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The Economic Impact of Wolves on the Moose Harvest in Sweden

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Abstract

In Sweden hunters and wolves both have an interest in hunting moose. This thesis is therefore a contribution to the current carnivore-game conflict resulting from this interest. The use of a production function approach is applied in order to value the impact of wolves on hunting values. An open access model is developed which derives a regression equation setting hunters' harvest of moose per km^2 as the dependent variable. Data on wolves, the moose harvest, hunting licenses and different Swedish game series is included in the analysis. Estimating empirically for the study period from 2002 to 2011, we identify the marginal product of wolves, the marginal cost in terms of loss in hunting revenues. We also compare the level of hunting effort with and without wolves in the system. This is done in the short term and for a steady-state equilibrium in the long term. The latter assumes a constant moose population and thus an effort adjustment by hunters. Our findings suggest a significant negative impact of the wolf on the moose harvest. When looking at both national data and different county groupings, there appear to be differences in marginal impacts as well as costs. Wolves in the counties with high wolf densities have lower marginal impacts than in counties with fewer wolves. This is reasonable, as wolf packs kill similar amounts of moose per year irrespective of their size.

The marginal productivity of hunting effort did not vary much within and between groupings, whether there were wolves present or not. Under the current debate, this study adds in terms of shedding light on the change in hunters' harvest revenues by wolves. However, the results do not consider social costs and thus conclusions for the wolf policy in Sweden have to be made with caution. Actions already attempt to address the conflict, yet it remains to be seen whether they are effective.

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Abbreviations

ÄFO	Moose management unit (*Älgförvaltningsområde)*
AIC	Akaike information criterion
ÄSO	Moose management area (*Älgskötselområde*)
HD	High-density
OLS	Ordinary least squares
SEK	Swedish Krona
VIF	Variance Inflation Factors

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To my family, my friends and all the inspirational fellow students I met over the years, you have shaped my life and made me who I am today. Thank you for being who you are and letting me get to know you.

Dedication

I dedicate this work to my family who has always been there for me.

1. General introduction

Among all Scandinavian game species, the moose is the most relevant one for local economies in terms of yield from cervid species (Nilsen et al. 2005). With having one of the highest moose densities and harvest rates in the world, the annual harvest of moose meat of 8.5 million kg amounts to a value of 14.5 billion SEK (Malmsten 2014). Apart from the high economic value, hunting is also an important recreational activity (Lavsund et al. 2003; Wikenros 2011).

Moose numbers were increasing throughout the 19th century because of different reasons. Wikenros (2011) named for example the absence of predators, new hunting laws, and a different forest management which created better conditions for moose. However, an initial number of 314,000 in the early 1980s was reduced to 225,000 in the beginning of the 1990s. Hörnberg (2001) found that this change was mostly caused by increased hunting. Nevertheless, the recolonization of the wolf, a large predator on moose, could also have played a part. The wolf population has been growing considerably since the 1990's and since then has caused increasing awareness in Sweden (Ericsson et al. 2004). Whereas wolves are still listed as an endangered species, they are perceived as a disruptive factor to the moose hunt, because hunters see the wolf as a competitor for game species. There have furthermore been reports of wolves attacking dogs used for moose hunting. The attitude towards the return of the wolf is therefore critical (Darpö 2011). Eriksson (2013) described the situation as a conflict between conservation goals and economic and cultural concerns.

The purpose of this paper is the attempt to answer whether wolves have a significant economic impact on the moose harvest shot by hunters. Assuming that wolves negatively influence moose mortality, there would be less moose available for hunting. We try to calculate the impact of wolves on the moose harvest value and how it depends on the hunters' effort adjustment.

More precisely the aim is to identify first the marginal product of one wolf. This gives its monetary impact under no effort adjustment. In addition, the paper will also give more insight with regard to the relation between effort and harvest, i.e. how the harvest changes for an additional unit of effort. Finally, we will look at the comparative statics of a harvest change due to wolves assuming a preceding effort adjustment. However, the marginal costs calculated in this study are not an estimate of social costs. We neglected values and benefits of wolves as well as costs connected with for example livestock compensation; hence, the estimated costs reflect purely foregone hunting profits.

We will use a production function approach to value the impact of wolves on hunting. Although this approach has been used for fisheries before (Barbier and Strand 1998; Foley, van Rensburg, and Armstrong 2010), it has never been applied to a predator-prey context. Besides, there have not been many studies which account for monetary predation losses due to wolves in the Swedish hunting sector. First, we develop a steady state model for moose harvesting in the presence of wolves. Based on this economic model, we derive a harvest function which can be estimated econometrically. With this harvest regression, we identify the marginal product of wolves and the impact on the harvest during our study period from 2002 to 2011. We use the model to quantify the marginal effect in terms of lost revenues due to one additional wolf. The study will evaluate secondary balanced panel data of moose and wolves for 20 counties in Sweden.

The remainder of this paper is organized as follows: Chapter 2 provides background information about moose and hunting management. Chapter 3gives a review of studies which have tried to measure wolf predation impacts before. Chapter 4 explains the methodology, and chapter 5 addresses the data we used; chapter 6 discusses the method and empirical results, and chapter 7 summarizes, concludes and gives policy recommendations.

2. Background

2.1 Moose Management – Regulations and Institutions

Throughout the last century, moose hunting had mostly been unrestricted. There had been increasing problems with over-exploitation due to unlimited hunting and open access in the 1980s and 1990s. The development in recent years has gone more towards an organized management with abundant moose (Hörnberg 2001; Lavsund et al. 2003; Sandström, Di Gasper, and Öhman 2013). The main goal today is to maintain a population which can endure high harvest rates with an overall low natural mortality (Nilsen et al. 2005). Changes in the moose population are of interest to hunters, but they also raise concerns in forestry companies, as moose cause browsing damage on trees (Hörnberg 2001; Sandström, Di Gasper, and Öhman 2013). Besides, moose have a negative impact on highway traffic safety (Lavsund et al. 2003). Since moose incur costs, the population should not exceed a certain limit (Månsson et al. 2011).

In Sweden, it is necessary to obtain a national hunting license to be able to purchase weapons and receive the right to hunt. A hunting license incurs an annual management fee of 300 SEK and includes an examination. Hunting licenses count for the time between July 1st in one year and June 30th in the following year (Naturvårdsverket 2015). If hunters want to hunt moose, they need to obtain additional local licenses ("lokalt jaktkort") (Svenska Jägareförbundet 2014). The issuance is linked with the quotas and allows hunters to kill one animal per local license (Plahn 2015; Skonhoft 2006a). Furthermore, hunters are obliged to report each moose shot to the county administrative board and pay a fee for it to the landowner ("älgavgift"). The fee can vary between 200 and 400 SEK for an adult, whereas calves entail no fee (Apollonio, Andersen, and Putman 2010).

The county administrative boards decide about periods for the moose hunt in each hunting area. The minimum of scheduled days amounts to 70 days per year. The hunting period for moose starts on the second Monday in October in all parts of the country, apart from a few municipalities in Värmland, Dalarna and Gävleborg where it begins on the first Monday of September. The hunting year continues until February 28th (29th). After that date, no more moose are allowed to be harvested according to hunting regulations[1].

To better organize the moose hunt, every county in Sweden is divided into moose management units, so called *Älgförvaltningsområden* (ÄFOs). ÄFOs are organized by a group containing six representatives. Three are elected by the landowners' and three by the hunters' association. Since 2012, they decide on an administration plan for the moose population. Guidelines for the management are provided by the county administrative board (Naturvårdsverket 2013). The board also examines and approves of the administration plans (Apollonio, Andersen, and Putman 2010). An administration

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[1] Svensk Jaktförordning Bilaga 2 (2015)

plan determines a harvest quota which decides how many moose can be hunted in an area. According to this goal, local licenses are issued (Naturvårdsverket 2013; Plahn 2015). However, such quotas can create problems when chosen too high (Levin and Hallam 1984) or when not adjusted quickly enough, which can increase the risk of collapse of a population system (Fryxell et al. 2010). They are determined according to the knowledge of moose's birth rates, density and damage level (Apollonio, Andersen, and Putman 2010).

ÄFOs are divided into smaller areas for which hunters have to apply for a number of moose (local licenses) that they can harvest (Apollonio, Andersen, and Putman 2010). According to Plahn (2015) there are two different types of hunting areas. First, there are license areas, in Swedish *Licensområden*. The quota mechanism is still decided by the representatives of the AFÖ. If the representatives propose for instance that one calf should be shot in every one-hundred hectares, the quota will be adjusted to the size of the license area. Second, there are moose management areas which in Swedish are called *Älgskötselområden* (ÄSOs) (Plahn 2015). Area representatives develop a three-year plan for the ÄSO (Månsson et al. 2011) which determines annual harvests and has to be adhered to by the hunters with a tolerance +/-10% (Plahn 2015). If more moose are shot than agreed on with the county administrative board, hunters have to pay a fine. It amounts to 7,000 SEK for a grown moose and 3,000 SEK for a calf. However, it does not have to be paid, either if the value of the killed moose is declared to be useless, or if it obviously is unreasonable to demand a fee. No regulations can be found for the case when less moose are shot than agreed[2].

Despite the fines in order to prevent excessive harvesting in Sweden, local quotas which are supposed to regulate the number of harvested moose seem not to be adhered to. When looking at recent statistics on algdata.se, as suggested in an email correspondence with a Swedish game administrator (Plahn 2015), we can observe that hunters still shoot irrespective of the quotas. There are a few hunt areas where harvest quotas are reached or even exceeded. In general, if this is the case, it is because of the harvest of more adult moose than agreed. However, the calf quotas are barely ever reached and thus the overall quota is principally below the target. The so called use rate, in Swedish called *nyttjandegrad*, can be calculated as dividing the number of moose harvested by the agreed quota. They represent how much of the agreed quota was actually harvested. The use rates on ÄFO-level confirm the observations of the unmatched quotas. They often lie well below 100% and in 2013 the average use rate accounted for 84.1% (compare table 1). This is emphasized by Zimmermann et al. (2015) who state that quotas are set higher than the number of moose harvested. According to them, the difference has been increasing over time. To conclude, the above mentioned regulations and findings let room to believe that present-day sanctions do not seem to make harvest quotas binding.

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[2] Svensk Jaktförordning 52 c § (2015)

Table 1: Quotas, harvest and use rates in Sweden in 2013

County	**Quota**		**Harvest**		**Use Rate (%)**
	Adults	Calves	Adults	Calves	
Blekinge	215	336	208	286	89.7
Dalarna	3891	3315	3555	2853	88.9
Gävleborg	3888	3430	3517	2966	88.6
Halland	659	692	795	845	121.4
Jämtland	11235	8556	9599	6001	78.8
Jönköping	1616	2430	1464	2084	87.7
Kalmar	1411	1698	1232	1440	85.9
Kronoberg	1361	1799	1335	1686	95.6
Norrbotten	8208	7814	7239	4885	75.7
Skåne	331	673	294	320	61.2
Stockholm	696	932	589	602	73.2
Södermanland	667	898	603	763	87.3
Uppsala	1092	1176	1008	1084	92.2
Värmland	4023	3782	3265	2448	73.2
Västerbotten	8149	7634	7871	5366	83.9
Västernorrland	2824	2025	3092	1819	101.3
Västmanland	662	884	595	654	80.8
Västra Götaland	3491	4186	3345	3914	94.6
Örebro	1210	1353	1133	1178	90.2
Östergötland	1604	2180	1492	1657	83.2
Sum	57233	55793	52231	42851	84.1

Source: author's creation with data from algdata.se

Because of this, we assume a market for moose hunt which is characterized by open access with respect to the resource. An open-access resource is defined as a resource which everybody can harvest and which is in no way protected against exploitation (Clark 1990). Especially resources which entail recreational activities, such as hunting, are commonly based on an open-access philosophy. In wildlife hunting, it is often difficult to control harvest efforts or the number of people that use such resources (Fryxell et al. 2010).

To sum up the characteristics of the market, hunting licenses and with it the right to hunt can be obtained by everybody fulfilling the requirements. There is the necessity of additional local licenses which have to be purchased for the moose hunt and are linked with the quota. Harvested moose have to be communicated and a one-time payment per animal is made to the county administrative board.

2.2 Factors Affecting the Size of the Moose Population

The population of moose and therefore the moose harvest in Sweden is influenced by different factors, such as traffic, diseases, predation and the harvest by hunters. All of these factors have a direct impact on the mortality of moose. Especially younger animals are affected by several factors. Moose calves are for instance exposed to winter mortality. Additionally, in the summer there is the risk of neonatal mortality for newborns (Nilsen et al. 2005). Another study discovered mortality causes such as a subnormal body condition, or the killing by dogs (Malmsten 2014, p.45). Moose calves were also found to be affected by bacterial infections which decrease their health as well as increase the mortality risk. Moreover, climate change may have an impact on moose mortality. Moose are for instance exposed to heat stress (Malmsten 2014). According to Sand et al. (2012 b), about 3-4% of the moose population dies in traffic each year. However, this mortality factor is only of minor importance (Seiler 2003).

Predators to moose are bear and wolves (Sand et al. 2012b; Dahle et al. 2013). Again, younger moose are more exposed to predation risk compared to adults. Bear predation is only of local importance during the winter, when there are good snow conditions for the species, such as crusty snow (Dahle et al 2013). As claimed by Dahle et al. (2013), bear predation does not account for an important mortality factor. Wolves (Canis lupus), on the other hand, mainly predate on moose (Eriksen et al. 2009). They have a very large hunting territory, and their main breeding areas are located in central Sweden and eastern Norway (Zimmermann et al. 2015). They predate on different species, such as roe deer, beaver and wild reindeer in Sweden. However, their diet consists with 95% of biomass (winter estimates) mostly of moose (Sand et al. 2012 b). In contrast to predation risk, which was found to be low for moose individuals due to a high prey-to-predator ratio, hunting success (resulting in the killing of the prey) was very high, whenever a wolf encountered a moose (Wikenros et al. 2009). One wolf for example was found to kill on average 0.061 moose per day (Zimmermann et al. 2015), so 22.265 moose per year. Nevertheless, wolf pups would not be considered as predators, while only adult wolves provide the killed prey (Boman et al. 2003; Zimmermann et al. 2015). Wolves show a clear preference for moose calves[3], and also prey upon a few older females and yearlings (Nilsen et al. 2005).

However, human hunting activity is the most important factor. Hunters kill about 100,000 moose annually (Dahle et al. 2013), which is about 25-30% of the moose population, before the hunting season (Wikenros et al. 2015). The annual hunting harvest is usually dominated by calves and males (Nilsen et al. 2005). The total number of moose shot by hunters will from now on be referred to as the moose harvest or simply the harvest.

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[3] Almost 90% of all moose killed by wolves were calves (Sand et al. 2008).

In summary, the two most important factors influencing moose mortality, which will be considered in this study, are human hunting activity and wolf predation.

3. Literature Review

The impact of wolves has been analyzed in different fields in literature. Many ecological studies exist which measure demographic impacts of the recolonizing wolf on the moose population and the moose management (Nilsen et al. 2005; Håkan Sand et al. 2005; Wikenros et al. 2009; Gervasi et al. 2012; Håkan Sand et al. 2012a a). In contrast, there have only been a few studies, such as Boman et al. (2003), Skonhoft (2006a) and Bostedt and Grahn (2008), about the economic impact of the wolf in general which account for the actual costs of wolves either with respect to hunting or livestock.

A common way of measuring the demographic impact of the wolf on the moose population in ecology studies is to show wolf-moose relations through the estimation of numerical or functional responses. Numerical responses, for instance, show how the reproduction rate of the predator, in our case of the wolf, changes following a change in the density of the prey or moose in our case (Lester and Harmsen 2002). According to Nilsen et al. (2005), because of the intensive wolf management[4], the Scandinavian wolf does not have a numerical response when the prey density changes. Hence, numerical responses can be neglected in impact measurements of wolves in Sweden. Functional responses, on the other hand, are a common measure (Bostedt and Grahn 2008; Zimmermann et al. 2015). They show how the per capita kill rate of the predator follows a change in prey density (Zimmermann et al. 2015). The Per capita kill rate, also called the predation rate (Lester and Harmsen (2002), is often measured by the number of animals killed per predator per unit time (Sand et al. 2012a). Zimmermann et al. (2015) for example used functional responses to estimate per capita kill rates which were found to increase with increasing moose availability. They were also discovered to even off above a threshold, which represents a point of saturation at which higher prey densities do not affect the number of moose killed per wolf anymore (Zimmermann et al. 2015).

Among the ecological studies, there are, furthermore, studies about the impacts of wolf predation on the Swedish moose management. For instance, Nilsen et al. (2005) showed that the moose population decreases, when wolves recolonize and the harvest is not adjusted. Especially the moose's growth rate is affected, as wolves mainly predate on calves. For this reason, harvest rates of calves in particular need to be reduced under the presence of wolves. Managers would have to keep in mind that predation has a stronger effect on smaller populations. Therefore, in order to minimize the loss to wolf predation, managers should aim for both a high number of female moose and a high density locally (Nilsen et al 2005). A study by Wikenros (2011) showed that hunters and managers immediately adjusted harvest rates during the first season under which wolves were present. During this season,

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[4] The goal for wolf management in 2009/2010 was to maintain 210 individuals in the wolf population (Wikenros et al. 2009).

female moose harvest decreased. The quick reaction by the management, however, pointed towards a precautious change in harvest, rather than a wolf-caused loss (Wikenros 2011). Harvest was hence not reduced because of predation, but by the management's initiated harvest adjustment. This fact verifies the necessity to account for effort adjustments when studying the impact of wolves on the moose harvest over some years. Wikenros et al. (2015) reinforced the assumption of a precautious change by showing that hunters reduced the number of female moose killed in wolf territories.

As noted before, even today the number of studies on monetary losses due to wolf predation seems to be limited. A Norwegian study by Skonhoft (2006a) measured the costs and benefits of a landowner under the presence of wolves. The author used the landowner's profit when wolves predated subtracted from the profit when there were no wolves to account for the yearly profit change. The potential economic loss by wolves could then be calculated by the change in income from hunting minus the change in tree damage costs by moose measured relative to the change in the size of the moose population. Predation occurred when measuring the size of the moose population in terms of a natural growth function. The natural growth function was measured by the population growth of the moose in the absence of wolves minus the harvest and the mortality due to predation. In order to determine the mortality due to predation, the author took both the size and the number of wolf packs into account. The wolves entered the predation function exogenously assuming one wolf positively affected predation. Wolves had positive values for the landowner's profit for smaller less sustainable populations of moose because browsing damage was reduced and thus profits increased. Yet, when the number of wolves was too high, less and less moose were available, and the moose harvest could not be sustained (Skonhoft 2006a).

Marginal costs of conserving a wolf, i.e. social costs, were estimated by Boman et al. (2003). To estimate these costs, they took the wolf's harvesting benefit, existence value, and predation costs into account. The predation costs included costs for depredation on dogs and game species. Impact by wolves in the analysis was linear. The authors linked the costs of preservation to wolf population densities as well as prey abundance (including reindeer, roe deer and moose). High prey abundance means that there is a large number of moose per hunter. Hence, the more moose per hunter exist, the less strong the impact of wolf predation, and the lower the marginal cost of a wolf in terms of harvest losses. Because of high prey abundance in counties with at the same time high wolf densities (Västernorrland and Gävleborg), marginal costs in these counties were comparatively lower than in counties with low prey abundance. Consequently, northern counties experienced high marginal costs due to depredation on reindeer. Costs are, thus, also affected by the spatial distribution of wolves (Boman et al. 2003).

Bostedt and Grahn (2008) studied the social costs of four Swedish carnivores, among others wolves, under the use of functional responses. In contrast to the studies mentioned above, their data focused on the costs in terms of compensation for livestock losses. Two groups of owners who receive damage compensation exist in the Swedish system. One group is made of the owners of domesticated animals such as sheep, horses, cows etc. and the other group is made of herders of semi-domesticated reindeer. However, when it comes to compensation of predation losses, there is consent that analyses do not take indirect cost into account. Therefore, actual costs of wolves may be higher for livestock losses (Steele et al. 2013; Ramler et al. 2014). Looking at the costs, Bostedt and Grahn (2008) found that cost functions were much lower for wolves compared to wolverines and lynxes. This result came about mainly because predation costs of wolves have been limited over the last years by solving some problems with livestock farming (Bostedt and Grahn 2008), for instance through certain measures such as electric fencing (Darpö 2011). Besides, wolf numbers are kept low in the northern part of Sweden due to the fact that wolves are not compatible with reindeer herding (Bostedt and Grahn 2008). Bostedt and Grahn (2008) accounted for the marginal cost of compensating livestock losses caused by a wolf which was significant at the 5% level and calculated at 7,480 SEK.

Important outcomes of some studies are summarized in table 2.

Table 2: Summary of relevant outcomes of studies in economics and natural sciences about the impact of the wolf

Ecological Studies

Study	Per capita kill rate
Zimmermann et al. (2015)	One wolf killed on average 0.061 moose per day (22.265 moose per year).
Westby (2004)	Estimations of the kill rate amounted to 10.9 moose per wolf per year. However, the study also found a kill rate of 8.4 days/moose which would actually mean that a wolf kills 43.5 moose per year.
Sand et al. (2005a)	In wolf territories, the average kill rate was estimated at 3.6-4.0 days per killed moose. So according to this, a wolf would kill on average 96 moose in a year.

Economic Studies

Study	Marginal costs
Boman et al. (2003)	Marginal costs of wolf predation on moose: 70,630 SEK for counties 1 to 4 in the analysis (nowadays counties of Blekinge, Skåne, Halland, Jönköping, Kalmar, Kronoberg, Östergötland and Södermanland), 61,657 SEK for counties 5 to 8 (counties of Stockholm, Uppsala, Västmanland, Örebro, Västra Götaland, Värmland and Dalarna), 28,799 SEK for counties 9 to 11 (counties of Gävleborg, Västernorrland and Jämtland), and 37,025 SEK for counties 12 and 13 (counties of Västerbotten and Norrbotten).
Bostedt and Grahn (2008)	Marginal cost of a wolf in terms of compensation to livestock holders was calculated at 7,480 SEK.

4. Conceptual Framework

Our model is based on Barbier and Strand (1998) and Foley et al. (2010) who look at how fish harvest is affected by certain habitat conditions. In Barbier and Strand (1998), they specifically analyzed how mangroves affect the shrimp harvest, and in Foley et al. (2010), how cold water coral affects the harvest of redfish. The concept of habitat factors, as mentioned by Foley et al (2010), refers to one or several factors that have a positive impact on the species, such as in their case for instance cold water coral. They additionally introduced the assumption of a facultative habitat. Facultative habitat use means that a species can use features, such as covers from predators or focal points for reproduction, but even if the factors are not provided, the species can continue to exist. It is assumed that it finds another (second best) habitat where the growth of the species continues. Here, the type of model used by the two papers is translated into the research question studied. With this we investigated how the presence of wolf affects the harvest of moose. This is well motivated as the original model by Clark (1990), on which Barbier and Strand (1998) and Foley et al. (2010) build, actually is a model of a predator-prey relationship. Therefore, the original model by Clark (1990), also includes habitat factors which influence a population negatively (Clark 1990). In this study, wolves are considered to be a facultative habitat factor, as moose exist independently of them. As mentioned above, we analyzed the situation of the moose hunt in the context of an open access model**.**

The most important factor aside from the harvest, which influences moose habitat and the moose harvest simultaneously, is the number of wolves W. The factor has an effect on the moose population in terms of growth and carrying capacity and on moose mortality. Different to Foley et al. (2010) who assume positive habitat impacts, but similar to Clark (1990), we assume that our habitat factor has a negative impact on the species. One would expect that the more wolves, the more predation occurs. The precise mechanism is not specified in the model (leaving it optional if the effect is positive or negative), but the model is defined such that the habitat influences the moose population and with it the harvest. Following the assumption of negative impacts, wolves would decrease the moose's natural growth and thus the moose harvest. The factor is also assumed to have a negative impact on the moose's carrying capacity $K(W)$, which is reduced to a lower carrying capacity $K(W)^{new}$. Figure 1 presents such an impact. The slope of the growth rate function $r(W)$ would decrease, such that the natural growth function shifts down and a lower carrying capacity is reached.

The moose's natural growth function $F(X, W)$ is then affected by wolves W, such that

$$F_W = \frac{\delta F}{\delta W_t} < 0.$$

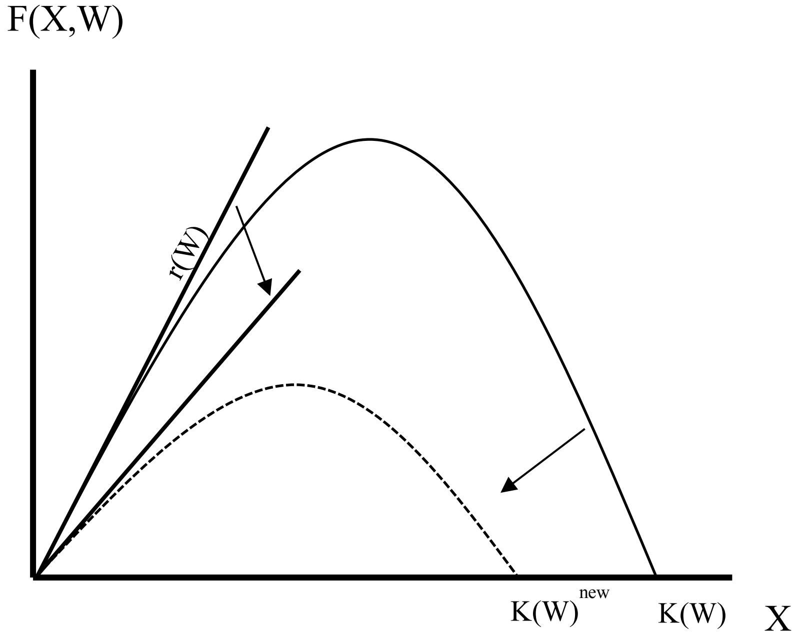

Figure 1: Effect on the logistic growth function by an increase in the number of wolves
Source: Foley et al. (2010)

As mentioned before, an increase in W presumably decreases the carrying capacity of moose. In the context of prey-predator relationships (Clark 1990), the carrying capacity K can then be described as

$$K_t(W_t) = K^0 - g * W_t$$

where g is a coefficient that is used to describe the effect of W on the moose stock, its carrying capacity and the intrinsic growth rate. Due to the facultative habitat, the carrying capacity K will be positive if $W = 0$, so that we get $F(X, 0) > 0$. If the carrying capacity is a function of the habitat, then it is essential that $g > 0$. If it is not affected by the habitat factors, g will be equal to zero.

4.1 The Change in Moose Stock

The moose stock X is affected by a biological logistic growth function $F(X, W)$ and the hunting harvest $h(X, E)$. The change in moose stock, in accordance with Foley et al. (2010), is consequently

$$X_{t+1} - X_t = F(X_t, W_t) - h(X_t, E_t) \quad . \tag{1}$$

The logistic growth function $F(X, W)$ describes the net expansion of X influenced by the biological growth and the number of wolves W. It can be described as follows:

$$F(X, W) = r(K^0 - gW)\, X \left(1 - \frac{X}{K^0 - gW}\right),$$

with r describing the intrinsic growth rate of the stock and K the carrying capacity, such that

$$F(X,W) = rX[(K^0 - gW) - X]. \tag{2}$$

The harvest can be described by a Schaefer production function (Clark 1990, Barbier and Strand 1998), such as

$$h(X_t, E_t) = qE_tX_t. \tag{3}$$

The function shows the impact of hunting effort on the stock. Harvest h can be denoted as a function of a catchability coefficient q, the hunting effort E and the stock of the moose. The harvest increases, if the number of moose increases, and if the effort increases respectively.

Representing equation (1) with equation (2) and substituting equation (3) into it produces the change in moose stock

$$X_{t+1} - X_t = X_t\, \{r[(K^0 - gW_t) - X_t] - qE\}. \tag{4}$$

Effort in an open-access condition adjusts over time. It is described by Barbier and Strand (1998) as

$$E_{t+1} - E_t = \phi[ph(X_t, E_t) - cE_t], \tag{5}$$

where ɸ represents the effort adjustment coefficient, p the value of moose and c the real cost. The effort adjustment coefficient measures how the effort adjusts in response to the profits.

To fully understand equation (5), we need to know the following definitions: Total revenue from hunting is described as in Clark (1990) by

$$TR = ph(X_t, E_t),$$

with p corresponding to the unit value for the Swedish moose hunt. TC is the total cost of hunting and can be written as:

$$TC = cE_t.$$

In an open-access situation, effort will tend towards an equilibrium where effort is such that total revenues equal total costs (Clark 1990). The profit from hunting activity is $\pi = TR - TC$, but as it is assumed to be equal to zero in equilibrium, we can write $ph = cE$ (Barbier and Strand 1998).

The equilibrium cost can then be calculated as in Barbier and Strand (1998):

$$c = \frac{ph}{E}. \tag{6}$$

There are two scenarios that cannot indefinitely be supported and thus lead to a long run equilibrium effort. First, in the case, where effort is above the equilibrium effort, total costs would exceed revenues. Some hunters would make losses and reduce their time spent on the hunting activity, which decreases the equilibrium effort. Second, if effort is below the equilibrium effort, total revenues would exceed total costs. Hunting then becomes attractive and hunters spend more time hunting such that equilibrium effort would increase (Clark 1990). The adjustment of effort towards equilibrium can be assumed to occur quickly, since, according to Wikenros (2011), the harvest was modified flexibly when conditions changed. Now, equation (5) shows that if costs of hunting are greater than benefits in period t, the effort decreases in the next period due to hunters reducing their time spent on hunting or, in the worst case, leaving the sector. Hence, the effort adjusts. On the other hand, if revenues increase, effort will also increase in $t+1$.

4.2 Open Access Equilibrium

In the open access equilibrium, hunting effort and moose stock are presumed to be constant over time, thus $E_{t+1} = E_t = E$ and $X_{t+1} = X_t = X$, and the equilibrium level of wolves is assumed to be $W_{t+1} = W_t = W$. We will look at the long run equilibrium of a change in the number of wolves on moose hunting harvest.

The steady-state levels of effort E and moose stock X can be derived from equation (4) and (5) respectively, such that

$$X = \frac{c}{pq}\text{, and} \tag{7}$$

$$E = \frac{r[(K^0 - gW) - X]}{q} \quad \leftrightarrow \quad E = \frac{\mathrm{r}(K^0 - gW)}{q} - \frac{r}{q}\mathrm{X} \quad . \tag{8}$$

Since effort is assumed to be in steady state, the effort curve is vertical for a certain level of stock (see figure 2). The slope of the stock curve is described by $\frac{dE}{dX} = -\frac{r}{q}$, which is derived from the equilibrium effort in equation (8).

Figure 2 depicts possible equilibrium conditions for a change in the number of wolves. By assumption, wolves negatively affect the moose's intrinsic growth rate as well as their carrying capacity. Therefore, if the number of wolves increases, the moose stock would decrease and thus shift the stock curve downwards. In order to reach the same level of moose stock X, the equilibrium steady-state effort would have to adjust to a new equilibrium effort E'. There are two possible scenarios. In the first, adjusting effort leads to a stable equilibrium (trajectory 1.). In contrast, the assumption that the hunting effort does not adjust over time would lead to a lower moose stock and could lead to a collapse of the stock in the long run (trajectory 2.). We will only look at the scenario of trajectory 1, assuming that it is likely that changes in effort are made instantaneously as a response to wolf recolonization and hence a new equilibrium is reached. The second trajectory is less likely to occur, as there is currently no known danger of a collapse of the moose stock.

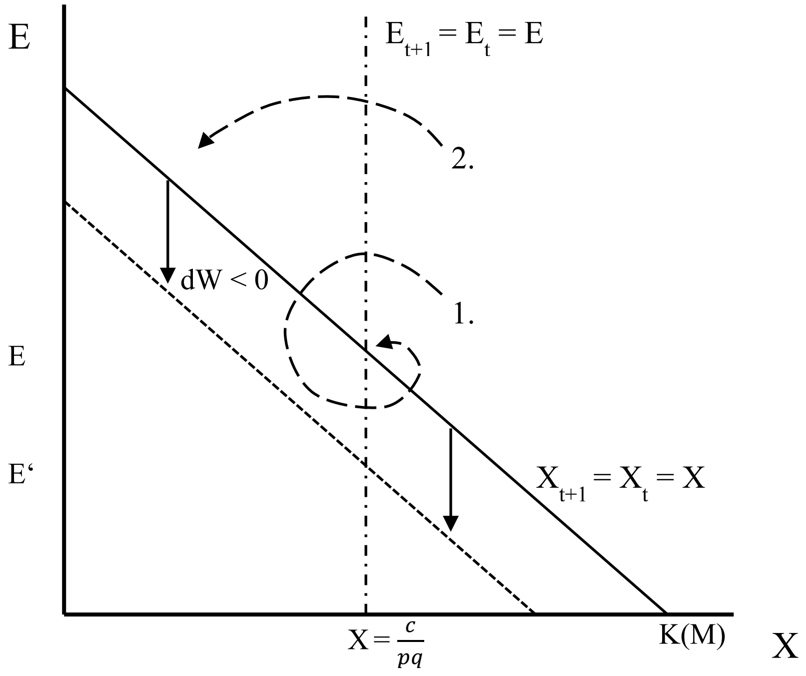

Figure 2: Open access equilibrium with trajectory 1. and 2.
Source: Barbier and Strand (1998)

4.3 The Comparative Static Effect of Changes in the Number of Wolves

Equation (8) yields the comparative static effect of a change in the number of wolves on the equilibrium level of hunting effort

$$\frac{dE}{dW} = -\frac{rg}{q} \qquad \leftrightarrow \qquad dE = -\frac{rg}{q}\,dW \tag{9}$$

This shows that an increase in the number of wolves W would decrease the effort E, which is intuitive assuming that more wolves eat more moose and hence decrease the number of moose that can be harvested. In a scenario with increasing wolf predation, the effort would have to be adjusted to keep a steady state level of moose stock.

If effort decreases, harvest also decreases (see equation (3)). The change in harvest can be calculated by taking the steady state level of moose stock from equation (7) and the change in effort of equation (8.1) and substituting it into equation (3)

$$\frac{dh}{dW} = \frac{dh}{dE} * \frac{dE}{dW} = qXdE = -\frac{rcg}{pq} \qquad \leftrightarrow \qquad dh = -\frac{rcg}{pq}\,dW \tag{10}$$

4.4 Regression of the Harvest Function

This paper has the purpose to evaluate moose harvest data over a ten-year period. It should quantify the effects of the growth of the wolf population on the moose harvest. For this, a regression was run on the harvest function to determine the impacts.

By substituting equation (3) in the steady-state effort (8) and assuming that the stock remains constant over time, we obtain an equation that shows the relationship between hunting harvest, wolves and effort:

$$E = \frac{r\,(K0 - gW)}{q} - \frac{rh}{q^2 E} \quad \leftrightarrow \qquad h \;=\; qK^0\,E \;-\; qg\,E * W \;- \frac{q2}{r}E^2.$$

Hence, for the regression we set $a_1 \;=\; qK^0$, $a_2 \;=\; -qg$, $a_3 = -\frac{q^2}{r}$. The coefficients will be measures of the impact by the different variables on the moose harvest. The harvest function appears as follows:

$$h \;=\; a_1 E \;+\; a_2 E \;* W \;+\; a_3 E^2 + u, \qquad (11)$$

where E describes the hunting effort, W the number of wolves, and u the error term. Notice that the model is described such that the habitat factor is only relevant when there is hunting activity (compare Foley et al. 2010).

Another functional form of the regression of the harvest function will be considered, which is achieved by dividing equation (11) by the effort E. It appears as follows:

$$\frac{H}{E} = \;a_1 \;+\; a_2 * W \;+\; 2a_3\,E\,. \qquad (12)$$

which is only defined for $E \neq 0$.

With equation (11) we can analyze how the harvest changes for an additional unit of effort, i.e. the marginal productivity of hunting effort:

$$\frac{dh}{dE} = a_1 \;+\; a_2 W \;+\; 2a_3. \qquad (13)$$

We will also look at the marginal product of one wolf, i.e. how the harvest changes when there is one more wolf but the effort is kept constant, such as

$$\frac{dh}{dW} = a_2 E. \qquad (14)$$

As a result, we can calculate the marginal revenue lost due to wolves as in Barbier and Strand (1998), which is

$$TR = p * dh. \tag{15}$$

5. Empirical Data

Our analysis includes balanced cross panel data for the variables harvest, effort, and wolves over a period of 10 years. The years included reach from 2002 to 2011. If we talk about the hunting year 2002, it refers to the period starting in July 2002 to the end of June 2003. The data was used to estimate equation (11) and (12). All variables occurring in the regression were adjusted for the size of each county in square kilometers to avoid that large counties had too much impact in the analysis. We divided all data on county-level by the size of the respective county. Data on the area of Sweden's counties was collected from Statistics Sweden (*Statistiska centralbyrån*). We included twenty of the twenty-one Swedish counties in our analysis. The county of Gotland is not included, since there are no wolves. Therefore, when we refer to the national analysis or the whole of Sweden in the remainder of this paper, it entails that Gotland is not part of it.

5.1 The Harvest

The harvest is measured in moose shot per square kilometer. Data was collected from viltdata.se. Especially, the North due to its low forest productivity and the far South due to its agricultural land, have low moose densities. The highest moose densities are found in central Sweden (Lavsund et al. 2003) which also occur to be the counties with the highest wolf densities. In general, harvest varies between the counties. When looking at the development of the moose harvest for each county during our study period, we can observe a general decrease until about 2006/2007 and an increase thereafter (see figure A.1 in appendix).

5.2 The Effort

We borrow the calculation of the effort variable in our regression from Foley et al. (2010). Their effort variable includes the number of vessels used for fishing and a percentage of the species fished among the total harvest of the fishery. It also includes days spent at sea and a ratio of the harvest per unit time fishing of a vessel compared to the harvest of a standard vessel. According to Sylvén (2003), hunting effort is very complex. It normally includes many characteristics of hunting groups, such as experience, traditions and hunting methods among others (Sylvén 2003). For this reason, we need to keep in mind that the effort variable is often just a simplified measure of the effort.

With respect to this, our effort variable only comprises two components. It would be more accurate to include additional parameters such as time spent hunting and the number of people who hunt moose. However, this is not possible as data is not available. We simplify therefore by assuming that the number of hunting days per hunter is constant over time. Consequently, the hunting effort E in our study is continuous and consists of the following components:

$$E_t = number\ of\ national\ hunting\ licenses \\ * percentage\ of\ moose\ shot\ among\ important\ Swedish\ game\ species^{5}$$

Data about hunting licenses was collected from Naturvårdsverket from 2002 till 2011. The number of hunting licenses refers to the licenses issued to people who take the hunter's examination to become a hunter. A study by Boman et al. (2011) discovered that among 280,000 hunters in 2005/06, 245,000 hunted moose. The short time period of our data analysis is due to the fact that there is no earlier data on hunting licenses available. The licenses from 2002 to 2004 for a region called "Mittnorrland" cannot exactly be assigned to one of the twenty counties included in our analysis. These data were proportionally allocated to the counties of Jämtland and Västernorrland. Moreover, we did not include foreigners who obtained a hunting license in Sweden, as data was missing for most of the years.

Effort also comprises a percentage of moose shot amongst important game species in Sweden. For this, we added up all available numbers of game shot and divided the annual moose harvest by it. The result times one-hundred gave us the percentage. This calculation was made on a yearly basis for both the whole of Sweden and for the counties individually. The data on game shot is yearly panel data for killings by hunters in Sweden. It was collected from viltdata.se and jagareforbundet.se.

We observed some differences in effort between counties as can be seen in figure A.2 in the appendix. The counties which started with high efforts in 2002 all decreased to an average level; whereas some of the counties with lower levels in the beginning increased or remained at low levels respectively. Some counties, however, maintained a low level of effort over the whole study period. The change in effort in our analysis could be caused by several effects, which are linked with the two variables that account for the effort variable. For instance, the percentage of moose shot is connected with the moose harvest as well as the harvest of other animals. We have to be aware of the fact that the percentage can also change due to a change in the harvest of other game species. In fact, the percentage of shot moose varies highly. In general, it increases from the South to the North of Sweden (see table A.3 in appendix). In the North, there are mainly moose and reindeer, whereas in the South there are many deer which make up for more alternative game. The number of licenses stayed relatively constant during our study period, although it experienced a slight overall decrease. The county of Västra Götaland has the highest number of licenses by far (see figure A.4 in appendix).

A relation can be observed, when looking at the average harvest and the average effort for all counties over the years (figure 3). They almost show the same pattern apart from an increase in average effort

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[5] The game shot comprises the number of red deer (Cervus Elaphus), fallow deer (Cervus Dama), roe deer (Capreolus Capreolus), wild boar (Sus Scrofa) and moose (Alces Alces).
Notice that the data for different types of deer and wild boars from Västra Götaland consist of collective data from four different counties (namely Göteborg and Bohus, Södra Älvsborg, Norra Älvsborg, and Skaraborg), which added up to Västra Götaland in 2011.

in 2005, while the harvest is still decreasing. The overall shape of the average harvest is decreasing until 2007 and increasing thereafter. The relation between harvest and effort is intuitive, because, if, for example, the hunting licenses decrease to a number close to zero, we can be sure that the moose harvest will also approximate to zero. A hunting license is usually obtained in the beginning of the hunting year. Thus licenses that you get in the summer 2005 should affect harvest in the 2005/2006 hunting season. Most moose hunting occurs in autumn throughout the season (Wikenros et al. 2015). Nevertheless, we would still expect harvest to follow effort, yet effort seems to follow harvest instead.

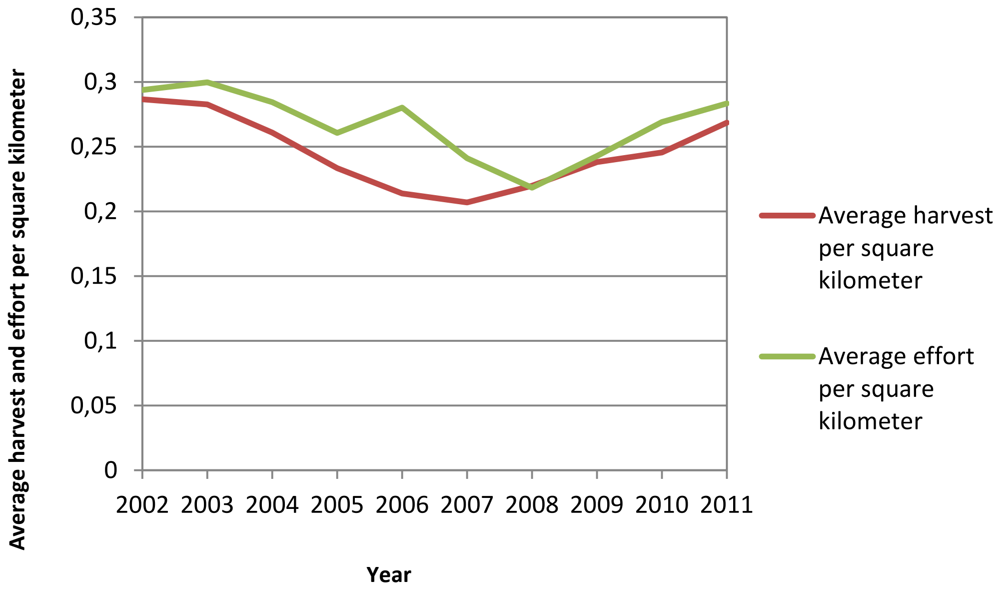

Figure 3: Average harvest and effort per square kilometer over the years

Source: author’s creation with Excel

5.3 The Wolves

There is data available from viltskadecenter.se on the number of wolves living in Sweden. These numbers are based on county level-observations. Yet, many times wolves cross borders and are therefore counted for several counties. If this was the case, we divided the number of wolves by the number of counties they were counted in. Since we cannot have half of a wolf, we rounded decimals up. Moreover, there are two scenarios to look at based on the observations. We can distinguish minimum values and maximum values. Minimum values are verified counts from experienced reporters and trackers. Maximum values include public sightings which are not verified. We only used minimum values, as they were verified by professionals.

Figure 4 shows the development of the wolf population for the different counties during our study period. The number of individuals at the end was almost four times as high as in 2002. As mentioned above, wolf numbers varied highly in the counties where wolves were present. In general, about half of the wolf counties had an increasing trend in wolf population. On the other hand, some counties maintained a low wolf population, while some counties did not have wolves at all.

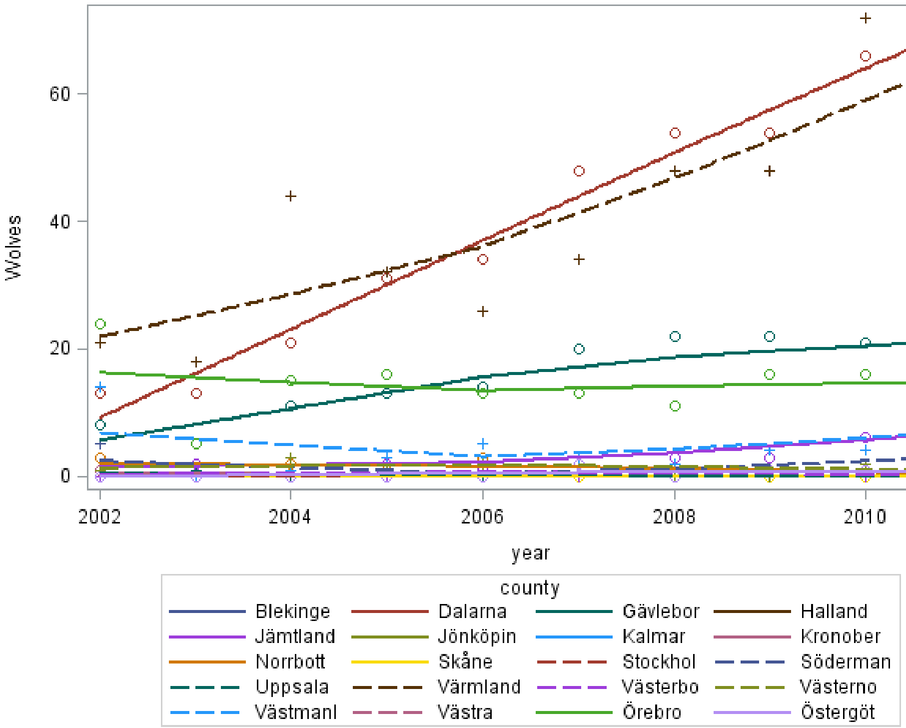

Figure 4: Total number of wolves per year for all the counties included in the national analysis

Source: author's creation with SAS

Because of this and the high variation of local conditions between counties, we decided to look at three different county groupings for the original harvest regression function. Besides, the small number of observations for one county would not have made it meaningful to run a regression just on one county. Another reason was also the fact that we had different availability of alternative prey animals as mentioned above. While there are just a few deer and boar in the north, the South has much more alternative prey apart from moose. Therefore, we chose to categorize for these different groupings to have counties with probably similar conditions together (see figure 5).

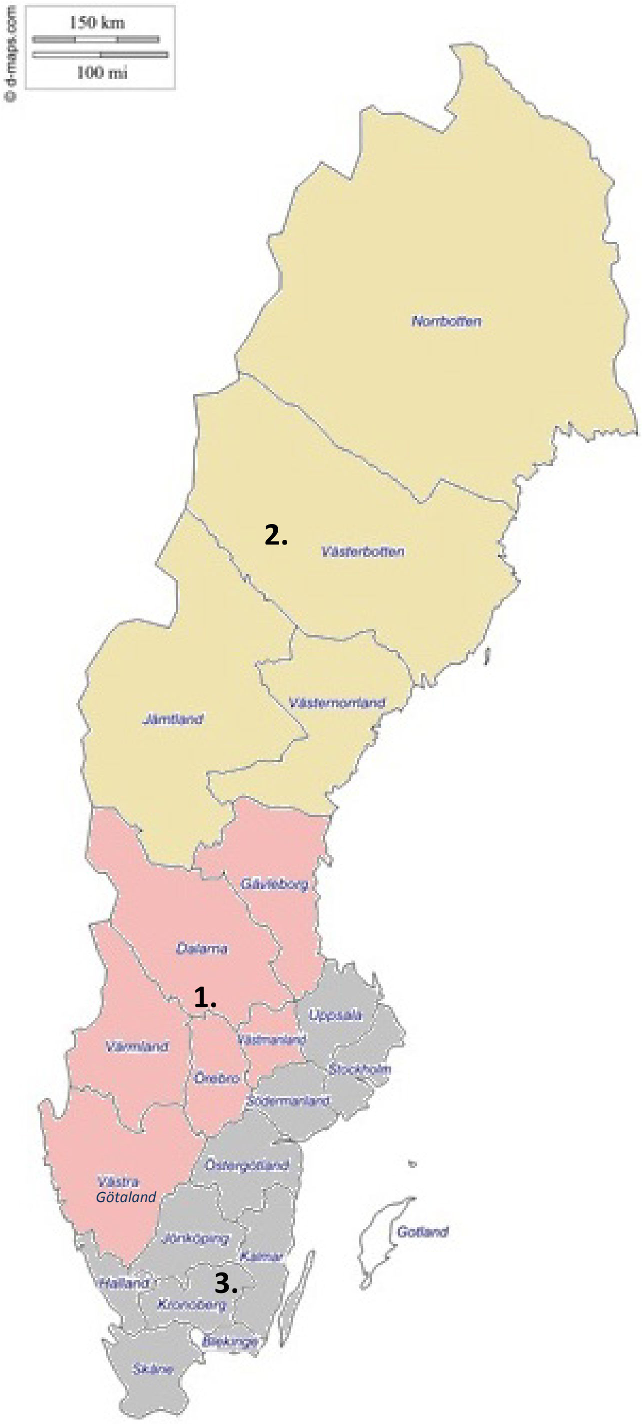

Figure 5: Map of the Sweden and its counties including the county groupings

Caption:

1. High-density (HD) wolf counties (>= 10 wolves at least during 1 year of the period): Dalarna, Gävleborg, Värmland, Västmanland, Västra Götaland, Örebro
2. Counties north of the high-density wolf counties: Jämtland, Norrbotten, Västerbotten, Västernorrland
3. Counties south of the high-density wolf counties: Blekinge, Halland, Jönköping, Kalmar, Kronoberg, Skåne, Stockholm, Södermanland, Uppsala, Östergötland

One grouping includes all counties with a high density (HD) of wolves. Our definition of a HD wolf county was that there had been at least one year within the 10-year period with 10 wolves or more. We chose to classify HD wolf counties, because of the assumption that the harvest in counties which just had a few wolves in one or two years would not be influenced as much by wolf predation as counties with a constantly big wolf population. HD wolf counties included 6 counties, namely Dalarna, Gävleborg, Värmland, Västmanland, Västra Götaland and Örebro. The development of the wolf population in these counties is shown in figure 6. The number of wolves in the HD wolf counties varied highly throughout the years.

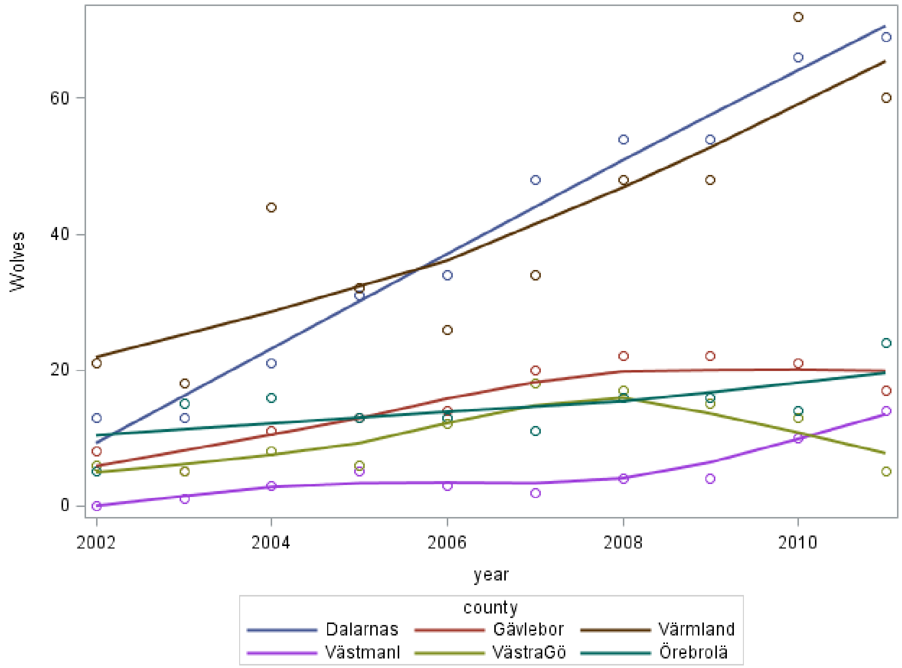

Figure 6: Total number of wolves per year in the counties with high wolf densities
Source: author’s creation with SAS

Furthermore, we divided the counties with low wolf densities between counties located north of the HD wolf counties and south of the HD wolf counties. In the North of Sweden, we have the conflict of wolves with reindeer herding which provides a special situation why wolves are not wanted in these counties. Besides, as mentioned before, the percentage of moose shot is higher in the North compared to the South.

In figure 7, which shows the four counties included in the North, we can observe that Jämtland had an increase in wolf numbers in 2010 from 3 to 8 individuals, whereas the other counties experienced a decrease in the end. Figure 8 shows wolf numbers for the remaining ten southern counties. Jönköping had a small increase in wolf numbers in 2010, but the other counties overall remain at a low number of wolves. We should bear in mind that the counties of Stockholm and Jämtland are located close to the HD wolf counties and therefore to the wolves’ main breeding area. This could be a reason for why numbers there are a bit higher compared to the rest. Table 3 contains summary statistics of the relevant variables.

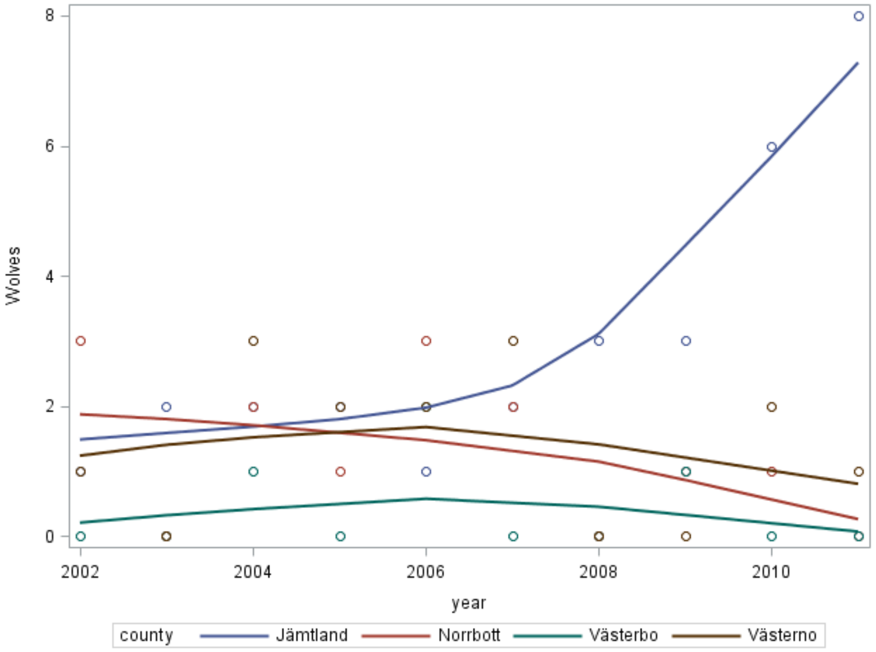

Figure 7: Total number of wolves per year for all the counties included in the analysis of the counties north of the HD wolf counties

Source: author’s creation with SAS

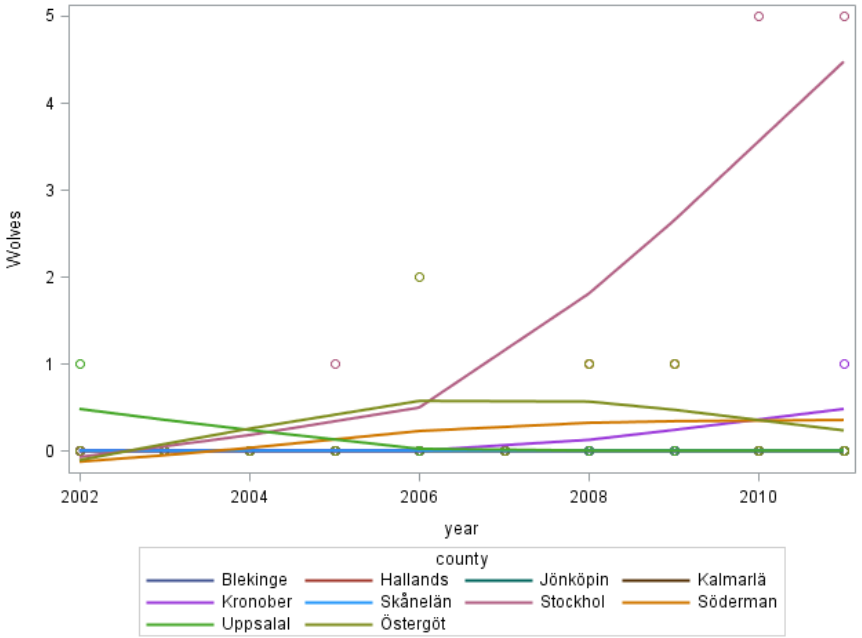

Figure 8: Total number of wolves per year for all the counties included in the analysis of the counties south of the HD wolf counties

Source: author’s creation with SAS

Table 3: Summary statistics of the data variables

	Harvest/km^2	Effort/km^2	Effort (licenses targeted to moose hunting)	Effort/km^2 squared	Wolves	Licenses	Percentage of shot moose
Minimum	0.03	0.04	56.8	0.001	0	1292	2
Maximum	0.52	0.61	20250	0.375	72	37401	95.6
Mean over all years and counties	0.25	0.27	5205.4	0.092	6.6	13139.1	37.4
Standard deviation	0.10	0.14	5448.7	0.090	13.6	7372.1	30.9
Sum	49.12	53.46	1041075.2	18.338	1335	2627817	-

Source: author's creation with Excel

5.4 The Value of the Moose Hunt

In order to obtain p to calculate equation (15), we took the unit value of the moose hunt as calculated by Boman et al. (2011). It was calculated to 7,000 SEK in 2005/2006. We use it to account for the monetary loss of moose hunting harvest due to wolves. Boman et al.'s (2011) value was based on willingness to pay-questions, such as how hunters value hunting including all costs and what they would be willing to pay to avoid the loss of hunting. We use this value instead of just a per kg meat price, because, as mentioned above, moose hunting has other values than just the simple value of meat. Hence, p includes both profits and the leisure value of hunting. Nevertheless, it is a simplification to assume that the value remains constant over our time period because there can be changes. Besides, the willingness-to-pay for the preservation of hunting can change in conjunction with income for instance.

6. Results and Discussion

6.1 Explaining the Econometric Approach

Since the data used in our analysis is panel data across time, it deals with natural autocorrelation issues. Autocorrelation, as defined by Dow et al. (1984) means that at some point in time, the outcome at that point is in general not independent of the outcome at points around it. We know that the development of variables in our analysis is dependent on earlier years, and we can assume similar conditions in the following years. For example, the effort in one year affects the effort in the next. Therefore, some autocorrelation was inevitably given in our data. We used the MIXED procedure in SAS which is supposed to fit different mixed linear models to data. The procedure does not use a time series correlation (SAS 2015); hence it takes care of the autocorrelation problem. Furthermore, after investigating the Variance Inflation Factors (VIF) and correlation between the variables, we concluded that mulitcollinearity is not an issue in our analysis.

There were two reasons why we decided to use a mixed effects model both with fixed- and random-effect parameters. First, and probably most important, we had to keep in mind that our regression equation as in (11) did not include an intercept. This is implied by the fact that there cannot be any harvest when the effort is equal to zero. Therefore, year and county had to be included as random effects, so that the regression runs through the origin. If we had chosen a fixed effects model, and we had had a fixed effect for county or year, there would have been one of the counties or years that would have defined an intercept. This again is not compatible with our model. Hence, a strictly fixed effects model did not work in this context. The mixed effects model we used had year and county effects sum to zero so that no intercept was included in our model. The effects were random effects, one accounting for random variation of county and another one accounting for random variation of year. There was no connection between these two effects. Another advantage of the mixed model is that the number of parameters to be estimated is fewer than in a fixed model. Nevertheless, the functional form $\frac{H}{E}$ of the harvest regression was estimated with an intercept, as specified in equation (12), since the form of the equation allows for an intercept.

From the graphs above, we could observe great variation between the counties which made them difficult to compare and the issue of heterogeneity relevant. It is obvious that there are local differences, when we think of the uneven wolf distribution, and the varying number of moose and moose hunters. Thus, second, we decided to eliminate a fixed effects model due to the high variation of data between the counties. By classifying into groupings of counties with similar characteristics, we also attempted to take care of the high variation.

6.2 Shortcomings of the Regression Analysis

Heteroscedasticity did not seem to be a problem, when looking at all the groupings. The national analysis and the analysis of both the HD wolf counties and the southern counties also showed a normal distribution (see figures A.5, A.6 and A.8 in appendix). Yet, we observed heteroscedasticity for the functional form $\frac{H}{E}$ of the harvest regression (see figure A.9 in appendix). There were also some problems with the regression of the northern counties. Residuals for the harvest were not evenly distributed and did not show a normal distribution (see figure A.7 in appendix). Therefore, we cannot interpret the results of this grouping.

To account for the R^2, we used the GLM procedure in SAS. The R^2 is only explanatory for the fixed parts of the model, i.e. the effort variables, while year and county effects were neglected. There is further critique that the R^2 for regressions that run through the origin is not meaningful. In fact, it does not give a good measure a fit and cannot be compared with the R^2 estimated in an OLS regression (Foley et al. 2010).

The endogenous effort variable comprises a percentage which was calculated with the data on moose harvest. Therefore, one could possibly argue about an endogeneity bias between the effort variable and the harvest variable, since the number of moose will influence both. However, both variables differ, since harvest as the response was divided by county size, whereas the percentage was used for the entire harvest. Furthermore, when we were looking at the harvest and the percentage over the years we found differences, for example when we were looking at Värmland and Norrbotten. The percentage was strongly increasing in the end while the harvest was not changing much (compare figure 9 and 10).

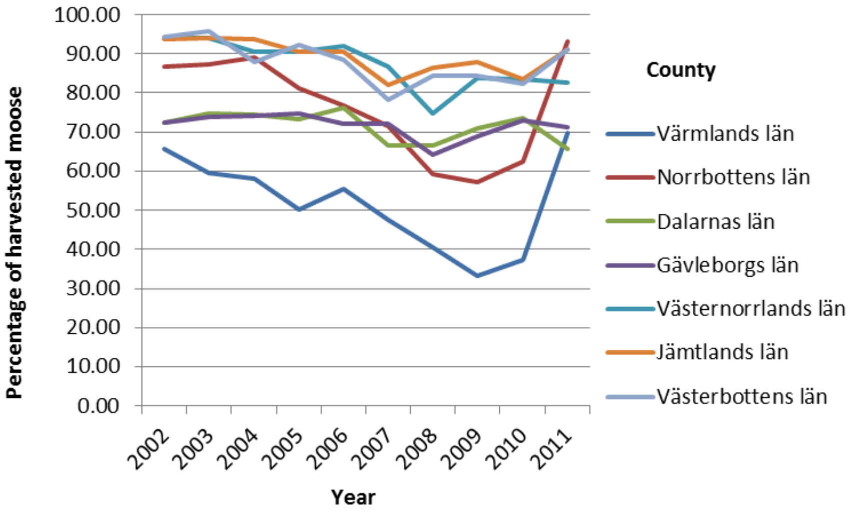

Figure 9: Percentage of harvested moose over the years for a selection of counties

Source: author’s creation with Excel

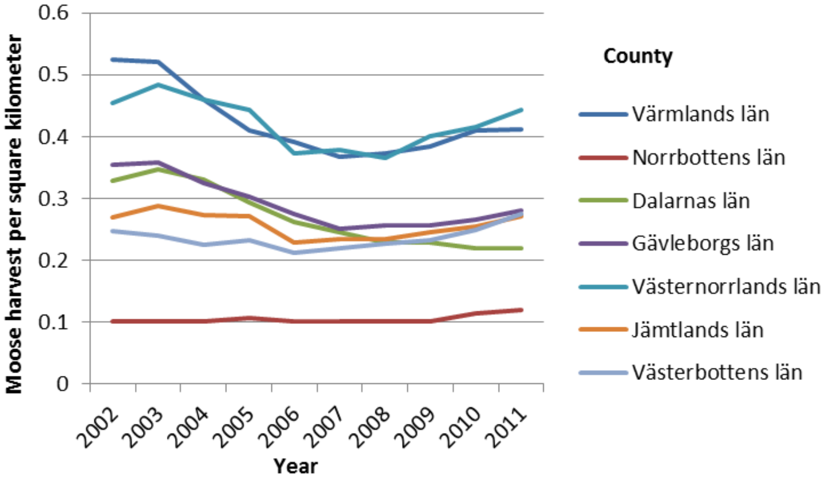

Figure 10: Harvest over the years for a selection of counties

Source: author's creation with Excel

The use of instrumental variables was also considered. However, it was impossible to find convenient substitutes for the effort variable due to the limited time and scope of the study.

6.3 Empirical Results

As mentioned above, the dependent variable of our analysis is harvest measured in moose shot by hunters per kilometer squared. The independent variables for equation (11) are: Effort (E), Effort • Wolves (EW) and Effort squared (E^2). Results for the analysis for the whole of Sweden are presented in table 4. As counties were very diverse in data, they also differed greatly in effects of the different variables for our groupings. When we ran the model on the national harvest regression function h as in equation (11) with 200 observations (table 4 (A)), we observed significance in all variables at the 1% level. Using the model's estimates, we calculated results for short-term harvest changes due to one wolf, short term marginal costs as well as the marginal productivity of effort.

The marginal product of one wolf at mean effort is equal to -19, i.e. the presence of one wolf reduces the harvest at mean effort by this many moose individuals per year. This fits in quite well with results of other studies where kill rates were estimated (see table 2 in chapter 2).

In the short term, when effort does not adjust, we estimated a marginal loss in revenues of -134,140 SEK per wolf due to the decrease in harvest. We also calculated the harvest change for a unit change in the effort as in equation (13) which under the presence of wolves, using mean numbers, was with 0.65 only slightly lower than without wolves where it was 0.68.

We used another functional form of the harvest regression function, as in equation (12), where we divided it by the effort such that $\frac{H}{E}$ (table 4 (B)). Table 4 shows the results of both functional forms. When comparing them, the Akaike information criterion (AIC) gave a much better fit for the original harvest regression (A). The AIC is used to reduce loss of estimated information. Moreover, (B)'s results with respect to the wolf variable were quite similar to the results of (A). While the model in (B) had heteroscedasticity issues, the model in (A) performed better (compare A.5 and A.9 in appendix). Because of these results, we decided to continue the analysis only with the original regression of the harvest function as in (A).

Table 4: Results for the general mixed model with estimates and the marginal impacts in the open access equilibrium for the national analysis (A) and the form $\frac{H}{E}$ (B)

	(A)	(B)
E	1.1***	-1.8***
EW	-71.7***	-
E^2	-0.8***	-
Intercept	-	1.6***
W	-	-82.3**
Observations	200	200
AIC	-723.6	-26.9
R^2	0.50	0.34
MP_E at the presence of wolves[6]	0.65	-
MP_E without wolves	0.68	-
MP_W[7]	-19	-
MC_W (in SEK)[8]	-134,140	-

* significant at p<0.1; ** significant at p<0.05; *** significant at p<0.01

Caption:

$E = \frac{Effort}{km^2}$

$EW = \frac{Effort}{km^2} * \frac{Wolves}{km^2}$

$E^2 = \left(\frac{Effort}{km^2}\right)^2$

$W = \frac{Wolves}{km^2}$

MP_E = marginal productivity of effort

MPw = marginal product of wolves

MCw = marginal cost of wolves

Table 5 shows the results for the different groupings of counties. All groupings showed very good AIC, even though they did not give as good of a fit as the original regression including the whole of Sweden. Again, the marginal productivity of hunting effort did not differ significantly. Yet, when

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[6] From equation (13) we know: $\frac{dh}{dE} = a_1 + a_2 * W + 2a_4$

[7] From equation (14) we know: $MP_W = a_2 * E$

[8] From equation (15) we know: $MP_W * P$

looking at marginal products, it was interesting that the HD wolf counties (1.) had only less than half of the decrease in harvest for one additional wolf than when all counties were included. In the HD wolf counties, E and E^2 were significant at 1%, while EW showed only significance at 10%. The marginal product per wolf amounted to -9 killed moose individuals, and the marginal cost was equal to 60,635 SEK. The grouping of counties north of the HD wolf counties (2.) only comprised 4 counties, whereas the grouping of the counties in the South (3.) comprised 10 counties. The impacts of the E and the EW variables on the harvest were not significant in the northern counties.

In the counties in the south, E and E^2 were significant at the 1%-level, and EW was significant at the 5%-level. The marginal product and the marginal loss in revenues were, with -62 and 432,721 SEK respectively, much higher in comparison with the national estimates. The marginal impact of one wolf is actually more than three times as high. The pattern of where to find high marginal costs and where to find lower costs were similar to the outcomes by Boman et al. (2003) (compare with table 2). A possible explanation could be the fact that, independent of the pack size, the number of moose killed by packs is mainly the same (Sand et al. 2011). This means, for instance, that if there was a pack of two wolves, and a pack of eight, both packs kill about the same number of moose per year. It leaves the wolves of the smaller pack with a higher marginal impact than the wolves in the larger pack. Yet, we did not include pack size in this analysis. We tried, however, to include the impact of traffic as an explicit habitat factor affecting moose mortality, but results were not as expected and actually did not change the coefficients respectively.

Table 5: General mixed model with estimates and the marginal impacts in the open access equilibrium for different county groupings

	1.	2.	3.
E	0.9***	-0.3	1.3***
EW	-32.4*	-248.5	-231.3**
E^2	-0.7***	0.8***	-1.4***
Observations	60	40	100
AIC	-222.5	-182.0	-355.1
R^2	0.2	0.8	0.5
MP_E at the presence of wolves	0.51	0.05	0.61
MP_E without wolves	0.52	0.15	0.52
$MP_W = a_2 * E$	-9	-66	-62
$MP_W * P$ (in SEK)	-60,635	-465,036	-432,721

* significant at 10%; ** significant at 5%; *** significant at 1%

Caption:

1. High-density (HD) wolf counties
2. Counties in the north of the HD wolf counties
3. Counties in the south of the HD wolf counties

6.4 Results of the Comparative Static Effect

The comparative static relationships enable us to simulate a change in the number of wolves on the equilibrium moose harvest. For this, we assume a change in effort to keep the harvest constant. We can also estimate the change in revenues due to the habitat factor. The bio-economic parameters g and q cannot be obtained from the regression equation (11), but we know from it that $a_2 = -qg$ and $a_3 = -\frac{q^2}{r}$. Besides, we know the change in equilibrium effort from equation (9) which is

$$dE = -\frac{rg}{q} dW = -\frac{a_2}{a_3} dW. \qquad (9')$$

The comparative static relationship from equation (10), following Barbier and Strand (1998), can be rewritten as

$$dh = -\frac{rcg}{pq}\, dW = -\frac{ca_2}{pa_3}\, dW. \qquad (10')$$

The change in revenue is

$$p\, dh = -\frac{rcg}{q}\, dW = -\frac{ca_2}{a_3} dW. \qquad (10'')$$

Theoretically, our argumentation follows the one by Barbier and Strand (1998). Underlying assumptions to equation (11) from the conceptual framework are that the data on harvest and effort satisfy the open-access equation (8). In order to fulfill the open-access equilibrium, both open-access equations ((7) and (8)) have to be satisfied. Hence, if harvest and effort values satisfy both equation (7), which assumes that the profit is equal to zero in the long run, and equation (11), then they will also satisfy the open-access equilibrium.

We then need to impute the value of the moose hunt p and the cost c to be able to compute the comparative static effect for the national as well as the county groupings. The value of the moose hunt is $p = 7{,}000\ SEK$, as discussed above. The total cost can be calculated by using mean values for h, p and E (see table 3) and equation (6) amounting to $c = \frac{7{,}000 * 0.25}{0.27} = 6431.8\ SEK$.

The marginal steady state change in effort, by using our estimates for a_2 and a_3 and equation (9'), amounts to -92. It means that this amount of effort would have to be decreased per wolf present, in order to keep the moose stock constant. Plugging our estimates and our values for p and c into equation (10’), we obtain the marginal change in equilibrium harvest for wolves in Sweden. It is equal to -84 moose. The same procedure for equation (10’’) accounts for a marginal cost of 589,246 SEK. Here, the HD wolf counties again showed much lower numbers. The marginal loss in equilibrium harvest is equal to -44 moose, which accounts for a marginal cost of 307,001 SEK. The marginal change in equilibrium effort accounts with -48 only for half of the effort change of the national analysis. The comparative static relationship for the southern counties was with -171 units of effort the highest among our groupings. The marginal product for one wolf was equal to -157 moose, and the marginal cost amounted to approximately 1.1 million SEK (see table 6 for results). For the comparative static effect, we could observe higher marginal impacts than in the short-term open access equilibrium.

Table 6: Results of the comparative static relationships

	1. National analysis	2. High density (HD) wolf counties	3. Counties north of the HD wolf counties	4. Counties south of the HD wolf counties
$MP_W^{Comp.}$	-84	-44	-	-157
$MC_W^{Comp.}$ (in SEK)	-589,246	-307,001	-	-1,098,613
$MP_E^{Comp.}$	-92	-48	-	-171

Caption:

$MP_W^{Comp.}$ = steady-state marginal product of wolves

$MC_W^{Comp.}$ = steady-state marginal cost of wolves

$MP_E^{Comp.}$ = steady-state marginal productivity of effort

If we take the total number of wolves and use the short-term and the steady-state marginal cost, we can calculate a total cost of the Swedish wolf population in terms of foregone hunting profit. Assuming we have a marginal cost per wolf multiplied by the number of wolves in Sweden which was equal to 203 individuals in 2011, we get a total cost of approximately 27.2 million SEK in the short term and 119.6 million SEK in the steady state respectively. However, this cannot be seen as the real outcome, since wolf pups do not hunt and thus do not have an impact. The total cost is therefore likely to be lower.

7. Conclusions

7.1 Summary

We applied the production function approach in a prey-predator context in order to determine the economic impact on wolves on the moose hunting. To address this problem, we developed a model borrowing from Barbier and Strand (1994) and Foley et al. (2010) and calculated the steady state conditions for the moose harvest under the presence of wolves. We then derived a harvest function with which we could identify the marginal product of a wolf, i.e. its marginal effect on the moose harvest. In addition, we quantified its marginal cost in terms of lost revenues from hunting and the marginal productivity of effort. Assuming that in the long term effort adjusts under the presence of wolves; this study also investigated the long-run equilibrium changes in effort, harvest and loss of hunting revenues. To account for the heterogeneity between regions, we grouped several counties in the analysis together. We ended up running a regression with the national data, one with the counties with a high density of wolves, one with the counties north of these counties and one including the counties in the south.

In summary, we saw that the counties with a low density of wolves, such as the southern counties, had a much higher marginal product and cost for wolves than counties with a high density of wolves. The estimates for the northern county grouping were also quite high, yet not significant. For the national analysis, we estimated numbers that lie in between the values of the southern counties and the HD wolf counties. There is scientific evidence that wolf packs hunt the same amount of moose per year irrespective of their size. This could possibly be an explanation for the observed differences in the county groupings. The southern counties barely have any wolves. Therefore, one wolf there has a much higher impact compared with a wolf in the HD wolf counties.

Moreover, the marginal productivity of effort was less than one moose per year in any grouping, which could be due to the fact that hunters hunt in groups and, thus, not every hunter kills a moose. Alternatively, there could be hunters who obtain a local moose hunting license, but do not go hunting. Nevertheless, these are assumptions and would have to be further investigated. The marginal productivity of effort did not seem to differ significantly, whether there were wolves present or not. Besides, it did not change much in between the groupings.

When looking at the comparative statics, i.e. a constant number of moose, the outcomes reflected similar results as in the open access equilibrium, although the numbers were generally higher. Hypothetically, the decrease in effort could be due to the precautious effort adjustment by hunters as mentioned above. Nevertheless, we cannot know for whichever reason the effort adjusts. On the whole, our results fit in well with the results of other studies so far. Yet, when estimating the total cost for the wolf population, we got a number which is likely to be smaller in reality. This could be due to the reason that wolf pups do not hunt and thus do not contribute to the costs.

Further studies could develop the concept of the method and take care of the possible endogeneity between the harvest and the effort variable in future studies. It could furthermore be interesting to look at hunting profit of tourists who come to Sweden for moose hunting, as we did not include them. There could also be further research investigating the conflict between wolves and hunting dogs, although there may already be a connection seen in this study. If we assume that hunting dogs help to harvest moose, the hunters may be less efficient when they cannot use their dogs unrestrictedly because of wolves. We found a reduced marginal productivity of hunting effort under the presence of wolves which could support this assumption. We did not explicitly include the wolves' impact on hunting dogs, however, as it requires a different model.

It should be noted that the method we used is only one method to measure the marginal costs of wolves for the moose hunt. As our model is a simplification, the estimations could therefore deviate in real live. Depending on the selection of the variables in the effort function, they may change as well. The effort variable was limited due to data availability and could possibly be expanded. Considering this, we should be careful not to over-interpret our results. Furthermore, regardless of the results, there should be respect and understanding for wolves as well as for hunters.

To conclude, this study shows a negative economic impact of wolves on the moose harvest. However, considering the costs caused by moose's browsing damage, there needs to be more research about the wolf's overall impact. This work can and should not be used as a reason to eliminate the wolf population in Sweden. It has the purpose to give more information and possibly get a better idea about the costs of living with wolves. The following policy recommendations talk about current EU actions on wolves and present some suggestions about how to interpret and deal with the results of this study.

7.2 Policy Recommendations

According to the outcomes of this study, concerns about the wolf being a competitor in moose hunting may be of relevance. Moose hunters in Sweden, therefore, cannot be neglected in the question of wolf preservation. For this reason, it is important to understand both sides if one intends to find a feasible solution and peaceful coexistence. Considering that hunters are significantly affected by wolves, on the one hand, and, on the other hand, the fact that the wolf is listed and protected as an endangered species, there cannot be a simple solution without harming either one of the parties. Long-term solutions promoting wolf acceptance would be necessary and have to be addressed, since, although legally protected under the Habitat Directive of the EU (Boitani et al. 2015), there still is illegal poaching of wolves (Sand et al. 2012a).

The EU supports specific actions with regard to wolves in its member states which also address the conflict. Summarized by Boitani et al. (2015), they are divided within a scale specifying high, medium and low urgency, as well as the expected benefit. For example, monitoring, standardized census and transboundary cooperation have a high urgency and an expected high benefit. Countries benefit from information sharing across borders, such as Sweden and Norway which corporate to some degree. With this knowledge, trends and the actual size of wolf populations are available. Based on this population management can be undertaken. There are additional measures to prevent illegal killing which have a high to medium urgency.

While there are several more actions aiming at all wolf populations in the EU, there are two specific ones targeted at the Scandinavian wolf population. Although, being marked by low urgency, these are of actual importance in the context of this study and the connected debate about wolf acceptance in Sweden. First, science-based estimates about the appropriate "Favorable Conservation Status" are supposed to be made (Boitani et al. 2015). This status describes a sustainable status of the population, which is questionable in Sweden at the moment due to the allowance of licensed hunt since 2010. According to a request from the European Commission, Sweden does not show successfully that the growth of the wolf population is not in danger (European Commission 2015). Second, there is an action targeting the development of practices or instruments in order to decrease the killing of hunting dogs. A possible instrument would be the creation of hunting vests for example (Boitani et al. 2015). The killing of moose being important, the issue of killed dogs is much more of an emotional issue in the whole debate. Compensation for killed dogs exists; however it is difficult to determine the amount of compensation. Dogs are usually regarded as part of the owner's family, so that they are more valuable to their owner. Hunting dogs may also vary in their value (Boman et al. 2003). Although only about 20 dogs are killed by wolves annually, this still contributes strongly to why the wolf faces low acceptance especially in rural communities (Boitani et al. 2015). As a consequence, instruments addressing attacks of hunting dogs could, therefore, be a big step towards the acceptance of wolves. They should have highest priority against the background of the current conflict.

In contrast to the negative impacts, one should forget that wolves have values and benefits. For example, they perform several ecosystem services. There is literature available on the benefit of wolves, in terms of food provision to other animals in the form of prey leftovers (Wikenros 2011; Wikenros et al. 2013). Moreover, wolves eliminate sick wildlife and thus potentially prevent the spread of infectious diseases (Haemig 2013). Wolves also have existence and tourist values, which means that some people value the knowledge of the presence of the wolf and some may like to go and see the wolf in the countryside (Boman, Bostedt, and Persson 2003; Skonhoft 2006b). Therefore, the benefits of the wolf could further be analyzed and promoted to make people more aware of the possible advantages of having wolves in the country. Besides, we should think about if wolves do not actually have the first right to hunt and exist, since they are a natural predator of moose.

Since the wolf is an endangered species, has important ecosystem values and is protected under EU law, the elimination of the wolf population cannot be a solution. Hence, the overall acceptance and value of the wolf could be promoted to make more people see, why it is useful to have wolves. There have been actions undertaken by the EU already which address increasing acceptance of the wolf in Sweden. Time will show how effective they are especially with respect to the dog issue. In conclusion, it is difficult to make explicit recommendations on what should be done. Nonetheless, actions, such as the ones mentioned above, are of crucial importance. It is inevitable to continue to establish and search for long-term solutions which allow both hunters and wolves to co-exist peacefully.

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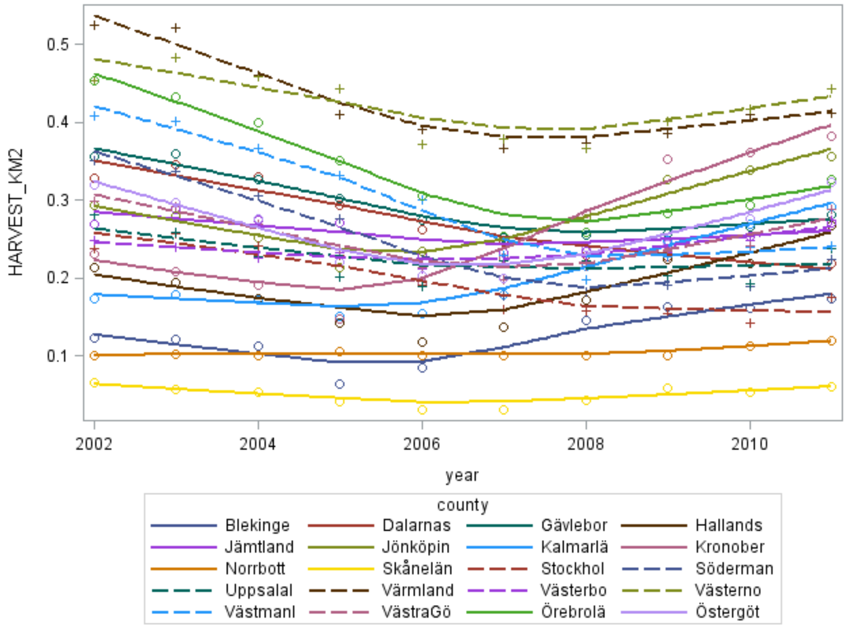
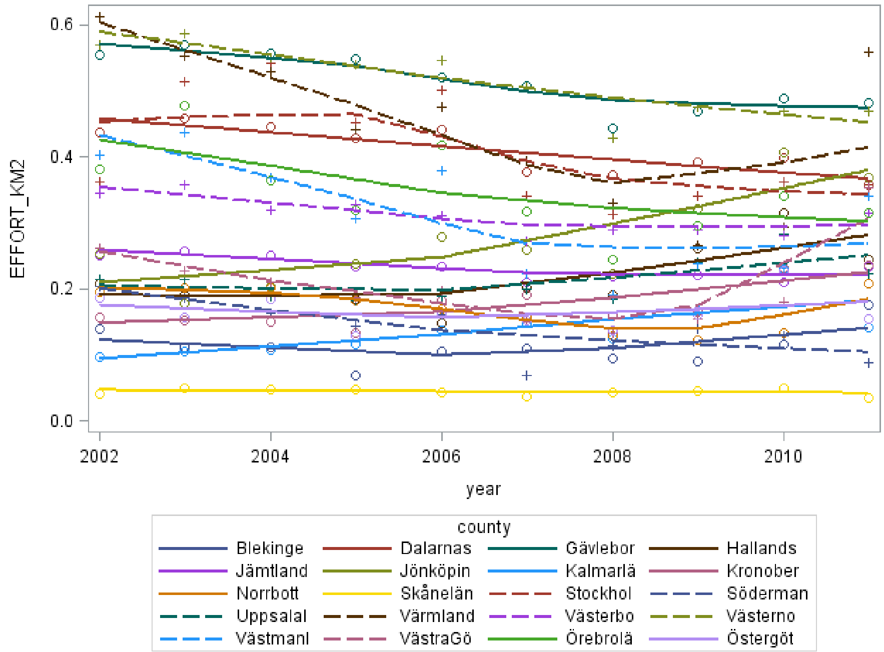
10. Appendix

Figure A.1: Harvest per square kilometer on county level from 2002 to 2011



Source: author’s creation with SAS

Figure A.2: Effort per square kilometer on county level from 2002 to 2011



Source: author’s creation with SAS

Table A.3: Percentage of moose killed in hunting

The table shows the percentage of moose shot for each county and year and the overall average for each year. We can observe how highly the percentage between counties varies and that the average is always between 30 and 40% throughout our study period.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stockholm	11.0	15.2	16.3	13.9	15.1	10.3	9.5	10.3	11.1	10.3
Uppsala	19.5	19.3	17.1	17.2	17.7	18.9	17.8	23.2	28.2	21.7
Södermanland	17.3	15.7	13.9	12.6	14.0	6.0	10.2	12.7	12.2	8.0
Östergötland	17.1	14.3	17.2	12.2	15.6	14.7	13.6	15.8	22.8	15.0
Jönköping	19.0	13.2	15.6	18.7	22.2	20.8	18.2	26.2	33.5	29.7
Kronoberg	14.4	14.1	14.1	13.3	18.2	19.2	16.3	16.8	23.6	23.6
Kalmar	9.7	10.7	11.1	12.3	14.7	16.2	13.7	18.4	25.8	15.6
Blekinge	7.6	6.1	6.2	4.0	6.2	6.5	5.7	5.5	7.1	10.6
Skåne	2.2	2.6	2.6	2.6	2.4	2.0	2.4	2.6	2.9	2.0
Halland	12.5	11.5	11.2	11.3	9.3	12.6	12.1	16.5	20.1	15.3
Västra Götaland	16.9	14.4	13.6	12.4	13.2	10.4	9.2	10.8	12.9	24.6
Värmland	65.6	59.4	58.2	50.1	55.4	47.6	40.5	33.1	37.2	69.8
Örebro	36.9	46.3	36.1	32.5	42.8	33.3	26.4	32.3	38.2	34.7
Västmanland	29.4	31.4	27.3	27.2	33.7	20.2	17.9	22.4	22.4	32.3
Dalarna	72.3	74.8	74.4	73.4	76.1	66.5	66.5	70.9	73.7	65.7
Gävleborg	72.4	73.9	74.2	74.7	72.0	72.1	64.3	69.0	73.1	71.3
Västernorrland	93.9	94.0	90.6	90.5	92.1	86.6	74.8	83.8	83.5	82.5
Jämtland	93.6	94.1	93.8	90.5	90.4	82.1	86.4	88.0	83.5	91.1
Västerbotten	94.4	95.6	87.9	92.4	88.4	78.1	84.2	84.3	82.4	91.0
Norrbotten	86.8	87.3	89.1	81.2	76.7	71.6	59.1	57.2	62.3	93.1
Average	39.6	39.7	38.5	37.1	38.8	34.8	32.4	35.0	37.8	40.4

Source: author's creation with data from viltdata.se and jagareforbundet.se. Game species included in calculations: red deer (Cervus Elaphus), fallow deer (Cervus Dama), roe deer (Capreolus Capreolus), wild boar (Sus Scrofa) and moose (Alces Alces)[9].

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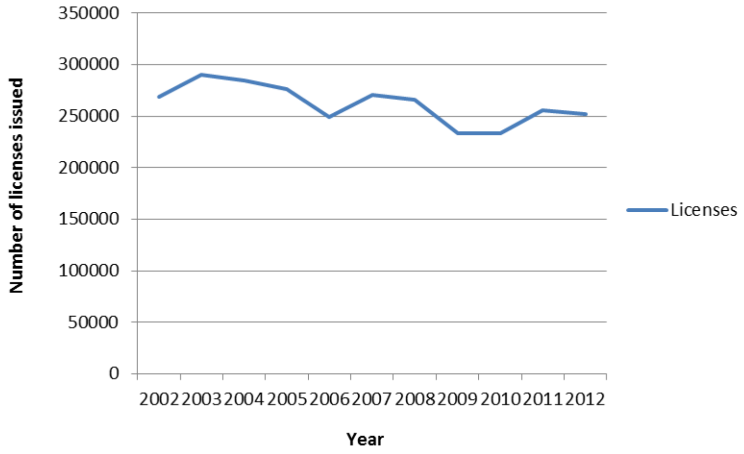
[9] Notice that the data for different types of deer and wild boars from Västra Götaland consists of collective data from four different counties (namely Göteborg and Bohus, Södra Älvsborg, Norra Älvsborg, and Skaraborg), which added up to Västra Götaland in 2011.

Figure A.4: Total number of licenses issued during the study period

We can observe that the number of licenses varied in between the years and show a slight overall decrease.



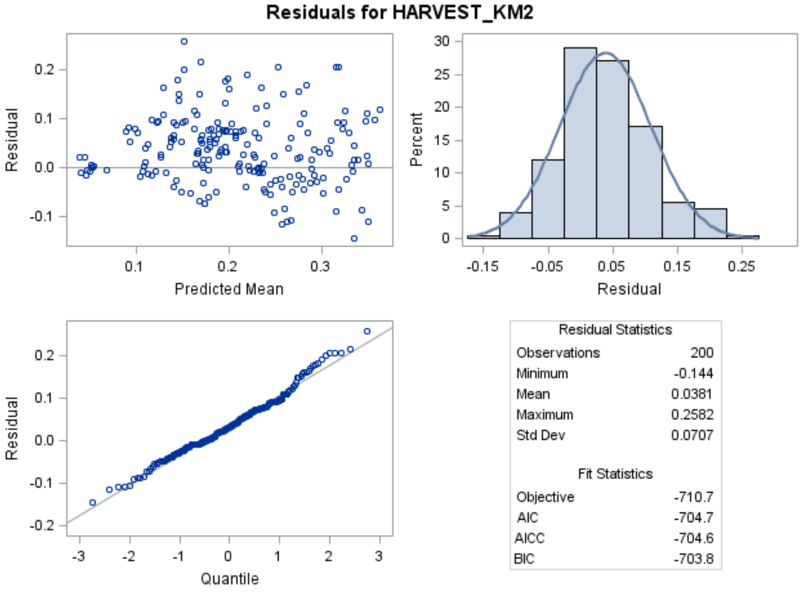
Source: author's creation with Excel

Mixed effects model for the regression of the normal harvest function

We include the residuals for the national analysis and the remaining county groupings to be able to show whether or not the groupings are comprised of appropriate data.

Figure A.5: Residuals for harvest per km2 for the original regression of the harvest function

The residuals are normally distributed and show no signs of heteroscedasticity.



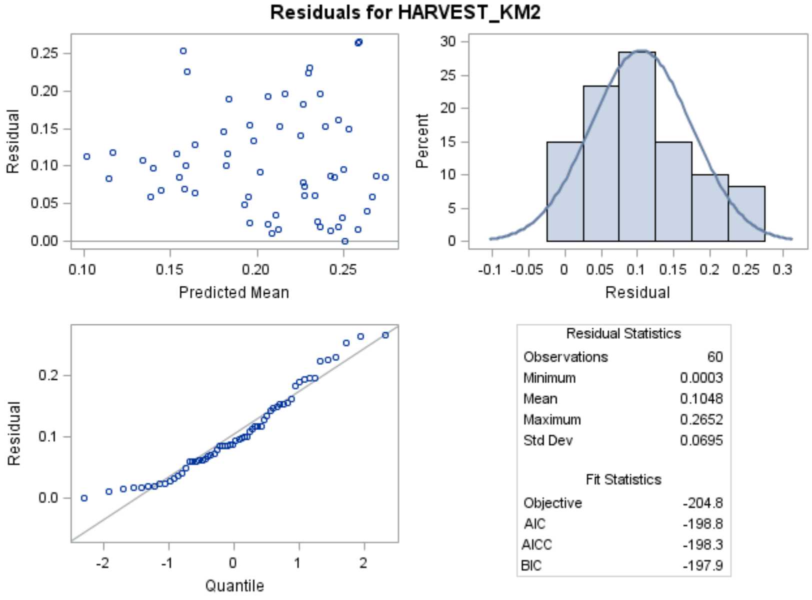
Residual Statistics	
Observations	200
Minimum	-0.144
Mean	0.0381
Maximum	0.2582
Std Dev	0.0707

Fit Statistics	
Objective	-710.7
AIC	-704.7
AICC	-704.6
BIC	-703.8

Source: author's creation with SAS

Figure A.6: Residuals for the harvest per km^2 for the high density wolf counties

The residuals are also normally distributed and heteroscedasticity does not appear to be a problem.



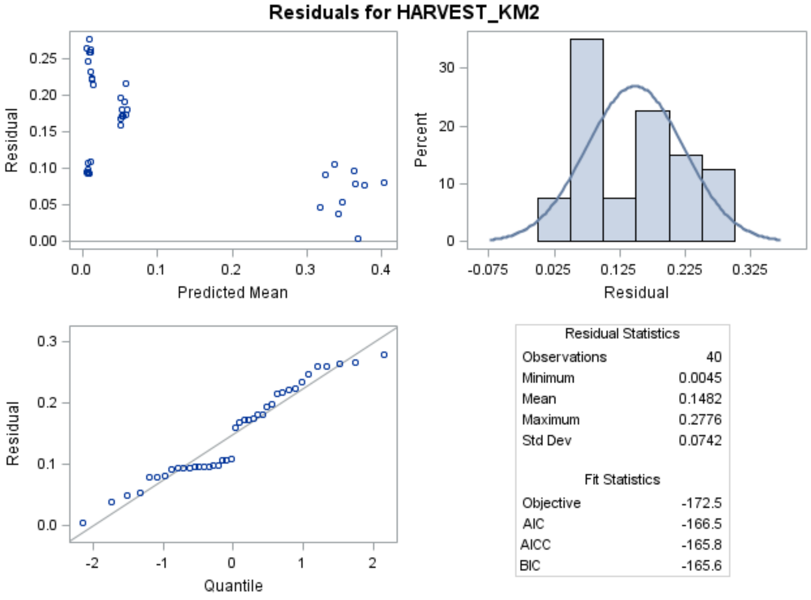
Residual Statistics	
Observations	60
Minimum	0.0003
Mean	0.1048
Maximum	0.2652
Std Dev	0.0695

Fit Statistics	
Objective	-204.8
AIC	-198.8
AICC	-198.3
BIC	-197.9

Source: author’s creation with SAS

Figure A.7: Residuals for the harvest of the northern counties

The residuals do not show a normal distribution.



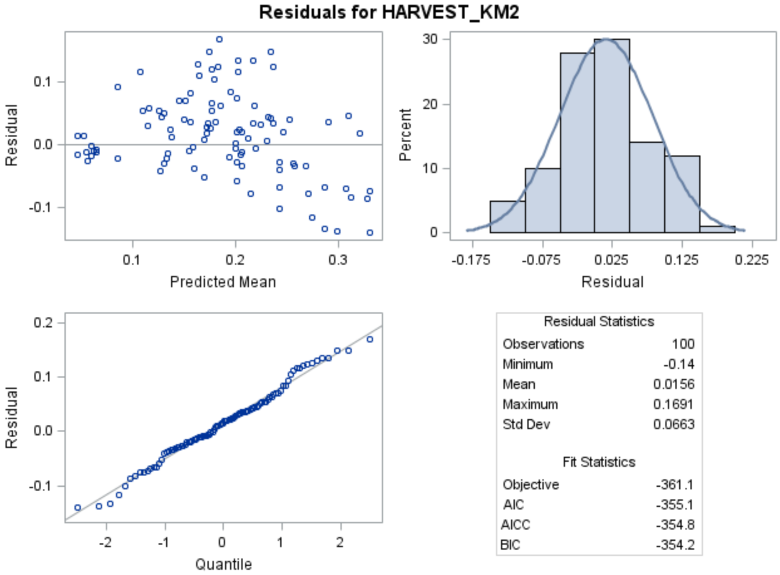
Residual Statistics	
Observations	40
Minimum	0.0045
Mean	0.1482
Maximum	0.2776
Std Dev	0.0742

Fit Statistics	
Objective	-172.5
AIC	-166.5
AICC	-165.8
BIC	-165.6

Source: author’s creation with SAS

Figure A.8: Residuals for the harvest of the southern counties

The residuals are normally distributed and show no problem of heteroscedasticity.



Residual Statistics	
Observations	100
Minimum	-0.14
Mean	0.0156
Maximum	0.1691
Std Dev	0.0663

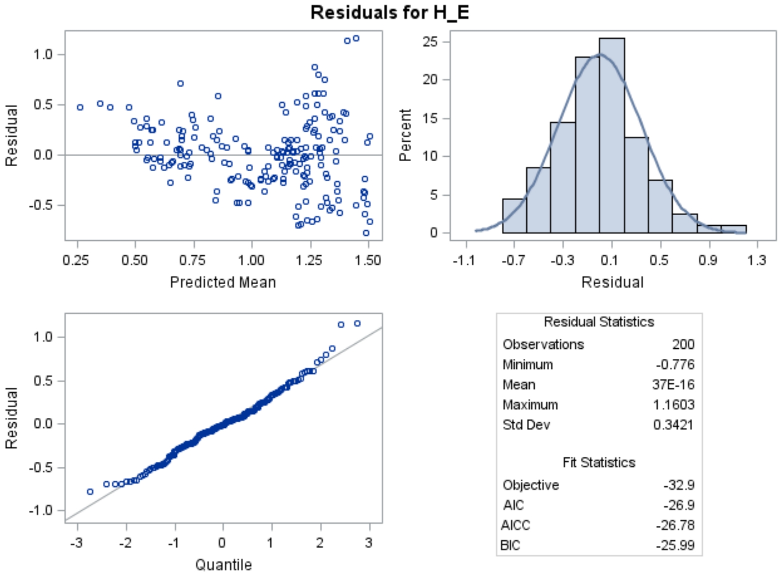
Fit Statistics	
Objective	-361.1
AIC	-355.1
AICC	-354.8
BIC	-354.2

Source: author's creation with SAS

Mixed effects model for the functional form of H/E

We include the residuals for the functional form of $\frac{H}{E}$ to be able to show whether or not it is comprised of appropriate data. The data shows a problem with heteroscedasticity.

Figure A.9: Results for the harvest function divided by the effort



Residual Statistics	
Observations	200
Minimum	-0.776
Mean	37E-16
Maximum	1.1603
Std Dev	0.3421

Fit Statistics	
Objective	-32.9
AIC	-26.9
AICC	-26.78
BIC	-25.99

Source: author's creation with SAS