left hand side cancels out, and hence leading to a non-equality. This leads to a corner solution of the maximization problem, resulting in no illegal protection effort at all. If it is the case that $p > q$, the term $-p(1-Q)K_W W_e > 0$, it could result in a solution to the maximization problem and illegal protective effort being made. It is easy to see that for a standard convex predation function, the illegal protective effort will be larger the higher the difference between the sheep value and the compensation value. The law against poaching is however limiting the chances of illegal protection effort being provided, since it makes the marginal cost of providing illegal effort higher than in the case where such regulation of the carnivore stock would have been legal. This result describes why we do not see any illegal protection of the sheep stock like poaching or poison traps in Norway.

From the figure we can easily see that the marginal revenue function will shift downwards with an increased Q. Hence increasing the compensation value will lower the revenue for all levels of effort. For $q = p$ it is clear that this function will lie along the e-axis. It is similar with the cost functions. If the marginal costs of illegal actions increase, $c_e \uparrow$, that being either harder punishments or higher risk of being caught, it is clear that the marginal cost function will shift upwards. Hence a higher cost of illegal effort will reduce the chances of poaching. The variables c_e and q can thus be considered policy variables, and can be used by the government to achieve the desired results.

The model might tell why there is close to no poaching in Norway. The question is if there would have been such activities in the absence of compensation and regulations. One should also consider that the farmers might have some moral issues with killing endangered species, and thus this restraints such behavior. There might also be some farmers that appreciate the existence value and the tourist value of the predators, and therefore might abstain from poaching. Another important factor is the alternative wage, r. It is often argued that the outside option value is high in Norway, and that the profitability in the agriculture is relatively low. Thus it might be that the alternative wage is so high that there is little to profit on from providing such effort. This outside option is discussed in section 6. In figure 6 this can be interpreted as the curve for marginal protection costs shifting so high upwards that there will be no intersection. In the end we should however conclude that the poaching might have been higher if there was no compensation made to the farmers.

3.1.2 Legal Protective Effort

Equation 6 has many of the same properties as equation 5. Since the terms on the left hand side cancels out when the compensation per killed sheep is equal to the value of the sheep, there will be no internal solution to the maximization problem, and no effort will be provided. With the assumptions that the predation is decreasing at a diminishing rate $K_E < 0$, $K_{EE} > 0$. It is evident that any possible internal solution will be a maximum and that the marginal revenue part of the equation is decreasing in the effort level. It is easy to see the similarities with the case of illegal protective effort, that the marginal revenue shifts downward as the compensation goes toward the sheep value. And if p=q

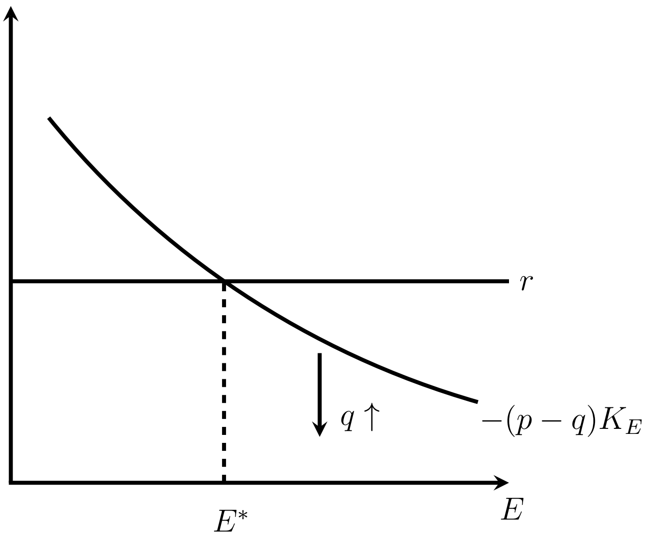

Figure 8: Legal Protective Effort and the Effect of Compensation

there will be no internal solution. In the full-compensation situation present in Norway, it can be argued as follows. If the sheep killed by predators are fully compensated, the farmer will be indifferent if he gets paid buy the butcher or gets compensated from the authorities. The monetary gain is the same anyways.

One should consider that the sheep herders may have other costs than the direct economical costs as well. There might be an emotional cost due to sheep loss. Herders often have a small herd size, and thus they get a closer relation to the animals. Loosing animals one has worked for, to something that seems unnecessary, might lead to some emotional costs. In addition it might lead to some loathe when one sees how brutally the sheep has been killed. These predations are more brutal than the slaughtering made by humans. Such a cost can take form in a function depending on the number of animals killed. Then the marginal effect will influence the effort allocation, leading to higher effort, both legal and illegal. If it however leads to an irrational hatred against the predators, the cost might be a function depending on the number of predators. In this case, it will be beneficial for the herders to try to lower the predator stock, without this affecting the legal protective effort.

3.2 The Social Planner Solution

To compare the ex-post and ex-ante compensation schemes, we must first see how the social planner would optimize the sheep herding and the carnivore stock. For the social planner solution we will look at the farmer's solution, including the external effects that the farmer do not usually take into account. However, for the social planner solution to be meaningfully compared to the ex-post compensation solution for the herder, we must look away from the cost of providing illegal effort, since the social planner indirectly has stated that the farmers should not provide such effort. The social planner wishes to maximize function 7.

$$\Pi^{SP} = p\left(X - K(E, W(e))\right) + r(L - E - e) + V(W(e)) \quad ; \quad e = 0 \tag{7}$$

The assumptions and specifications will be the same as in the case of ex-post compensation. However the social planner do not wish that the farmer should spend any illegal protective effort. In Norway it is so that the conservation agency wishes that the farmers spend no time on poaching, rather having other professional agents dealing with the carnivore population control. And therefore the prohibition of poaching is used. Because of this the social planner would prefer that $e = 0$. And we should also understand that the social planner because of this do not evaluate any illegal effort and the costs of this. The existence value is added to the profits since the carnivores have a value to the society, which the farmers usually do not consider. It is assumed that this existence value is increasing in the carnivore stock at a diminishing rate, $V_W > 0$ $V_{WW} < 0$. The social planner consider the compensation just as a transaction through the society, and not a gain. Hence this is not a part of the profits to the society. The social planner will maximize the profits with respect to the time constraint, which is already included in the equation 7.

$$\frac{\partial \Pi^{SP}}{\partial E} = -pK_E - r \lesseqqgtr 0 \quad ; \quad 0 \leq E \leq L \tag{8}$$

Equation 8 decides the optimal protective effort from the perspective of the society. This equation gives an internal solution for maximum given that the function is concave in the variable E, and that the alternative wage is initially lower than the revenue from protective effort. Concavity is ensured with the assumptions we already have made about the second order derivatives of effort. It must furthermore be that there is an internal solution, since we in fact observe that the Norwegian authorities try to achieve protective effort. This observation also underlines that it should be a solution to the local herder's maximization problem when there are no compensation. Hence it is from this solution argued that also the ex-post solution could have an internal solution, but that this can cancel out due to the compensation.

It is clear that equation 8 gives the socially optimal level of protection, E^*. Hence it must be considered a problem that the farmer allocates the time use differently due to the compensation given. With full compensation the farmer will not protect the livestock, which clearly differs from the optimal protection level.

The compensation of sheep killed by predators must be seen as a redistribution from the society, which benefits from the presence of lynx and wolverine, to the farmers that suffers from sheep loss. Hence the redistribution is not any improvement in the social planner case. The lack of protective effort provided is thus considered a problem. We do not achieve the socially optimal level of protective effort with such a compensation scheme.

In Zabel et al. (2010-I) the compensation is used so that the farmer would abstain from poaching. But since the carnivore controlling effort is criminalized in this model, it seems like there is really no use for a full compensation scheme to achieve this. Thus it seems like the compensation scheme is not a tool for carnivore conservation. The compensation is rather considered a redistribution from the society who causes damage to the farmers, and thus a legal, rather than economical tool. Because of this result, I will in section 5 consider that the conservation agency manages to get to farmers to abstain from poaching due to the cost of criminal behavior, and look at the carnivore stock as fixed.

3.3 Matters to Improve Protective Effort

It follows from the social planner solution that compensating for wildlife damage is good in terms of preserving the wildlife and protecting the carnivores from poaching. However the compensation also leave the farmers with no incentives to protect their herd in legal matters either. There are some matters from the conservation agency to maintain the optimal level of the protective effort, like argued in section 2. The farmers are paid to maintain some of this effort. One way is to pay for the costs following cadaver verification, another way is financial support to engage in protecting of the herd. The project of radio-collared sheep has been widely founded by the authorities (Haugset et al. , 2011; Hansen et al. , 2013), and reducing the grazing period is supported as well. (Ekspertpanel , 2011) Another aspect is that the conservation agency is using effort themselves to protect and patrol the grazing areas. Such subsidization of protective effort is not included in the model in Zabel et al. (2010-I), however it can easily be extended to the model. Hence, if the payment to maintain protective effort is a function $\rho(E)$, the local herder's maximization problem is given by equation 9.

$$\Pi^{LH} = p\left(X - K(E, W(e))\right) + qK(E, W(e)) - c(e) + r(L - E - e) + \rho(E) \tag{9}$$

This maximization problem will give the same solution as in the previous local herder case for the decision about the illegal protective effort. Therefore it will be no poaching when the farmer is compensated in full. However the first order condition for the control variable E has changed. This is now given by

$$\frac{\partial \Pi^{LH}}{\partial E} = -pK_E + qK_E - r + \rho_E \lesseqqgtr 0 \quad ; \quad 0 \leq E \leq L \tag{10}$$

If it is the case that the herders are fully compensated, the equation collapses into $\rho_E = r$. Hence the marginal cost of effort must equal the marginal payment for providing such effort. In this case we have an internal solution with an effort level larger than zero. However, for the internal solution to be a maximum, it is clear that $\rho(E) \geq rE$. In other words one can say that the local herder will only choose to provide protective effort if it is subsidized in full or even overpaid. If the compensation partly covers the loss, we can allow the $\rho_E < r$ and still get the optimal level of protective effort.

One problem with such subsidies is the problem of moral hazard. Since effort use in many cases is hard to measure, the farmers might be able to claim these subsidies, but still deviate from the intended behavior. Thus such subsidies would only make sense where there are direct and exact measurable protective tools being put into use. Radio-collaring animals and reduced grazing period are examples on measurable protective tools. The first one due to the fact that the agency just can deliver the tool themselves to the farmers at no cost to the farmer, while the reduced grazing period cost easily can be verified through the reduced slaughter weight. The farmers' allocation of time is harder to measure and control. The farmer may still deviate from the agreed time allocation, due to lack of transparent information. So compensating for the time a farmer would use for protection would not help maintaining the effort level.

What seems interesting to note is that this protective effort can be ensured by the authorities in two ways. The first being indirectly, by paying the farmers to keep some level of protection. While the other way is just by providing direct protective effort without involving the farmers. This can therefore explain some of the reason why the authorities wishes to monitor the development and patrol the grazing areas. Such controls are both essential to ensure that the carnivore populations stays at the desired levels, but are also providing some protective effort that the farmer do not provide due to the compensation scheme. In other ways, one can say that the effort allocation is professionalized through the agency, instead of it being provided by the farmer.

It is interesting to note that due to the compensation, the society must take care of the protection costs, and hence this will increase the profitability of the farmers. Such an intervention could be considered an additional grant to the farmer. Ekspertpanel (2011) shows how subsidies for protective effort plays a huge part of the Norwegian compensation scheme. The transfers due to the compensation scheme will be analyzed in section 4.

There is another aspect of this that should be mentioned as well. Since the full compensation ex-post scheme is removing all the incentives for protecting the herd, it also removes possible mistakes in time allocation. If one consider the game that occurs between the farmers, assuming that there is positive spillover from protective effort it can be the case that a single farmer supplies too much effort than considered socially optimal. This is because the farmer does not consider the positive effects from the other farmers protection effort. Calculating such a situation is shown in the appendix, section 8.1. However since the ex-post compensation scheme is removing the incentives for such protection, both legal and illegal, this misallocation is also removed. Hence the social planner can ensure that the social optimal level of effort is reached through subsidies.

4 The Ex-Ante Compensation Scheme

4.1 The Alternative Approach

An alternative to the ex-post compensation scheme is to pay farmers for the potential damage before the predation happens. As a contrast to the most common ex-post compensation scheme, Sweden took advantage of this idea in 2006 when they introduced an ex-ante compensation scheme for wildlife damage caused to Sami reindeer herders. (Zabel and Holm-Müller, 2008) The compensation scheme is not based on a direct per-animal-killed transfer, but depends of the number of predators in the area. Hence, we will see that the protective effort will not be reduced because of the compensation. The compensation value is calculated from the expected damage a predator in the geographical location would cause a sheep stock. Hence, the farmers get compensated more, the higher predator stock there is. Sheep farmers would have an incentive to keep a high carnivore population since they get paid directly for the amount of predators in their vicinity.

I will let the transfer be noted as $T(W(e))$. The compensation will be affected by the number of predators nearby. And it is assumed that the illegal protective effort still can be used to control the carnivore population. This way the model still relates to the model used in Zabel et al. (2010-I). The cost from illegal poaching is still included here, just to underline some of the policy tools. It is assumed that the compensation should increase in the carnivore stock at a constant rate. With the same conditions as earlier, the static maximization problem of a sheep herder given ex-ante compensation would be given by equation 11.

$$\Pi^{LH} = p\,(X - K(E, W(e))) - c(e) + r(L - E - e) + T(W(e)) \tag{11}$$

The first order conditions that follows are given by the equations 12 and 13.

$$\frac{\partial \Pi^{LH}}{\partial E} = -pK_E - r \lesseqgtr 0 \quad ; \quad 0 \le E \le L \tag{12}$$

$$\frac{\partial \Pi^{LH}}{\partial e} = -pK_W W_e - c_e - r + T_W W_e \lesseqgtr 0 \quad ; \quad 0 \le e \le L \tag{13}$$

It follows clearly from the condition 12 that the level of protective effort will not be affected by the compensation. The farmer would have incentives to protect the grazing sheep stock in ways that do not reduce the carnivore population. This condition is also being equal to the social planner condition, which ensures that the protection of the herd should be at the social optimal level. At the same time, equation 13 states that the farmers will not engage in illegal protective effort as long the marginal transfer is high enough compared to the marginal damage from a predator. That is, if $T_W = pK_W$ we will not get an internal solution, and the farmer would have no incentives to reduce the carnivore population by illegal means. If we consider criminilization of poaching as well, it is even easier to avoid this behavior. The reasoning behind this is that the herders are not compensated directly through the loss, but indirectly through the level of carnivores. With the ex-post compensation scheme they were compensated in relation to the actual loss the had. Hence there was no reason to reduce loss. With ex-ante compensation scheme the compensation is indirectly related to the loss, through one of the factors contributing to the loss, the carnivore stock. Farmers will prefer to have a carnivore stock as this yields a payoff, and there will be no poaching. After receiving the compensation, the farmers can still reduce loss, and hence do better than without the protective effort.

There might however be a problem related to how the $T(W)$-function is put together. Zabel and Holm-Müller (2008) states that the payment is calculated from the expected damage the predators will cause during their lives. But expectation is often based on previous observations. So we should expect that the predation rate should be given by $\frac{K}{W}$. However, since the predation might be altered from protective effort, the expected damage from predators changes as well. If the farmers experience that the ex-ante compensation transfer is given by $T = T(W, \frac{K(E,W)}{W})$, this should again lead to a deviation from the social planner optimal use of protective effort. The problem is thus to make the transfer as independent from the predation, and from the historical predation rate, as possible. If the farmers sense any relation to their allocation of effort, the solution will be altered, since we do not have $T_E = 0$.

On the other hand, we could have the opposite problem. Considering that the carnivore stock might be taken as fixed to the farmer due to the criminalization, the ex-ante compensation would be a lump sum transfer. Like mentioned in the descriptives of the Norwegian compensation scheme, the Norwegian farmers are subsidized through production grants. With a lump sum compensation transfer, it might not be obvious that this is compensation for the presence of carnivores. Thus if this lump sum transfer seems to farmers to be non-related to the carnivore stock, and recognized just as another grant, it might not remove incentives to restrain poaching. It is therefore important for the conservation agency to enlighten the fact that the compensation really depends on and relates to the carnivore stock.

4.2 Comparing Costs

One of the interesting aspects of the compensation schemes from the view of the authorities is the size of the transfers caused by both compensation and subsidies. How much must the herders be supported to fully compensate for damage and still provide the social efficient level of protective effort. Zabel et al. (2010-I) shows that it is more expensive with ex-ante compensation than ex-post compensation. This is due to the fact that the ex-post compensation scheme is calculated without any consideration of the effort level. However with the Norwegian compensation ex-post scheme one could expect a different result. Since the protective effort is kept at the optimal level by financial support, we know that the transfer size should be larger than in the model by Zabel et al. (2010-I), and that the conclusion might differ.

The ex-ante solution is given by the equation 13. Here we can find the compensation value that will ensure that there are no poaching and an optimal level of protection. However, this compensation scheme is still governed by the Norwegian law that all the farmers should be fully compensated for the wildlife damage. From the profit equation we have the damage value function $pK(E, W(e))$. Hence if the farmer should be fully compensated we must have that $T(W(e = 0)) = pK(E^*, W(e = 0))$. This being for the optimal level of protective effort set from the social planner solution in equation 8 and from the notion that no illegal effort should be provided. In the ex-ante case, this is the only transfer from the authorities to the farmer. Hence this is also the total program cost of this scheme.

The ex-post solution has some of the similar properties. The solution is given by equation 4. But also here it is given that the authorities is going to compensate the farmer in full. Hence the compensation should be of the size $qK(E^*, W(e = 0)) = pK(E^*, W(e = 0))$. The level of protective and illegal effort are still set through the governing authorities, hence these values are still the same as in the ex-ante solution. Because of this rule of full compensation, we end up with equal size of the compensation in the two cases. However, it is clear that this ex-post solution has additional transfer costs since the farmer is paid to keep the protective effort at the optimal level. We saw that the protective effort had to be fully covered by the social planner. Hence there is also the transfer $\rho(E)$ to take into account. Leading to the fact that ex-post complete compensation with protective effort compensation is more costly than the ex-ante complete compensation.

$$\textit{Ex-post costs} = pK(E^*, W(e = 0)) + \rho(E^*) > pK(E^*, W(e = 0)) = \textit{Ex-ante costs}$$

It can easily be interpreted that both schemes will lead to the optimal level of protection, however in the case of ex-ante scheme the farmer covers the costs of protective effort, where as the social planner is covering the costs in the case of ex-post compensation. Hence it can be stated that the ex-post compensation scheme with support for protective effort should be more profitable to the farmer than the case with ex-ante compensation.

Zabel et al. (2010-I) do a fairly more complex analysis of this topic than what is presented here. However with the cirminalization of illegal effort, the success of the compensation scheme is not measured by the removal of poaching. Thus is is hard to compare the transfer costs of the two schemes when there are only partly compensation. One way to look on this is to compare the transfer size of the schemes when the compensation ratio is equal. However, for equal compensation ratio, also the size of the compensation is equal. Thus the ex-post compensation schemes must still be the more expensive in transfers due to the additional subsidies of protective effort.

5 Dynamic Analysis

5.1 Dynamic Ex-post Analysis with a Fixed Carnivore Stock

In a dynamic analysis we isolate the dynamic and the static parts of the problem. The sheep stock will be denoted by X_t, and the growth in the sheep stock is given by $\dot{X}_t$. It is now assumed that the farmer face a given carnivore stock, and that they cannot influence the size of this. Hence there are no illegal protective effort present in this model, and the conservation agency sets the desired carnivore stock. If the carnivore stock is denoted W and the level of protective effort noted as E_t, the growth in the sheep stock is given by equation 14.

$$\dot{X}_t = sX_t - h_t - nX_t - K(W, X_t, E_t) \tag{14}$$

The intrinsic growth rate of the sheep stock is given by s. This means that I look away from the usual assumption that species are subject to logistic growth. The reason behind this assumption of linear growth is due to the fact that the sheep stock is directly regulated by humans. Hence the sheep is not exposed to such as resource redundancy or density problems. Subjects like food supplies are rather reflected in the cost functions of the herders. The sheep sent to the butcher, h_t is reducing the sheep stock. The normal loss rate of the stock is given by n. That leaves the last part of the expression, where K is the number of sheep lost due to predation. This loss depends on the carnivore stock and the effort level, like we examined in the static model. The difference here is that the predation also depends on the sheep stock itself. The higher sheep stock cet.par., the higher availability of sheep, and the likelihood of predation is increased. Hence it is assumed that the predation is increasing in the sheep stock, $K'(X) > 0$, increasing in the carnivore stock, $K'(W) > 0$, and decreasing at a diminishing rate with the effort level, $K'(E_t) < 0$ and $K''(E_t) > 0$. The static profit expression in each period of time is given by equation 15.

$$\Pi_t = ph_t - C(X_t) + q_t K(W, X_t, E_t) + ro_t \tag{15}$$

h_t denotes the number of sheep that is slaughtered each year, while p is the slaughter value. The slaughter value is assumed to be fixed. The profits Π_t is given by the total revenue from harvested sheep ph_t and subtracting for the costs of the sheep stock $C(X_t)$. In addition we have to take account for the compensation given for the predation in this point of time. q_t is the ex-post compensation per animal killed, while K is the total predation. The ro_t-function depicts the costs related to the protective effort, given by the opportunity wage. The farmer face a time constraint, like in the static model, in each period of time given by $L = E_t + o_t$. Inserting for the outside option in the equation 15 gives the equation 16 where the alternative cost of effort is exposed.

$$\Pi_t = ph_t - C(X_t) + q_t K(W, X_t, E_t) + r(L - E_t) \tag{16}$$

We should note that q and W are the only existing policy variables, but they are assumed to be given due to the existing regulations in Norway. The q is given since it should be equal to the sheep value, while the W is given since the carnivore stock is decided by the conservation agency. I will look on some effects of changes in these variables later, but this will not be the initial stand.

This model relates clearly to the static model used in the previous sections, and thus it also relates to the model used in Zabel et al. (2010-I). The clear distinction between the models is the use of a growth equation for the sheep stock, and also the fact that the predator stock size is considered given. Zabel et al. (2010-I) do not consider such a dynamic model, however the authors have written a unpublished paper considering a dynamic approach. (Zabel et al., 2010-II) In the dynamic model in Zabel et al. (2010-II) it is however so that the sheep stock is subject to logistic growth, a condition that is altered in this model that will be presented here. It is also the fact that the predator stock size might vary in the model by Zabel et al. (2010-II), and hunting of carnivores are allowed. The models also differs greatly in the analytical approach, because of these assumptions.

Given the profit equation and the sheep growth constraint, the herder's optimization problem is to maximize the present value of the profits with respect to this constraint.

$$\max \quad \int_{t=0}^{\infty} \Pi_t e^{-\delta t} dt \quad \text{subject to} \quad \dot{X}_t = sX_t - h_t - nX_t - K(W, X_t, E_t) \tag{17}$$

I assume that the herders knows the size of the initial sheep stock, X_0. The ending X_∞ is free for all values above zero. And the control variables, h_t and E_t, is non-negative. The current value hamiltonian is given by equation 18.

$$\mathcal{H} = ph_t - C(X_t) + q_t K(W, X_t, E_t) + r(L - E_t) + \lambda_t (sX_t - h_t - nX_t - K(W, X_t, E_t)) \tag{18}$$

This system has got two control variables. One in the harvest h_t, and one in the protective effort E_t. There is one state variable in the sheep stock X_t. Hence we will have two maximum principles (MP) and one portfolio balance equation (PB). These are given by equations 19, 20 and 21 respectively.

$$\frac{\partial \mathcal{H}}{\partial h_t} = p - \lambda_t \lesseqqgtr 0 \quad ; \quad h_t \geq 0 \tag{19}$$

$$\frac{\partial \mathcal{H}}{\partial E_t} = -r + (q - \lambda_t)\frac{\partial K}{\partial E_t} \lesseqqgtr 0 \quad ; \quad 0 \leq E_t \leq L \tag{20}$$

$$\dot{\lambda}_t - \delta\lambda_t = C'(X_t) + (\lambda_t - q_t)\frac{\partial K}{\partial X_t} - \lambda_t s + \lambda_t n \tag{21}$$

First of all, I would like to underline the fact that this Hamiltonian leads to a maximization due to the assumption that the cost function is strictly convex in the sheep stock. This makes the Hamiltonian strictly concave in the state variable. It might be that the predation function is not linear in the sheep stock, and thus influences the results, but it is assumed that a concave predation function would be less of importance than the convex cost function. This is discussed further in section 5.3. It should also be underlined here that since we have linearity in one of the control variables, we will see a most rapid approach path (MRAP) to the steady state. This means that the dynamics of this model will lead to the steady state solution. If there is a shift so that we observe non-equilibrium, we will have a immediate transition to the new steady state. Therefore I will only study the steady state of the model.

MP1, equation 19, gives the optimal condition for the control of the sheep stock through the harvesting. This equation states that the price of the sold sheep should equal the shadow price of the sheep stock. Hence the marginal revenue of the harvest should equal the marginal cost of a reduced future sheep stock.

MP2, equation 20, is a fairly more complex equation. But it does in fact state very much the same as the equation 3 from the static model. The first part of the equation is the marginal cost of providing effort. This must, in absolute value, equal the second term. This states that the gain from the protection is the value of increased sheep stock in the future, subtracted for the reduced compensation in the current time. It is not for sure that this equation has got an internal solution for $E_t > 0$, and thus corner solutions should be considered.

The PB, equation 21, is stating the change in the shadow price over time. The growth in the shadow price of the sheep stock, subtracted for the depreciation of this shadow price should equal the net growth, $s - n$, in sheep stock, the marginal cost of an increased sheep stock, and the marginal cost of increased predation when the sheep stock increases.

5.1.1 Steady State

In the steady state we have by definition no change in any of the variables over time, hence $\dot{\lambda}_t = \dot{X}_t = 0$. In addition it is possible to ignore all time subscripts. Equation 19 is easily manipulated to the condition 22. Thus the shadow cost of the harvest should equal the marginal revenue of the harvest.

$$\lambda = p \tag{22}$$

Inserting for λ in the MP2 and PB-conditions given by equation 20 and 21 results in equation 23 and 24.

$$-r + (q-p)\frac{\partial K}{\partial E} \lesseqgtr 0 \quad ; \quad 0 \leq E_t \leq L \tag{23}$$

$$(s-n) = \frac{1}{p}\left(C'(X) + (p-q)\frac{\partial K}{\partial X}\right) + \delta \tag{24}$$

Equation 23 is pretty much identical to the equation 3 in the ex-post solution. Hence we can draw the similar conclusion. The condition will have a possible internal solution. But if the case is like in Norway, that we have full compensation $p = q$, there will be no solution for $E > 0$. Equation 24 is the sheep herder's *golden rule* condition. The *golden rule* states the steady state equilibrium and can be used to find the steady state sheep stock given by the parameters. It should be underlined that the discount rate in this equation indicates that profits are not considered equally over time. Thus with a discount rate, the farmer is inpatient, and this would lead to a lower sheep stock than what would have been optimal without such a discount rate.

Similar to the MP2, a large part will disappear from equation 24 if we have the case of full compensation. The equation will hence collapse into

$$(s-n) = \frac{1}{p}C'(X) + \delta \tag{25}$$

This equation will set the steady state sheep stock. An examination of this sheep stock size will be dealt with later in the paper.

5.2 The Dynamic Social Planner Solution

The sheep growth equation will be the same as in the case for the local herder ex-post compensation scheme, given by equation 14. The difference between the ex-post scheme and the social planner base line model is in the profit equation. The social planner do not evaluate the compensation, but consider the existence value of the carnivores. Hence the profit equation changes to the following.

$$\Pi_t = ph_t - C(X_t) + r(L - E_t) + V(W) \tag{26}$$

Here $V(W)$ gives the existence value of the predators W. The current value hamiltonian changes to equation 27.

$$\mathcal{H} = ph_t - C(X_t) + r(L - E_t) + V(W_t) + \lambda_t(sX_t - h_t - nX_t - K(W, X_t, E_t)) \tag{27}$$

Hence the necessary conditions for optimum changes to equation 28, 29 and 30. The maximum is ensured given that the same conditions in the ex-post analysis hold. We will also have a MRAP situation in this case, since the hamiltonian is linear in the control variable.

$$\frac{\partial \mathcal{H}}{\partial h_t} = p - \lambda_t \leq 0 \quad ; \quad h_t \geq 0 \tag{28}$$

$$\frac{\partial \mathcal{H}}{\partial E_t} = -r - \lambda_t \frac{\partial K}{\partial E_t} \lesseqgtr 0 \quad ; \quad 0 \leq E_t \leq L \tag{29}$$

$$\dot{\lambda}_t - \delta\lambda = C'(X_t) + \lambda \frac{\partial K}{\partial X_t} - \lambda s + \lambda n \tag{30}$$

The first condition (MP1), given by equation 28, is similar to the dynamic ex-post counterpart in equation 19. The second condition (MP2), equation 29, differs however from equation 20. The condition states that effort should be provided so that the marginal cost of effort, given by the opportunity cost, should be equal to the marginal value of the protected sheep in the next period. This result compares to the differences between the ex-post compensation scheme and the social planner baseline in the static analysis described in section 3.2. From the similar reasoning, it seems to be the case that there is an internal solution to this social planner problem.

The portfolio balance equation 30 has changed, compared to the equation 21. This is due to the fact that the herder does not care about the predation in the ex-post scheme, and hence does not consider how an increased sheep stock will influence the predation. This is taken into account in the social planner's portfolio balance equation.

5.2.1 Steady State

The steady state solution follows from the same calculations as the ex-post steady state. Hence the social planner steady state is given by

$$(s-n) = \frac{1}{p}\left(C'(X) + p\frac{\partial K}{\partial X}\right) + \delta \tag{31}$$

This steady state solution differs from the ex-post steady state solution in equation 25 in the term within the right hand side brackets. The difference is that the social planner consider the increased predation from increasing the sheep stock, cet.par., while this is not interesting to a farmer that is completely compensated. The result should be that the social planner would consider a lower sheep stock than the local herder under two conditions, the predation must increase in the sheep stock and the cost function of the sheep stock must be convex. This can easily be shown through the following example.

Since all except the term inside the right hand side brackets in equation 31 and equation 25 are parameters, we can compare the term inside the brackets. For the equalities to hold, it must be that

$$\left(C'(X)\right)^{EX\text{-}POST} = \left(C'(X) + p\frac{\partial K}{\partial X}\right)^{SP} \tag{32}$$

Since we know that the predation is increasing in the sheep stock, $\frac{\partial K}{\partial X} > 0$, it must be true that

$$\left(C'(X)\right)^{EX\text{-}POST} > \left(C'(X)\right)^{SP} \tag{33}$$

From the assumption that the farmers face positive and increasing marginal costs it is clear that the sheep stock in the ex-post compensation scheme must be larger than the sheep stock in the social planner solution.

The ex-post compensation scheme which is compared here is the one with full compensation, $q = p$. On the other side one can consider the social planner steady state as the no compensation situation, $q = 0$. For ex-post partial compensation, $0 < q < p$ it would therefore be a solution that would lie in-between the two extremes. This can be seen in section 5.3.1, discussing the comparative statics.

Bulte and Rondeau (2007) analyze how local herders who are compensated experiences increased profitability and how this might deviate from the social optimal solution. Bulte and Rondeau (2005) also describe how increased profitability might damage the carnivore conservation. This effect is not present in this model, since the carnivore stock is considered fixed. However the local herder faces an increased marginal profitability of the sheep stock here as well, which results in the large sheep stock. Thus it seems like the ex-post compensation scheme might cause various problems due to such increased marginal profitability.

5.2.2 The Ex-Ante Solution

The ex-ante solution will not differ from the social planner solution. Considering that the herder is given a lump sum transfer based on the number of predators, this collapses into much of the same expression as the social planner. The profit equation for the herder in the ex-ante compensation scheme is given by equation 34, where $T(W)$ is the ex-ante compensation.

$$\Pi_t = ph_t - C(X_t) + ro_t + T(W) \tag{34}$$

Compared to the social planner profits in equation 26 the only difference is the function depicting the gain of the size of the carnivore stock. In addition to this, in both cases this function holds a fixed value since it is assumed that we have a fixed carnivore stock. Thus it can be stated that the ex-ante compensation scheme must equal the social planner solution, and hence lead to the socially optimal state. Because of the general similarities between the social planner solution and the ex-ante solution I will later in this paper only compare ex-post and social planner solutions.

5.2.3 The Dynamic Norwegian Compensation Scheme

In section 3.3 it was discussed how the governmental institutions could correct for the lack of protection effort. A similar correction could be discussed in this dynamic case. I assume that the local herder sets the carnivore stock, so for the conservation agency the sheep stock should be considered fixed, $X = \overline{X}$. The conservation agency can now, under this complete compensation ex-post scheme, only correct the missing protective effort. The protective effort under these conditions can be found through equation 29.

The solution to this condition could lead to the same level of effort as in the ex-ante solution, or the solution where the social planner could set the optimal sheep stock, under the condition that the predation function is additively separable. In mathematical terms, if $\frac{\partial^2 K}{\partial E \partial X} = 0$, we will have a correction of the effort level so that the effort corresponds to the social planner solution. If we by chance should have that $\frac{\partial^2 K}{\partial E \partial X} < 0$, it would be the case that the effort level should be higher than the social planner solution, so as to compensate for the higher sheep stock. When the sheep stock increases it is so that it gets more effective to protect the sheep, and thus the more effort should be provided. For the graphical analysis I will consider the Norwegian local herder with the full compensation ex-post optimal stock, given from equation 25, and the social planner optimal protective effort, given by equation 29. It is considered that the social planner would set the protective effort through grants like discussed in the section 3.3.

5.3 Steady State Comperative Statics

5.3.1 The Simple Case of Full Ex-Post Compensation

I would like to examine how the steady state is affected by the different parameter values. I will first look upon the simple steady state solution for the complete compensation ex-post scheme, before we study the topic in more general matters. Hence this simple illustration serves as both a base line for the more complete analysis, and as an example on the extreme case of full compensation. The full compensation ex-post equation 25 can be differentiated, and this is given by equation 35.

$$(s - n - \delta)dp + pds - pdn = C''(X)dX \tag{35}$$

From this it is easy to find the comparative statics solutions and analyze how the steady state is influenced by differences in p, s and n. The equation 36 states that the sheep stock will be higher, the higher the sheep value. It is important to note here that compensation value, q, must still be the size of p since we must follow the case of full compensation for this to be true. Equation 37 states that the sheep stock should be higher the higher the sheep reproduction rate, cet. par. And on the other side equation 38 states that the sheep stock is lower the lower the normal loss rate is.

$$\frac{dX}{dp} = \frac{s - n - \delta}{C''(X)} > 0 \tag{36}$$

$$\frac{dX}{ds} = \frac{p}{C''(X)} > 0 \tag{37}$$

$$\frac{dX}{dn} = -\frac{p}{C''(X)} < 0 \tag{38}$$

5.3.2 Comperative Statics of Partial Compensation

The extended analysis takes interest in the partial ex-post compensation. From this situation it is also easy to analyze the social planner and ex-ante compensation steady state comparative statics. Differentiation of the steady state equation 24 leads to the equation 39, and can be rearranged to equation 40.

$$\begin{aligned}(s-n-\delta)dp + pds - pdn = \\ C''(X)dX + \frac{\partial K}{\partial X}dp - \frac{\partial K}{\partial X}dq + (p-q)\frac{\partial^2 K}{\partial X^2}dX + (p-q)\frac{\partial^2 K}{\partial X \partial W}dW > 0\end{aligned} \tag{39}$$

$$\begin{aligned}\left(s-n-\delta-\frac{\partial K}{\partial X}\right)dp + pds - pdn + \frac{\partial K}{\partial X}dq - (p-q)\frac{\partial^2 K}{\partial X \partial W}dW = \\ \left(C''(X) + (p-q)\frac{\partial^2 K}{\partial X^2}\right)dX\end{aligned} \tag{40}$$

In this differentiation it is indirectly assumed that the predation function is additively separable. The $K(W,X,E)$-function can be written as $K(W,X,E) = K_1(W,X) + K_2(E)$. This is a simplification that eases the mathematics greatly. It is also is necessary for the analysis that will be done in section 6. The comparative statics can hence be analyzed from the equations 41, 42, 43, 44 and 45. It should be noted that the social planner solution is equal to the case when there are no compensation, $q = 0$.

$$\frac{dX}{dp} = \frac{s-n-\delta-\frac{\partial K}{\partial X}}{C''(X) + (p-q)\frac{\partial^2 K}{\partial X^2}} \tag{41}$$

$$\frac{dX}{ds} = \frac{p}{C''(X) + (p-q)\frac{\partial^2 K}{\partial X^2}} > 0 \tag{42}$$

$$\frac{dX}{dn} = -\frac{p}{C''(X) + (p-q)\frac{\partial^2 K}{\partial X^2}} < 0 \tag{43}$$

$$\frac{dX}{dq} = \frac{\frac{\partial K}{\partial X}}{C''(X) + (p-q)\frac{\partial^2 K}{\partial X^2}} > 0 \tag{44}$$

$$\frac{dX}{dW} = -\frac{(p-q)\frac{\partial^2 K}{\partial X \partial W}}{C''(X) + (p-q)\frac{\partial^2 K}{\partial X^2}} < 0 \tag{45}$$

We know from our previous assumptions that the predation is increasing in the sheep stock, $\frac{\partial K}{\partial X} > 0$, but we have not assumed anything about the rate that this increases. If this increases at a constant rate, the equations does not change much, since the derivative of the second order is equal to zero. However we might lift this assumption. But we know from the maximization of the hamiltonian in equation 18 that this denominator is the negative value of the second order condition of the hamiltonian. Thus for the hamiltonian to lead to a maximum, the denominator has to be larger than zero, $C''(X)+(p-q)\frac{\partial^2 K}{\partial X^2} \geq 0$. If we consider the case where the predation is increasing the sheep stock at an increasing rate, it is so that the denominator in the equations 41, 42 and 43 are bigger than their respective equations from section 5.3.1 in the case of full compensation. And thus the dynamics show that the change in sheep stock size should be less responsive to changes in the parameters than in the case of complete ex-post compensation. Zabel et al. (2010-I) states that predation functions that are convex in the carnivore stock should indicate that the predator gains a technological advance from hunting in packs. While functions that are concave indicates that the predators are competing for territory and thus spend less time on predation.

Examining the numerator in equation 41 the marginal effect of the size of the sheep stock on the predation is included. We should however evaluate the numerator as positive, since we assume that introducing new sheep does not lead to the predation increasing with more than the sheep introduced. And thus we find that the steady state comparative statics has the same effects as in the analysis of full compensation. A higher value of sheep will yield a higher sheep stock, cet. par. The higher the reproduction rate of sheep, the higher the sheep stock. The lower the normal loss rate, the higher the sheep stock. However, since we know that the denominator might be larger than in the case of complete compensation, it is so that the changes is smaller in size. Hence, a complete compensation ex-post scheme should react more to parameter changes than the social planner would have done. Regardless of the assumptions about the denominator, the local herder will react too much to a price change.

Equation 44 states simply that the sheep stock should be increasing in the compensation value. This corresponds to what we discovered in the section 5.2.1. The ex-post full compensation was shown to lead to a higher sheep stock than the social planner solution. These two cases was considered two extremes of q either being equal to 0 or the sheep value, p. Since the values q can take could be interpreted as a continuous function between 0 and p, it seems like the the sheep stock should increase in the compensation between the extremes. The comparative statics underlines this fact.

Equation 45 states that the sheep stock in steady state is lower the higher the carnivore stock, cet.par. If there is full compensation, this cancels out, and there will be no effect. Considering the variations in the compensation ratio, it seems obvious that this fraction will have a lower value the higher the compensation ratio.

In this short comparative statics analysis the effects from possible changes in the level of protection as the sheep stock changes has been ignored. It might be that the effect of protection of sheep are greater on the predation level when the sheep stock is higher, and thus changing the effort put into protection. At the same time the marginal profitability of the sheep stock might change as the protection level increases, and thus changing the size of the sheep stock. However this effect is considered to not affect the the sign of the comparative statics.

5.4 Graphical Analysis of Steady States

5.4.1 Ex-Post Steady State Analysis with Complete Compensation

The steady state solutions can easily be illustrated with some figures. First I will only consider the case of full compensation since the case of partly compensation easily can be figured to lie in-between the extremes of full compensation and no compensation. I will consider the graphical relations of the elements in the steady state given by equation 25. For comparison I will consider the sheep stock growth equation 14, where we in steady state will observe zero growth. I will use this to identify the sheep stock in steady state, and from this evaluate the other variables in steady state. From this representation it can also be shown some graphical comparative statics, to see how a change in one of the parameters p, s, n will affect the steady state variables.

We can split the steady state equation 25 in two parts. $p(s-n-\delta)$ on one side, should equal the marginal cost of the sheep stock on the other side. In the graphical representation, the first part will be a straight line in the X-diagram, since it only contains parameters and does not change with the sheep stock. The marginal cost of the sheep stock is however, like previously assumed, increasing in the sheep stock. If the marginal cost starts out at a lower value than the parameters-line, it is clear that this will eventually lead to an intersection, illustrating the steady state. This solves the steady state solution for $X = X^*$, which is depicted in figure 9.

Considering the sheep stock growth equation in steady state, we have that $\dot{X} = (s - n)X - K(W, X, E) - h = 0$. This can be rearranged to $h = (s - n)X - K(W, X, E)$. A graphical representation of this in the X-diagram can from the X^*-value help us to identify the steady state predation and harvest. We know that the birth rate, s, must by definition be larger than the natural loss rate, n, and that the growth in sheep stock from this must be increasing in the stock. The predation is also assumed to be increasing in the sheep stock. In the graphical representation, this is for simplicity matters represented as a straight line. This relation could as well be concave, however it would not change

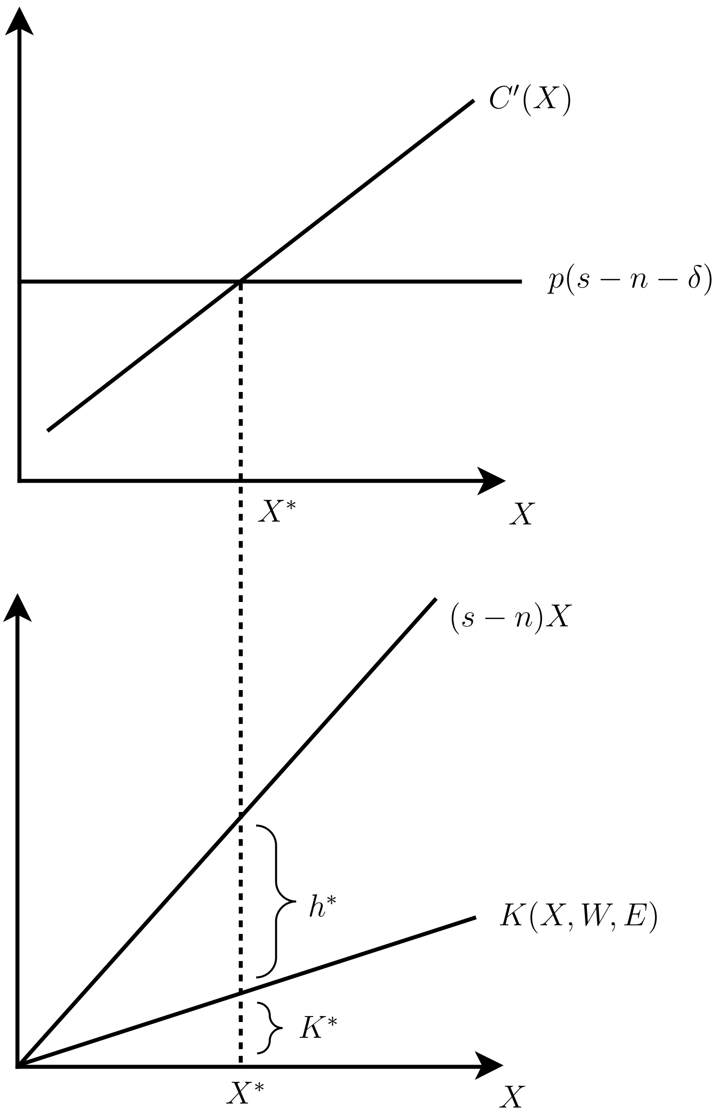

Figure 9: Steady state solution for complete ex-post compensation

the outcome of the model. It seems like an impossible task that the predation could be strictly convex in the sheep stock, since this eventually would lead to $K > X$. Hence the case with linearity or a concave relation seems more plausible.

The sheep stock is given from the steady state solution. The sheep stock can then be used to read the predation, and thus also find the harvest size from the difference between the predation and the natural growth in the sheep stock.

Some comparative statics is easy to grasp from this figure. First of all we can see that the sheep value is only included in the steady state connection. Hence the line marked $p(s-n-\delta)$ must sift upwards, leading to a higher sheep stock in steady state, if the parameter p increases. This must also result in a higher predation and a higher harvest. Given that the predation function is linear, the share of human consumed sheep and carnivore consumed sheep would be equal. If we had a concave relation between predation and the sheep stock, it follows that the share of human consumed sheep increases while the share of carnivore consumed sheep decreases.

An increased birth rate, s, would lead to the similar effects to the steady state stock. However, the birth rate also affects the sheep growth condition. The part $(s-n)X$ will therefore pivot to the left. The predation-part of the growth equation will not be changed. Hence, we will have much of the similar effects of the increased sheep value, but in this case, the human consumption share will increase while the carnivore consumption share will decrease, even though the predation function is linear. This is due to the fact that $(s-n)X$ gets steeper in X, while the steepness of $K(W,X,E)$ remains unchanged.

Recent outbursts of tick in the Norwegian grazing areas might have lead to more diseases, thus discussions of the effect from changes in n is interesting. A change in this parameter will pretty much be the opposite of the increased birth rate. An increase in the normal loss rate will lead to a downward shift in the horizontal part of the steady state equation, leading to a lower sheep stock. In the growth equation we will see a less steep $(s-n)X$-line, while the $K(W,X,E)$ remains unchanged. That will result in a steady state with lower sheep stock, and hence a lower predation. However the harvest will be lowered even more, since the steepness has changed. Hence the share of human consumed sheep will decrease while the share of carnivore consumed sheep will increase.

5.4.2 Analysis of Ex-Post Partial Compensation and Social Planner Solution

The social planner solution have many similarities with the partial compensated ex-post solution. I will therefore analyze both the social planner and the ex-post solution here. This social planner solution is given when the $q=0$,while partial ex-post compensation is given when $0<q<p$. The change from the ex-post full compensation scheme is the expression $-(p-q)\frac{\partial K}{\partial X}$ which appears in the steady state condition. We know from the definition that this differential is positive, and since $q<p$ it must be the case that the horizontal line in the steady state diagram must shift downwards compared to the horizontal line from the ex-post full compensation in figure 9. If the predation is linear in the sheep stock, this new line will be parallel with the previous graphical representation. If the predation is concave in the sheep stock, the steepness of the line will change and not longer be horizontal. Since concavity means that the marginal effect is decreasing, it must be that this line will slope downwards. However, this will not lead to any large difference in the results, and thus the line is drawn linearly for simplicity matters.

It follows first of all from the steady state solution that we now will have a lower sheep stock in steady state than with the full compensation. This is marked by the difference between the solution in A to the solution in B. However, we must recall the second maximum principle, stating that a lower compensation or the social planner scheme will lead to a higher effort level allocated towards the protection of the sheep stock. Hence

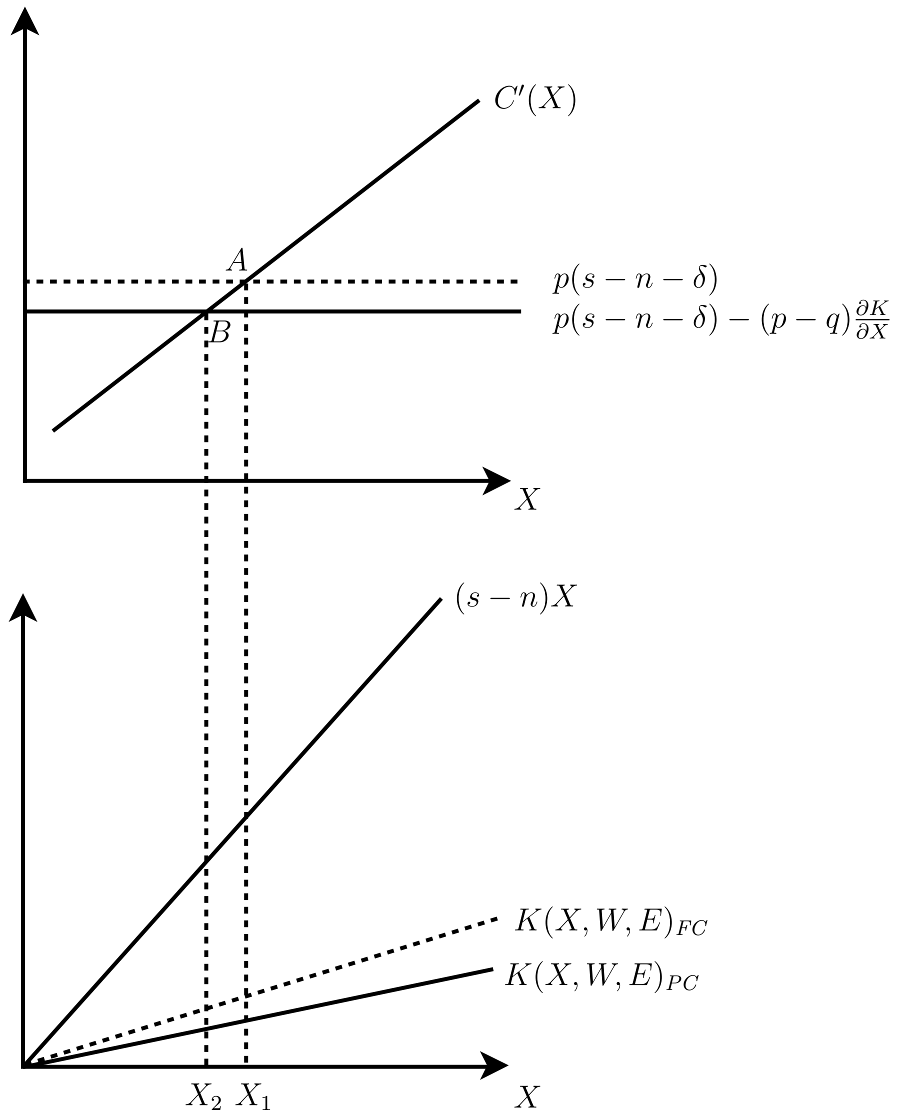

Figure 10: Steady state differences between ex-post and social planner solution

it is clear that $E\uparrow$ compared with the full compensation ex-post solution. This comes into effect in only one part of the system, the predation. When the protective effort increases, the predation will decrease. Hence the predation function will shift downwards from $K(W,X,E)_{FC}$ to $K(W,X,E)_{PC}$. If the predation function is additively seperable in the effort this must be seen as a parallel shift. Because of the function specification, this is my main stand. However in the graph this is illustrated as a pivot around origo due to the fact that this is a more realistic assumption.

The complete compensation ex-post steady state stock is noted by X_1, while the social planner sheep stock is noted by X_2 if $q=0$. The predation in the partial compensated scheme is given by point D, where the predation is given by the X_2 sheep stock. The harvest is given by the difference between the points C and D.

5.4.3 A Graphical Intepretation of Comperative Statics

The graphical representation in figure 10 can both be used to consider what happens if the compensation share changes, $q \downarrow$, or what happens with the steady state if one should change from ex-post to ex-ante compensation scheme, or vice versa. It is clear that if the compensation rate decreases, this will lead to a decrease in the steady state sheep stock through the steady state condition. It is by definition given that the costs of the sheep stock $C(X)$ also will decrease. Due to the downwards shift in the predation relation, it is a bit unclear how the harvest will change, however the predation will decrease. It follows also from the shift in the predation relation that the share of human consumed sheep will increase while the share of carnivore consumed sheep will decrease. While the result on the harvest is unclear, and it cannot be stated how large the changes in the different variables will be, it cannot be concluded how this will affect the farmers' profits.

The social planner solution is given by $q = 0$. Thus the ex-post solution will differ from what is socially optimal. It is clear that the ex-post steady state has got a too high sheep stock, too high costs of the sheep stock, and a too high level of predation.

5.5 Comments on the Herders Dynamic Optimum in Norway

Figure 11 shows how the socially optimal steady state is deciding values for K and h given by the optimal sheep stock X^*. The complete compensation ex-post solution is described in section 5.1 and shown to be leading to a $\overline{X} > X^*$. Since this solution features no protective effort, the predation function shifts upwards like analyzed, and leads to the ex-post solutions for the harvest $h^\dagger$ and the predation $K^\dagger$. The Norwegian model features the option that the conservation agency either pays the farmer to stay at a higher level of effort protection, or provides the protective effort themselves. The optimal effort level was discussed in section 3.3, and is assumed to be equal to the social optimal level from the social planner solution. Hence the predation function will be at the initial level, and the predation in the Norwegian model is given by $K^\#$ and the harvest by $h^\#$.

It should be underlined though, that if it is the case that the predation function is not additively separable in the sheep stock and the protective effort level, it follows that the effort level should be higher than the effort level from the social planner solution. And this would again lead to a greater shift downwards in the predation function, so that the new predation function is even less steep than the original function from the social planner solution. This follows from the assumption that the protective effort is more effective on the margin the higher the sheep stock. And hence the social planner that face a fixed sheep stock should deviate from the original effort level. The results from this steady state analysis is summarized in table 3.

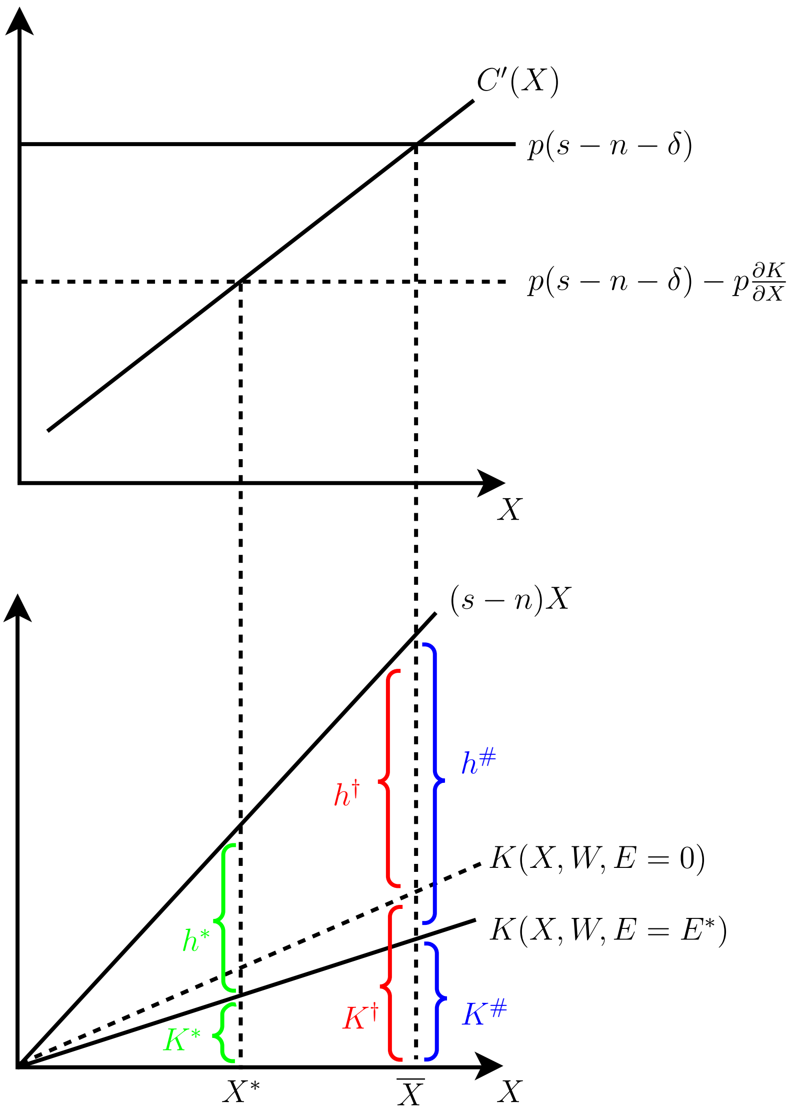

Figure 11: The Norwegian ex-post compensation with effort increasing subsidization

5.5.1 Policies of the Social Planner

As the full compensation ex-post scheme leads to distortion, the social planner is trying to correct for this by setting the protective effort level themselves. This is described in the latest graphical analysis. However, the fact that the local herders do not consider the increased predation when the sheep stock increases leads to a lower marginal sheep stock cost, and thus a higher sheep stock. It has become more profitable on the margin to have sheep. This can be adjusted by the social planner by taxing the sheep stock, so that the sheep get equally costly on the margin as in the social planner solution. Thus a correction would be to include a tax on the sheep stock, with the tax rate equal to the change in marginal sheep stock costs, $t = q\frac{\partial K}{\partial X}$.

In the descriptive section, it was discussed how the conservation agency supported the farmers through grants. For such grants to be socially effective, it must be the case that there is an external effect that makes the farmers have a lower sheep stock than socially optimal. I will not discuss the matters that can lead to such positive external effects of the sheep stock, but it is clear that these must either be related to the sheep stock itself or to the harvest size. If one consider that there is such an external effect that should be regulated through grants, one should also expect that this grant should be reduced by the amount that leads to the increased sheep stock in the previous section. Hence, since the farmers already are supported through the ex-post compensation scheme, and thus do not notice all the costs from a high sheep stock, they should be taxed so to bring the sheep stock to the optimal level. If there are positive external effects that are not included in this model, the grants from this correction should be decreased by the size of the taxes, so that the sheep stock gets to the optimal size.

	Social Planner	Ex-Ante	Ex-Post	Norwegian Model
X	X^*	$X^{EA} = X^*$	$X^{EP} > X^*$	$X^{NO} = X^{EP}$
$C(X)$	$C(X)^*$	$C(X)^{EA} = C(X)^*$	$C(X)^{EP} > C(X)^*$	$C(X)^{NO} = C(X)^{EP}$
E	E^*	$E^{EA} = E^*$	$E^* = 0$	$E^{NO} = E^*$
K	K^*	$K^{EA} = K^*$	$K^{EP} > K^*$	$K^{EP} > K^{NO} > K^*$
h	h^*	$h^{EA} = h^*$	$h^{EP} \gtreqless h^*$	$h^{NO} > h^*, h^{EP}$

Table 3: Dynamic results summarized

6 Numerical Analysis of Specified Functions

6.1 Function Specifications and the Steady State

For the next section I will insert some numerical examples in the models, so that it is possible to examine how the compensation schemes will differ from the social planner solution. To be able to do so, the functions used so far must be specified. There are two important functions, the cost function and the predation function. The marginal cost of the sheep stock is used to decide on the optimal sheep stock size in steady state. Assuming the cost function 46, this leads to a simple solution for the marginal costs.

$$C(X) = \frac{cX^2}{2} \quad \text{and} \quad C'(X) = cX \tag{46}$$

Inserting for this costfunction in the full compensation ex-post steady state solution given in equation 25, we can find the optimal sheep stock in equation 47.

$$X = \frac{p}{c}(s - n - \delta) \tag{47}$$

For the social planner, the predation function is also determining the optimal sheep stock. This function is specified like function 48, so that it is assumed that the function is additively separable in the effort variable. This is a simplification, but a necessary simplification to get a proper answer to the simulations, due to the existing data sources.

$$K(W, X, E) = K(W, X) + K(E) = \alpha W X - 2\epsilon E^{1/2} \tag{48}$$

Under the assumption that the predation function is additively separable in the effort variable, it is so that there is a level of effort that leads to the ultimate protection. Thus there exists an $E = E_{max}$ which lead to $K = K_{min} = 0$. In this section it is important to be aware of this limit on the effort level.

This predation function leads to the marginal predation rate of the sheep stock, $\frac{\partial K}{\partial X} = \alpha W$. I will call this the predation pressure, which is the increase in the predation from increasing the sheep stock. This rate should be considered constant, since α is a predation parameter and the carnivore stock is given. Since this rate is constant, the marginal predation should also equal the empirical average predation per sheep.

From this marginal effect and the steady state solution in 24 we can find the optimal sheep stock for the case of partial compensation, and for the social planner. These are given by equation 50 and 49 respectively.

$$X = \frac{p}{c}\left(s - n - \delta - \alpha W\right) \tag{49}$$

$$X = \frac{p}{c}\left(s - n - \delta - \left(1 - Q\right)\alpha W\right) \tag{50}$$

We may note that the difference between the equation 50, the sheep stock for a local herder with partial compensation, and equation 49, the social planner solution, is that the social planner would have evaluated the situation when there are no compensation. That being the social planner consider the same case as the general local herder equation, for the case when the compensation ratio is zero, $Q = 0$. At the same time we can find the local herder complete compensation sheep stock by inserting $Q = 1$. For the rest of this analysis I will therefore mainly look at the general case, and thus only draw conclusions regarding social planner and the local herder by inserting for Q. That will shorten the calculations and ease the analysis. Using the general equation would also enlighten the difference between the social planner solution and the local herder solution. From equation 50 it is for example easy to see that the term $-\left(1 - Q\right)\alpha W$ is the only one including the compensation ratio. Thus when the social planner would evaluate the part $-\alpha W$, while the local herder would evaluate this less the higher compensation ratio. This makes sense since this part of the equation tells how the predation increases from increased sheep stock. The local herder is less interested in evaluating this, the higher the compensation is.

While it is assumed that the marginal predation in the variable X is constant, the function differs in the effort use. It was stated that the effort should reduce the predation at a diminishing rate. It must also have a solution where the effort use can be equal to zero. Thus it is so that the elasticity of effort on the predation must be positive, but less than 1. A simple choice for $K(E) = -2\epsilon E^{1/2}$, which satisfies these conditions.

The general solution of effort use is given by equation 23. Taking use of the compensation share $Q = \frac{q}{p}$, the effort use can be described as equation 51. The ex-post solution is found from $Q = 1$, and we can easily see that this goes towards a solution of no effort provided. On the other hand we have the social planner solution given when $Q = 0$.

$$E = \left(\frac{\epsilon p(1 - Q)}{r}\right)^2 \tag{51}$$

We can take use of this expression to eliminate the effort-variable in the predation function given by equation 48. Thus it is not needed to make a measurement for the effort itself. The predation is therefore given by equation 52.

$$K(W, X, E) = \alpha W X - \frac{2p\epsilon^2(1-Q)}{r} \tag{52}$$

Inserting for the sheep stock into the predation equation, the general predation can be stated as the following

$$K(W, X, E) = \alpha W \frac{p}{c}(s - n - \delta - (1-Q)\alpha W) - \frac{2p\epsilon^2(1-Q)}{r} \tag{53}$$

We can consider the case of the fully compensated local herder if $Q = 1$, and the case of the social planner when $Q = 0$. The compensation ratio is present two times in the equation. The first one shows how the predation will be larger in the case of compensation than what is socially optimal. This is because the local herder do not consider the increased predation due to increased sheep stock, and thus have a lower marginal cost from raising the sheep stock. Since that will increase the sheep stock, also the predation will be higher. The second part of the equation notes the effect the protective effort will have on the predation. The fully compensated local herder will not consider this, and thus not lowering predation. We should also note that this term is of larger importance the higher ϵ cet. par. ϵ can be considered as the protective effort effectivity parameter. The higher this parameter, the more effective the protection will be. Thus the difference between the predation in the social planner solution and the fully compensated local herder solution should be greater the larger this parameter is.

Equation 53 can furthermore be used to find the highest possible effectivity parameter. This is because we can not have negative predation. Thus ϵ_{MAX} is given when $K = 0$ and $Q = 0$. Rearranging equation 53 leads to equation 54.

$$\epsilon = \left(\frac{r}{2c}\alpha W(s - n - \delta - \alpha W)\right)^{1/2} \tag{54}$$

My main focus will be to numerically analyze the social planner solution against the solution for the fully compensated local herder. I will then consider the cases for $Q = 0$ and $Q = 1$, with some estimates for the parameters. First I will look at some of the general results, with some numbers. This will lead to estimates for the sheep stock costs given by equation 46, the sheep stock given by equation 50, the effort level given by 51, the harvest in steady state given by equation 55, and the profit for the society in the different schemes. The profit should be considered without the transfer, since this is just a transaction through the society, thus both the social planner and the local herder comparable profit should be counted by equation 56.

$$h = (s - n)X - K(W, X, E) \tag{55}$$

$$\Pi = ph - C(X) - rE \tag{56}$$

In the next section I will discuss these solutions. But there will also be a discussion about the harvest and the profit at different protective effort effectivity parameter. This is discussed by graphical representations in the section 6.3.

6.2 Numerical Analysis

Skonhoft (2008) analyses the sheep herding in Norway with a numerical model. Some of the parameter values can be utilized in this numerical illustration as well, while others will be tweaked so that the model fits to the analysis and the sheep stock size in Norway today. There are also some numbers that can be utilized from the descriptive discussion in Ekspertpanel (2011).

In Ekspertpanel (2011) it is stated that about 2 million sheep are grazing each summer. From these about $125,000$ are lost due to various reasons. 30% of this is due to predation. In numbers this accounts to $37,500$ sheep are lost due to predation each year. The rest of the loss is normal loss, which accounts for 70% of the loss, or about $87,500$ sheep. From this it is easy to calculate the normal loss rate, n, which is given by equation 57.

$$n = \frac{87,500}{2,000,000} \approx 0.04 \tag{57}$$

Skonhoft (2008) uses $n = 0.05$ and $n = 0.09$ for adults and lambs respectively. As geographical variations might occur, and also that this might vary over time, it seems like $n = 0.04$ might be a low estimate. I will therefore use $n = 0.05$ in my estimates.

In the same matter we can find the predation pressure, or the average predation per sheep, since we know that this is linear in the sheep stock. Assuming that there are no protective effort in Norway, with a loss about $37,500$ sheep, we should have an expected loss rate of

$$\alpha W = \frac{K(W, X, E)}{X} \frac{37,500}{2,000,000} \approx 0.02 \tag{58}$$

Skonhoft (2008) uses the predation fraction 0.03 and 0.05 for adults and lambs respectively. Considering that there are great variations in predation across Norway, it might be considered that the predation rate in a carnivore dense area is significantly higher than the country average. Also, this approximation of the predation rate is only valid if we assume that there is no protective effort in Norway today. If this assumption is wrong, the predation pressure might be higher. Thus I will use $\alpha W = 0.04$.

Skonhoft (2008) uses a sheep slaughter value of 100 and 120 euros for adults and lambs respectively. I will ignore the wool value, and just focus on the slaughter price. Thus I will assume that the price is 120 euros per sheep. Furthermore Skonhoft (2008) uses a variable marginal cost $c = 1.1$. This corresponds to the cost parameter c in the presented model. However, Skonhoft (2008) also uses a fixed marginal cost, which the cost function specification presented in equation 46 ignores. Thus the marginal costs might be under-represented. I will therefore use $c = 1.2$ to correct for this. Skonhoft (2008) also uses the sheep fertility rate $s = 1.53$, which is the number of lambs per adult.

The discount rate will be set to $\delta = 0.03$. The discount rate is assumed to be equal to the social planner and the local herder. The local herder might not evaluate time in the same matter as the social planner, and thus we should be aware of this when analyzing the results.

The off-farm wage rate, or herding alternative cost, r, and the protection effectivity parameter ϵ is harder to specify. However, these two variables work only in relation to each other. Thus if the herding alternative wage is erroneously set, it can be corrected by assigning the effort effectivity parameter a different value. The effort effectivity parameter has not been estimated directly, and thus I will only discuss different levels of this. With this in mind, and since we do not have or need any definition on measurement on the effort level, one may rather use an index for the wage rate, rather than the actual wage level. Thus I will use $r = 25$.

From equation 54 it was stated that there would be some maximum value for the protective effort effectivity parameter, since the predation can not be negative. With the assumed values of the parameters that are summarized in table 4, we can find that the highest value ϵ can take is $\epsilon \approx 0.766$. The lowest value ϵ can take is zero, and for that case protective effort have no use.

Variable	**Description**	**Value**	**Min**	**Max**	**Unit**
δ	Discount rate	0.03			
n	Normal loss rate	0.05			
s	Sheep reproduction rate	1.53			
p	Sheep value	120			Euro per animal
c	Sheep marginal cost	1.2			Euro
r	Herding alternative cost	25			Euro per hour
αW	Predation pressure	0.04			
ϵ	Protection effort parameter		0	0.75	

Table 4: Parameter values

6.2.1 No Effect of Protective Effort

First I will consider the case where protecting the herd is useless. $\epsilon = 0$ and there are no means to reduce the predation. I consider four cases. The social planner solution, which is equal to the ex-ante compensation solution, the ex-post compensated local herder solution with full compensation, the ex-post partial compensated local herder solution, and the ex-post fully compensated local herder with subsidized protective effort.

Using the values from table 4 and $\epsilon = 0$ results in the table 5 we will find the effort use by equation 51, which obviously counts to nothing for all the different schemes. The sheep stock can be found through the golden rule equation 50. The costs of the sheep stock follows from equation 46. The predation is then given by equation 48. The harvest in steady state is given by equation 55. And the profits follow from equation 56.

The four different scenarios are analyzed in this table. In the first column, the results for the social planner are displayed. In the second column, the results for the fully compensated local herder are shown. Results for a partial compensated local herder is shown in the third column, where the compensation ratio is set to $\frac{1}{2}$. The fourth column depicts the compensation scheme that includes effort increasing subsidies, like we might see in Norway. Since we have assumed a predation function that is separable in the effort parameter, it is assumed that the effort level adjusts to the effort level in the social planner state. But the sheep stock size is set to the fully compensated local herder model.

In table 5 it is assumed that there are no effect from protective effort, $\epsilon = 0$. Under this situation, the social planner will not provide any effort either, since it is of no use. Thus the only thing that differs between the social planner solution and the local herder solutions is the size of the sheep stock, which is larger for the local herder due to the increased profitability through the compensation. The increased sheep stock do influence the other variables, since they variate with the sheep stock. It leads to larger costs of the sheep stock than in the social planner solution. It also yields a higher predation, however, this is not due to lack of effort, but due to the increased predation alone. Because of the high stock, the harvest also increases, even though the predation is higher to the local herder. Hence the increased sheep stock outweighs the increased predation.

	Social Planner $Q = 0$	**Local Herder** $Q = 1$	**Local Herder** $Q = 0.5$	**Local Herder** $Q = 1$, $E = E^{SP}$
E	0	0	0	0
X	141	145	143	145
$C(X)$	11,928.6	12,615	12,269.4	12,615
K	5.64	5.8	5.72	5.8
h	203.04	208.8	205.92	208.8
Π	12,436.2	12,441	12,441	12,441

Table 5: Key values when no effect of protection

The partial compensated local herder will due to the partial compensation not experience the same increased profitability as the fully compensated local herder, and thus the adaption would lie in-between the social planner solution and the local herder solution. The fully compensated and effort subsidized local herder solution will not differ from the regular fully compensated local herder solution. This is because the socially optimal effort level is equal to zero and equal to the fully compensated local herder effort allocation.

It might seem like a paradox that the profit in the models are lowest in the social planner solution. This is due to the fact that the discount rate moves the social planner solution away from the static maximum because of impatient behavior. With these numbers, the dynamic local herder solution actually gets closer to the static maximum than the social planner solution.

6.2.2 Some Effect of Protective Effort

	Social Planner $Q = 0$	**Local Herder** $Q = 1$	**Local Herder** $Q = 0.5$	**Local Herder** $Q = 1$, $E = E^{SP}$
E	0.2304	0	0.0576	0.2304
X	141	145	143	145
$C(X)$	11,928.6	12,615	12,269.4	12,615
K	5.544	5.8	5.672	5.70
h	203.136	208.8	205.968	208.896
Π	12,441.96	12,441	12,445.32	12,446.76

Table 6: Key values for the situation with some effect of protection, $\epsilon = 0.1$

In table 6 the ϵ-parameter is changed to 0.1. Thus it tells that the protective effort will help at some level. This alters the results since the social planner now would prefer to provide protective effort. The sheep stock and the costs remains the same as in table 5, but the predation will be lower in the social planner case than it was before. Therefore the harvest will be higher and the profits will increase as well. The fully compensated local herder will not differ in the solution from the previous case, but the partially compensated local herder will change behavior to some degree, but not as much as the social planner.

In table 7 the effect from the protective effort on the predation is even higher. Thus the results change even more. We can notice an increased difference between the social planner solution and the fully compensated local herder solution. Furthermore we can see that the harvest in the social planner solution increases as ϵ increases, and that the profits increase while the ϵ-parameter increases. On the other side, we can see that the local herder solution is unaffected by this parameter change, since protective effort is of no interest anyway. Thus the social loss from having a full compensation ex-post scheme is affected by how effective the tools for protective effort is.

6.3 The Protective Effort Effectivity Parameter

We observed in the numerical examples from the last section that the effectivity of the protection effort influences the results. We would face the same sheep stock, X, regardless

	Social Planner $Q=0$	**Local Herder** $Q=1$	**Local Herder** $Q=0.5$	**Local Herder** $Q=1$, $E=E^{SP}$
E	0.9216	0	0.2304	0.9216
X	141	145	143	145
$C(X)$	$11,928.6$	$12,615$	$12,269.4$	$12,615$
K	5.256	5.8	5.528	5.416
h	203.424	208.8	206.112	209.184
Π	$12,459.24$	$12,441$	$12,458.28$	$12,464.04$

Table 7: Key values when some effect of protection, $\epsilon = 0.2$

of the effort effectivity parameter, but the effort used, E, changes due to increased profitability. Because of this also predation, K, harvest h and profits, Π alters. In section 5 the steady state was analyzed, and we noticed that the harvest in the ex-post solution could not be decided to be greater or smaller than the social planner solution. This was summarized in table 3. In this section it is possible to analyze to see if there exists an effectivity parameter which makes the harvest in ex-post and social planner solutions equal. And it is possible to see how the difference in the harvest changes with a varying effectivity parameter. To do this, we need some additional calculations. The harvest in steady state is given by equation 14 for $\dot{X} = 0$.

$$h = (s - n)X - K(W, X, E) \tag{59}$$

Inserting for the predation K from equation 53 and for the sheep stock from equation 50, and rearranging, we can find the following expression for the harvest, or sheep sold through the butcher.

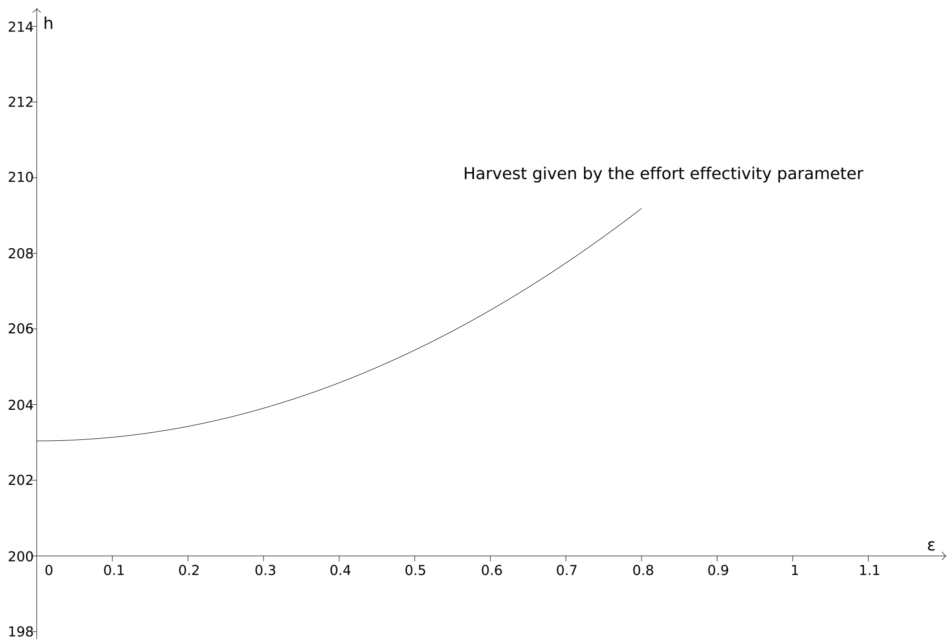

Figure 12: The optimal social planner harvest at different effectivity parameters. The effectivity parameter ϵ is on the horizontal axis, while the vertical axis measures the total harvest.

$$h = \frac{p}{c}(s - n - \alpha W)(s - n - \delta - (1-Q)\alpha W) + \frac{2p^2\epsilon^2(1-Q)}{r} \quad (60)$$

With the parameters we used earlier, the harvest will vary in the ϵ-parameter. Thus, for any given compensation rate, Q, this will graph in the the (ϵ, h)-diagram. In figure 12 we can see this drawn for $Q = 0$, the social planner case. We see from expression 60 that for the case of full compensation ex-post scheme, $Q = 1$, the part of the equation with the effectivity parameter cancels out, and thus the h-line will be a constant in the (ϵ, h)-diagram. This corresponds with the results for the fully ex-post compensated local herder in section 6.2. The reason is that the effectivity parameter only affects the use of effort. Since the local herder will not provide protective effort under the fully compensated ex-post scheme, there will therefore be no alteration to the predation, nor to the harvest.

The difference between the harvest in the social planner solution and the ex-post compensated local herder solution can be calculated by $h^{SP} - h^{LH}$, where h^{SP} is the harvest with $Q = 0$ and h^{LH} is the harvest with $1 \geq Q > 0$. Calculation of the difference in harvest yields the equation 61, this is calculated with some help from the notes in section 8.3 The result is graphed in figure 13 for $Q = 1$. This illustrates the difference in harvest between the social planner solution and the local herder solution. Since h^{LH} with full compensation $Q = 1$ is a constant value, and not influenced by ϵ, it would be so that the harvest difference function is equal to figure 12, but with a downwards shift.

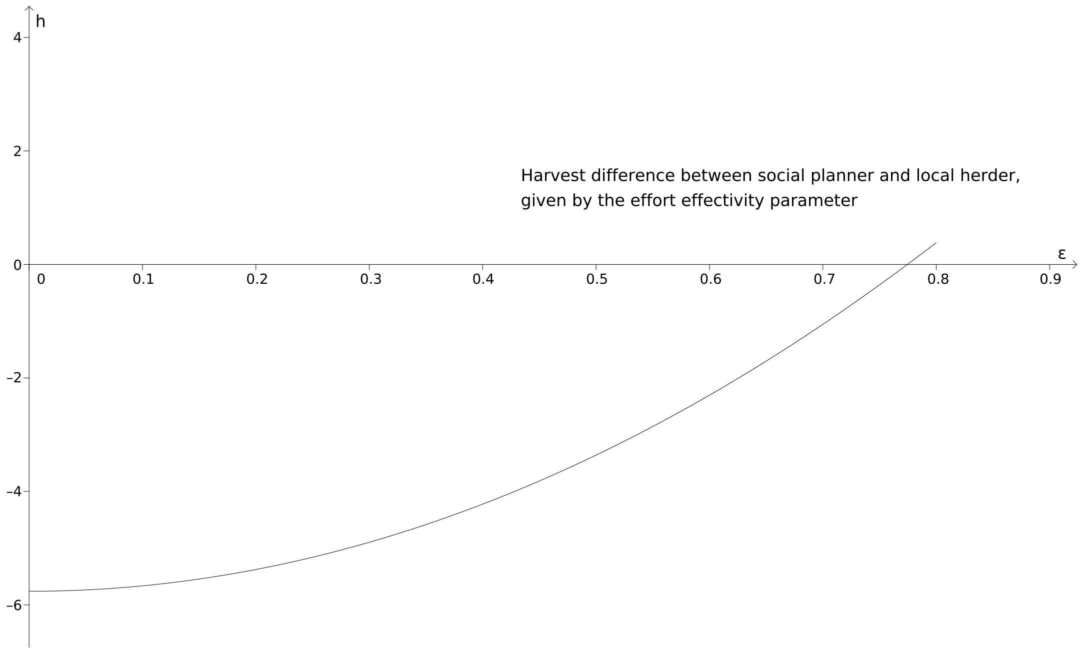

Figure 13: The difference in harvest between the social planner and the local herder solution. Negative values indicates higher harvest in the local herder solution than what is consider optimal to the society.

$$h^{SP} - h^{LH} = \left(-\frac{p}{c}\alpha W(s - n - \alpha W) + \frac{2p^2\epsilon^2}{r} \right) Q \tag{61}$$

In this equation it is obvious that if $Q = 0$, there is no compensation, there will be no difference between the social planner solution and the local herder solution. The first part within the brackets is the difference between the solutions due to increased sheep stock in the compensated local herder solution. The difference in the last part of the equation is due to the increased effort use in the social planner solution. Thus there are two different effects, one leading to higher harvest, while the other effect works in the opposite direction. We can however see from the figure 13 that the stock effect is dominant for the most values of ϵ.

The profit can be examined similarly. Using the profit from equation 56, we can insert from the harvest from equation 55, the predation from equation 48, the costs from equation 46, the sheep stock from equation 50 and the effort use from equation 51. Shortening the equation leads to equation 62.

$$\Pi = \frac{p^2}{2c}(s - n + \delta - (1+Q)\alpha W)(s - n - \delta - (1-Q)\alpha W) + \frac{(1-Q^2)p^2\epsilon^2}{r} \tag{62}$$

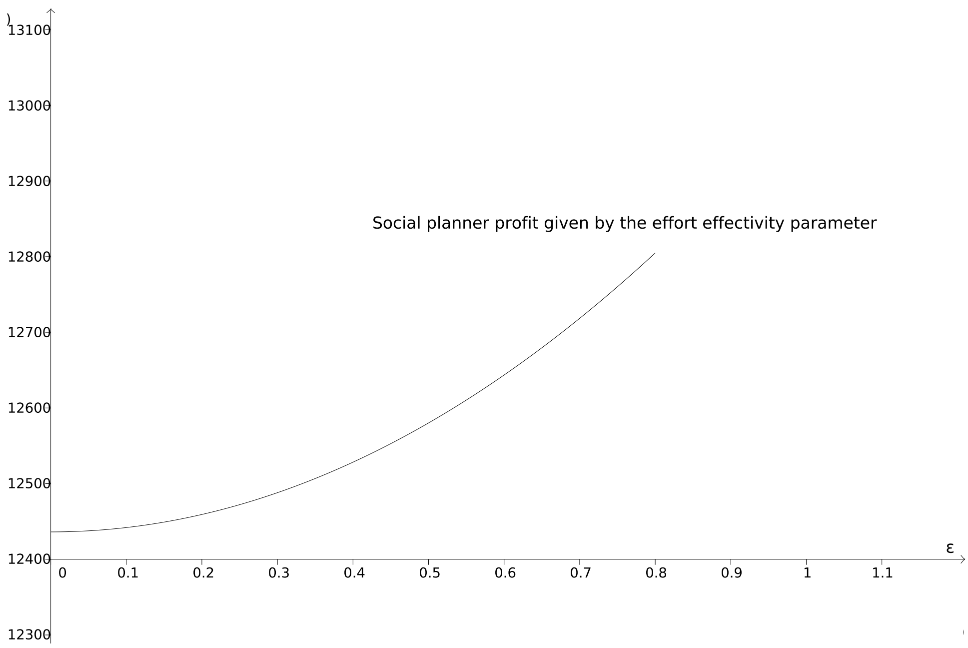

Figure 14: The social planner profit for different levels of the protection effort parameter. The higher the effect of the protection, the higher is the social planner profits.

The profit in equation 62 graphs in the (ϵ, Π)-diagram. For the local herder, with $Q = 1$, we can easily see that the part of the equation with the effort parameter cancels out, and the profit gets a constant in the diagram. In the social planner solution, $Q = 0$ it will be the case that the profit increases as the effect of protective effort increases. This is graphed in figure 14.

It is possible, like in the case of the harvest function, analyze to see how the difference between the local herder solution and the social optimum changes in the effort effectivity parameter. Using equation 62 with $Q = 0$ gives the social optimum, and subtracting for the case of the local herder with $1 \geq Q > 0$ should yield the difference in the profits. With some algebra from section 8.3, the results are given in equation 63.

$$\Pi^{SP} - \Pi^{LH} = \frac{p^2}{2c}\left((\alpha W)^2 Q - 2\delta\alpha W\right) Q + \frac{p^2\epsilon^2}{r} Q^2 \tag{63}$$

Under the full compensation ex-post scheme, the local herder will face $Q = 1$. This gives us a function varying in the protection effort parameter. The higher the protection effort parameter, ϵ, the higher is the difference in the profits, and thus the society loss from using an ex-post scheme. The relation between the profit difference and the protective effort parameter is graphed in figure 15.

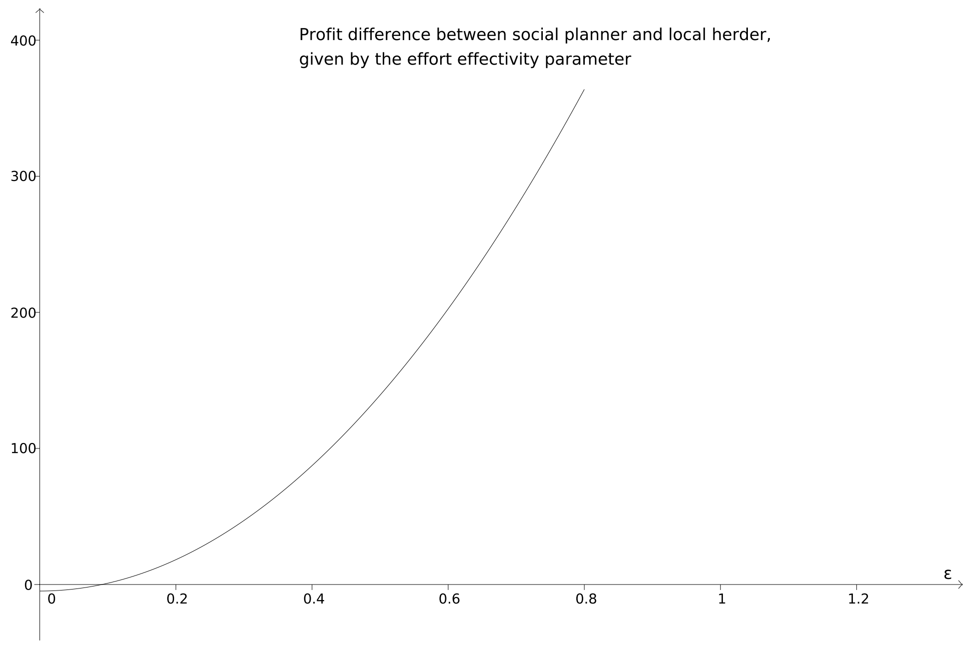

Figure 15: The profit difference between the social planner and the local herder solution for different levels of the protective effort parameter. The larger difference from zero, the higher is the deviation from social optimal solution from using an ex-post full compensation scheme.

7 Summary and Conclution

This master thesis has examined the Norwegian compensation scheme for sheep lost to protected carnivores. A compensation scheme is often a tool of fairness, but due to problems of transaction costs and moral hazard, the compensation does not necessary lead to the social optimal solution. The question for this paper was how this compensation scheme relates to the social planner optimum, and how an alternative model could be utilized. Furthermore I wanted to analyze how the sheep stock, harvest size and the predation relate to the social planner solution under the different schemes. The models used in this thesis are mainly based on the work in Zabel et al. (2010-I), but are changed so that they fit to the scheme used in Norway today.

In section 2 the Norwegian compensation scheme is discussed in both a historical context and with a biological background. It is discussed that both the Norwegian ex-post model and the Swedish ex-ante reindeer compensation model have both strengths and weaknesses. The negative characteristics of the Norwegian ex-post model is in particular the problem of verification of cadavers, the work load this causes to the conservation agency, and the time lag before the farmer receives the compensation. There is also a problem with the lack of transparent information, that could lead to frauds. The problem of verification and how individual judgment has to be used for the evaluation of the compensation is also a problem to the farmers. It might give a feeling that the compensation is not be paid for all of the predation, and that farmers might feel that they are treated differently than other farmers.

The ex-ante scheme is claimed to remove some of the problems that follow from the usual compensation scheme. The removal of time lags are obvious, since the compensation is paid in advance. It should also be clear that this scheme thus removes the conservation agency's work load at the end of the year. However, for the compensation scheme to actually compensate the expected loss, one has to closely monitor both the carnivore stocks and their predation habits and predation rates. Thus in the end the scheme is still dependent on the cadaver verification. It is not sure that this scheme will ease the conflict level that arises either. If the farmer assumes that there is a mismatch between what should be compensated and what is compensated, this should lead to dissatisfaction with the scheme. In addition there are some problems that rises regarding the distribution of the compensation. This might increase the problem of fairness in the compensation scheme.

In section 3 it is shown that the farmer looses the incentives to protect the herd under the usual ex-post compensation scheme. If we have full compensation ratio, there will be no need of protecting the herd. The sheep yields the same in compensation value as in slaughter value. This is a problem, since the social planner solution do indicate that protective effort should be put into use. One solution to this problem is that the farmers are subsidized to maintain a certain effort level. However the problem of moral hazard arises since the protective effort is hard to measure and to control. Thus the subsidies should mainly be focused on protective effort that is easily measurable, such as the shortening of the grazing period and radio-collared sheep and predators. It is discussed in section 2 that some of these means are not necessarily effective in protecting the herd. Still it might be wise to use them as it eases the verification of the cadavers, and thus might lead to a higher acceptance among the farmers.

The ex-ante model is analyzed in section 4. It is shown that the scheme is fairly equal to the social planner solution. Since the compensation does not depend on the predation rates, but rather on the predator stock itself, it does not alter the use of protective effort. It seems like this model is a great tool for avoiding poaching and illegal killings of the protected carnivores, without reducing the incentives to legal protection. However since the poaching is criminalized in Norway, the need of economical incentives to avoid poaching is non-existent. Thus the compensation scheme is rather a scheme of juridical interest and the concept of fairness rather than a tool for carnivore conservation. It is also shown that at any given compensation ratio, the ex-post model with subsidized effort is more expensive in transfers than the ex-ante model. The ex-ante model is still criticized because of slack assumptions. Since the compensation is based on the expected predation, and expectations often is based on historical rates, the farmers might sense that the future compensation might be reduced if they provide too much protective effort.

In section 5 the static model is changed to one of the dynamic sort. The predator stock is considered given to the farmers because of the criminalization of poaching, and thus the static profits are only subject to the sheep growth equation. Under these assumptions the lump sum compensation in the ex-ante model leads to the same solution as the social planner solution. The farmers that are given an ex-post compensation is however experiencing increased marginal profitability since they do not need to evaluate the increased predation from an increased sheep stock. Because of this, the sheep stock is larger than what is considered socially optimal. This does in turn lead to a too high predation, but in the theoretical framework the effect on the harvest is ambiguous. It is suggested that a tax on the sheep stock, with the tax rate equal to the marginal predation in the sheep stock, would correct for this. In Norway the sheep herders receive a production grant. It is often argued that this is essential because of external values of maintaining the farming activities in Norway. Assuming that such grants are optimal, it should be clear that also the ex-post compensation scheme leads to higher sheep stock, and thus indirectly is also a production grant.

The models are analyzed with numerals in section 6. It is shown how the local herder solution relates to the social planner solution. Since the social planner is assumed to use a discount rate, the steady state sheep stock is lower than what it would have been without such myopic behavior. Because of this, the steady state profits are lower than the highest static profits. Since the local herder have incentives for a higher sheep stock, it might in fact lead to a higher steady state profit despite not being socially optimal. However, it is not considered that the local herder might have different time preferences than the social planner. The simulations also highlight how the solutions relate to the effect of protective effort. It is shown how the harvest and the profits and the differences in this differs in protective effort parameter. The larger this effort parameter, the larger is the social planners allocation of time to protective effort, and the larger is the mismatch between the social planner and the local herder solutions for the effort allocation. The results might be different for the herd size and the profits since also the stock effect comes into play. It was discussed in section 2 that the effect of protective effort might not be high. Thus if this effect is close to zero, the main problem that occurs in the ex-post analysis is that the stock size is evaluated differently than the social optimum.

The discussion in section 5 and 6 has a weakness since it relies on the predation being additively separable in the effort variable. This is a necessary simplification since the data sources available lack estimates for the effort parameter, and the cross effects between the sheep stock, predator stock, and the protective effort. It should be considered that it might be easier to protect one sheep than hundred sheep. However the function specification might be a fair approximation given the sheep and predator stock in Norway.

It seems like there are ways to reach the social optimum under the ex-post analysis, given that the lack of protective effort is subsidized and that the sheep stock is taxed. There might be a problem of moral hazard in the subsidization of the protective effort, however this effort might not be very effective anyway. It is stated by Ekspertpanel (2011) that one of the main goals of the Norwegian compensation scheme is to raise the local herder's acceptance of the predators. This might be easier to achieve with subsidized effort so that as many sheep cadavers as possible are identified, and that less of the compensation is based on individual evaluations. The ex-ante scheme has some downturns which seem to make it hard to incorporate in Norway. The scheme might lower the farmer's acceptance of predators and there might be a problem to achieve a fair distribution. The ex-post compensation scheme will have transaction costs since there has to be made three different transactions to correct the errors in allocation. The first due to the compensation itself, the second due to the effort subsidies, and the third due to the taxation of the sheep stock. Thus the ex-post solution must go through more transactions to reach social optimum than the ex-ante solution.

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8 Appendix

8.1 Farmers Acting within the Herding Group

A single sheep farmer does not work in a closed environment, but is affecting and is affected by the actions of many other farmers. If a farmer provides protective effort, this comes also to the other farmers benefit. Let us say that a farmer did regulate the carnivore stock by hunting, then the reduced carnivore stock would benefit all the farmers. Equally, if a farmer provided protective effort so that sheep killings were discovered at an earlier stage, thus making it possible to discover the carnivore patterns easily, it would also benefit the other farmers. Hence, there is some positive external effects in this system. Let us examine a simple model to see how this comes into play.

For this simple example, I would like to specify a model where there is no difference between the effort provided, poaching or legal protective effort. The effort from all farmers affects the kill rate. It is assumed that the kill rate is decreasing in the total effort level, and furthermore that it is decreasing at a diminishing rate. It is therefore less use of effort the more effort is provided. The farmer has costs due to protective effort. This cost is assumed to be increasing at an increasing rate. The assumption relies on the fact that much of the effort provided is due to time usage, hence the protective effort gets more costly on the margin. A farmer i has the profit Π_i, this profit is given by equation 64.

$$\Pi_i = p\left(h_i - kE^{-1}\right) - cE_i^2 \tag{64}$$

The value per sheep is p and is assumed to be fixed, the number of sheep for farmer i is h_i, k is the number of sheep killed by predators and is affected by the protective effort by the farmers $E = \sum E_i$. The farmer has costs related to the protective effort, cE_i^2, and wants to maximize it's profits with respect to the effort level. Hence the farmer wishes to maximize equation 64 with respect to E_i. The first order condition is given by equation 65.

$$\frac{d\Pi_i}{dE_i} = pkE^{-2} - 2cE_i = 0 \tag{65}$$

Note that the second order condition for maximum is satisfied for all positive values of the parameters. It should also be needless to say that $E_i \geq 0$. For simplicity, assume that all farmers are equal. From this generalization it can be stated that all farmers are likely to provide similar level of effort based on the maximization scheme. Hence we know that $E = nE_i$, the total effort is the individual effort multiplied with the number of farmers. From this assumption we can calculate the optimal level of effort from each farmer, and furthermore the total effort provided by all farmers. This total effort is given by equation 66

$$E = nE_i = \sqrt[3]{\frac{pkn}{2c}} \tag{66}$$

From this solution it is easy to see that the level of effort is increasing with the size of p and k. Hence the higher the value of the sheep, the more likely the farmer is to provide protective effort. And also the more the carnivores are likely to kill, the higher the effort should be. We also note that the effort level is decreasing in the cost related parameter c. Most important is still the fact that the effort is increasing in the number of farmers. The more farmers n, the higher the effort provided by the farmers. If we analyze the social optimal solution, this can often be considered to be the case of a monopolist. If all farmers were cooperating, so that they could be counted as one, the optimal effort would be given by equation 67.

$$E^{COOP} = \sqrt[3]{\frac{pk}{2c}} \tag{67}$$

For the case where we will have several farmers providing protective effort, the farmers will provide more effort than in the cooperative solution. Hence the farmers will provide higher effort than what is socially optimal. If this effort is considered to be hunting for predators, there will be more hunting than what is socially optimal. But not only hunting will be high, also the legal protective effort would be too high. However, with the Norwegian ex-post compensation scheme the effort level is indirectly regulated as shown in section 3.1. This regulating might avoid such a problem due to the fact that all predation costs are compensated. It should be underlined that this result depends on the costs of effort not being linear. Thus in the time constraint specification from the original model, this result do not appear.

8.2 Coase Theorem Applied with Reversed Property Rights

If we consider the Coase theorem, economical efficiency can be obtained regardless of who has the property rights. (Coase , 1960) This can be applied in a theoretical example on the sheep versus predator problem. Say that the society owns the land and the right to use the land for the carnivore population. The carnivores have some existential value in the society that makes it important for them to keep it there. Sheep herders use the areas for grazing. The herders should thus have interest in paying the society for lowering the size of the carnivore stock and for getting access to the grazing fields. We make the same assumptions for the functions and variables as in 3, however this time this will not be modeled in a social planner framework. We consider rather the society on one hand, having the profits from the value of carnivores by the value function, $V = V(W)$. While the local herder face the profit function given by equation 2.

Let us now say that the sheep farmers wish to pay the society so that there are less predators roaming the grazing area. They will have to pay b for each reduced unit of predators, N. Thus N lowers the carnivore stock with one unit so that $W = W(e, N)$ and that $W_N = -1$. It is assumed that there are no transaction costs, so that the carnivore stock can be reduced this way without any costs to either the society nor to the local herder. Thus the society's profit can be expressed by equation 68 and the local herder's profit can be expressed by equation 69.

$$\Pi^{Society} = V(W(e, N)) + bN \tag{68}$$

$$\Pi^{LH} = p\,(X - K(E, W(e))) - c(e) + r(L - E - e) - bN \tag{69}$$

The society wants to maximize the profits. Since e is given to the society and can not be influenced in this simple model, the only variable to maximize the function is N. Thus it should be so that equation 70 is satisfied. The first order condition states that the marginal received payment, b, should be equal to the marginal predator value, V_W. And thus this solution forms a relation between the payment b and the reduced carnivore stock N. So that the higher the payment b the higher is the desire to reduce the sheep stock. Note that if we consider the second order condition, it would be reached as long as the value function is concave.[8]

$$\frac{\delta \Pi^{Society}}{\delta N} = -V_W + b = 0 \tag{70}$$

The local herder has now got three different variables to maximize the profit equation. This gives three first order conditions. Equation 71 is equal to what is socially optimal in equation 8. While equation 72 shows however that the local herders will have incentives to poach unless the punishment for such behavior is well executed. The last equation shows how much the local herder will wish to lower the carnivore stock at a given price. Here we can see that the price for lowering the predator stock, b, should be equal to the marginal damage the predators cause, K_W. The second order conditions and the possible corner solution of the two first maximum principles were discussed in section 3. The argument for a maximum in equation 73 goes like the argument for the maximum in the society's

[8]This might be easier highlighted if one calculates the problem with the alternative costs instead of the gains. Thus the profits of the society would have given by $\Pi = V(W) - qW$, where the last part of the expression is the loss in income from having the carnivores.

profit function.

$$\frac{\partial \Pi^{LH}}{\partial E} = -K_E - r = 0 \tag{71}$$

$$\frac{\partial \Pi^{LH}}{\partial e} = -K_W W_e - r - c_e = 0 \tag{72}$$

$$\frac{\partial \Pi^{LH}}{\partial N} = K_W - b = 0 \tag{73}$$

The equations 70 and 73 form the solution to the transfer from the local herders to the society. Equation 70 forms an upward sloping line in the N, b-diagram like shown in figure 16 under the assumptions of the predator value function used in section 3. This is easily verified through differentiation of the first order condition.

$$-V_W + b = 0 \tag{74}$$

$$\frac{db}{dN} = -V_{WW} > 0 \tag{75}$$

Equation 73 forms a straight or a downward sloping line in the same diagram, forming combinations of N and b acceptable to the local herder. If these lines intersect, we will find a solution for how many predators that will be removed from the stock, and how much the local herders will pay the society for this predator reduction. That the line is downward sloping can be verified in the same manner as with the combinations for the society.

$$K_W - b = 0 \tag{76}$$

$$\frac{db}{dN} = -K_{WW} \leq 0 \tag{77}$$

If the lines intersect, we should have a solution to the problem. Combining the expressions from the local herder and the society, we can see how this solution will be in terms of social efficency. The payment in the expression 70 and in equation 73 must be equal. Combining them will thus yield

$$V_W = K_W \tag{78}$$

Equation 78 states that the trade leads to a situation where the marginal value of the predators should be equal to the marginal damage the predators cause. This shows that the trade leads to social efficiency regardless of who has the property rights, under the assumption of no transaction costs.

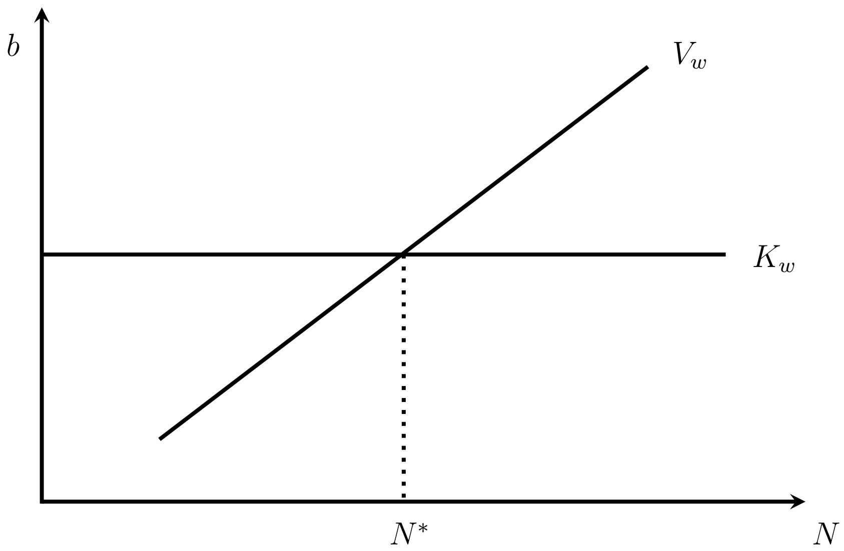

Figure 16: The Coase bargaining solution with reversed property rights.

8.3 Some Calculations

Some of the calculations in section 6.3 is both time and space consuming. They are not of much economical interest, but to show how they are done, they will be listed here in the appendix. What I had to calculate were the difference between the local herder solution and the social planner solution for both the profits and the harvest. The harvest was given by equation 60, where we would find the social planner solution for $Q = 0$. The equations from this is easy to compare in the latest part of the equation, however the first part is a bit more difficult to evaluate. Thus it is necessary to multiply the parentheses in the first part of the expression. The multiplication of the parentheses is given by the following calculation.

$$\begin{aligned}(s-n-\alpha W)(s-n-\delta-(1-Q)\alpha W) &= s^2-2sn-s\delta-s(1-Q)\alpha W \\ &+n^2+n\delta+n(1-Q)\alpha W \\ &+(1-Q)(\alpha W)^2-s\alpha W+n\alpha W+\delta\alpha W\end{aligned} \tag{79}$$

The social planener solution should be equal to the case of $Q = 0$. Thus the comparison of the two equation parts can easily be found by removing the parts without the Q-variable, only comparing the differences. Thus, if we consider the social planner solution and subtract for the local herder solution, the result from the parentheses must be given by the following calculations.

$$\begin{aligned} -s\alpha W + n\alpha W + (\alpha W)^2 + (1-Q)s\alpha W - (1-Q)n\alpha W - (1-Q)(\alpha W)^2 \\ = -Qs\alpha W + Qn\alpha W + Q(\alpha W) \\ = -Q\alpha W(s - n - \alpha W) \end{aligned} \tag{80}$$

Thus with this difference it is possible to finish the calculations and consider the other factors of the first part of the equations, and the difference between the second part of the equations, it leads to the result in equation 61.

The similar calculations are executed for the difference in profits between the local herder and the social planner solutions. The local herder solution is given by equation 62, and the social planner solution is given when $Q = 0$. The parentheses have to be multiplied like in the last example. For the local herder we then get the following calculations.

$$\begin{aligned} &(s - n - (1+Q)\alpha W + \delta)(s - n - \delta - (1-Q)\alpha W) = \\ &s^2 - sn - s\delta - s(1-Q)\alpha W \\ &+ n^2 - sn + n\delta + n(1+Q)\alpha W \\ &- \delta^2 + s\delta - n\delta - \delta(1-Q)\alpha W = \\ &s^2 + n^2 + (1-Q^2)(\alpha W)^2 - 2sn - 2s\alpha W + 2n\alpha W + 2\delta Q\alpha W - \delta^2 \end{aligned} \tag{81}$$

Using the same technique as for the calculations of harvest difference, I choose to analyze the difference where the Q-variable is included. This follows by the next calculations.

$$(\alpha W)^2 - (1-Q^2)(\alpha W)^2 - 2\delta Q\alpha W = Q^2(\alpha W)^2 - 2\delta Q\alpha W \tag{82}$$

Together with the multiplier in the first part of the equations, and calculating on the second part of the profit equations, this leads to the result presented in equation 63.