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Consequential costs of sheep depredation by large carnivores in Sweden

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Abstract

The aim of this paper is to investigate consequential costs of livestock depredation by large carnivores. We estimate costs for productivity losses and additional labor using Swedish survey data on sheep farmers. Impacts on productivity and labor are identified through a comparison of sheep farmers in areas with low and high carnivore densities, farmers that have suffered attacks, and summer pasture farmers that have and have not suffered attacks, respectively. Results indicate that sheep herds in areas with high densities of carnivores and in herds that have experienced carnivore attacks have lower reproductive rates than do herds in areas with low densities of carnivores. Farmers who have experienced a carnivore attack on their livestock spend extra labor on fence maintenance, searching for lost animals, and bringing the animals in for the night. The use of enforced so-called carnivore fences has a significant impact on time spent on fence maintenance and on searching for lost animals. Finally, results show that costs for farmers that have experienced an attack differ between farms that keep the sheep within fences, and summer pasture farms that apply free-range grazing. Results from the study can motivate the use of a flat rate compensation per ewe in the herd, which is differentiated between farms in areas with high carnivore densities and conventional and summer pasture farms that have suffered an attack.

Keywords: Brown bear; Lynx; Sheep; Wildlife compensation; Wolf; Indirect costs.

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Introduction

Economic losses due to carnivores' predation on livestock are a worldwide concern for livestock holders (Bulte and Rondeau, 2007; Kaczensky, 1999; Naughton-Treves et al., 2003; Treves and Karanth, 2003). Direct costs occur due to killed and injured animals, but there can also be consequential costs in terms of decreased productivity and additional labor required to prevent attacks and manage the consequences of attacks. In many countries, compensation is paid for costs associated with killed and injured animals, while compensation for consequential costs is more rarely granted (Nyhus et al., 2003; Sommers et al., 2010).

Carnivore presence and attacks can reduce productivity, due to the secondary stress imposed on livestock. Stress has a negative effect on animals' health and reproduction, leading to reduced fertility, less offspring, lower birth weights (Dobson and Smith, 2000; Doney et al., 1976), and making the animal more susceptible to virus and bacterial infections (Faries and Adams, 1997). Carnivore presence and attacks can affect the grazing behavior of livestock negatively, with consequential effects on animal conditions and reproduction (Howery and Liberto, 2004; Kluever et al., 2008). Several studies have attempted to estimate the magnitude and value of predators' impact on productivity. Using panel data for 18 farms, Ramler et al. (2014) find that the slaughter weight of calves' from farms that experienced gray wolf (*Canis lupus*) attacks was 3.5% lower compared to other farms, implying a revenue loss of about 6000 EUR per year for an average cattle ranch. In contrast, they find that wolf packs having a home range that overlaps the ranch has no significant effect on calf weight. The monetary value of the impact on slaughter weight is 7.5 times greater than the compensation paid. Sommers et al. (2010) show that, when calves are killed by grizzly bears (*Urcus arctos*) and gray wolves, the mortality of other calves in the herd also rises considerably, implying that compensation ratios should be 3.8:1 for grizzly bear depredation and 6.3:1 for gray wolf depredation, if the additional calf losses are to be accounted for. Using available data on different impacts of wolves on cattle production, Steele et al. (2013) simulate the aggregate economic effects of predation, including costs of dead and injured animals, reduced growth and reproduction, and reduced animal health. They conclude that the total costs to farmers are 2–3 times larger than is the compensation paid, despite the compensation ratio already being set to 7:1 in the study area.

Farmers in areas with large numbers of predators and farmers who have experienced attacks incur costs for additional labor for prevention of carnivore attacks, for example, for bringing the animals in for the night, enforcing fences, early weaning, delayed lambing or calving, and limited grazing, followed by increased costs for fodder (Shelton, 2004). We have not found studies that systematically try to estimate the increase in labor costs based on farm-level data. However, Steele et al. (2013) account for increased labor time for managing the consequences of an attack. In addition, Asheim and Mysterud (2004) include increased labor as one of the factors that add to sheep farmers' carnivore-related costs. Using a simulation approach comparable to that in Steele et al. (2013), they estimate that carnivores cause a 2.3 % net loss in sheep farmer income, and that one-tenth of this is due to additional work with fence maintenance and reparation.

The purpose of this paper is to estimate the consequential costs of carnivore predation and presence for sheep farmers in Sweden. There are around 600,000 sheep in Sweden, and 500–600 are killed by carnivores each year. Gray wolves have attacked approximately 400 sheep per year over the last years, while brown bears and lynxes (*Lynx lynx*) have attacked around 100 and 40–100 sheep, respectively, per year since 2001 (Elofsson et al., 2015). There have only been a few instances of wolverines (*Gulo gulo*) attacking sheep. The annual compensation for livestock killed or injured by these species is approximately 150,000 EUR in total. The compensation is mainly paid for income losses due to verified killings and injuries. In principle, consequential costs can be compensated, but the extent to which this is done varies between different county administrations and farmers. One reason for the variation is the requirement that costs are verified, which is difficult to do for productivity decreases and own labor time. This practice has been questioned by farmers exposed to carnivores, who argue that the negative impacts on productivity and the increased labor are very costly (Hedén, 2014; Wolf Committee, 2013).

To estimate productivity- and labor-related farm costs of carnivores, we make use of data from a survey of Swedish sheep farmers. We identify the consequential costs of carnivores through a comparison of farm production activities across groups of farmers, which differ with regard to the level of exposure to carnivores. The results indicate that sheep herds that have experienced attacks and sheep herds that are located in areas with high densities of carnivores both have a lower reproductive rate than do herds in areas with low densities of predators. Farmers having experienced an attack spend more time on fence maintenance, searching for lost animals, and bringing the animals in for the night. We add to the literature through a systematic identification of labor-related costs associated with carnivore attacks, based on farm-level data, and by a comparison of the consequences of carnivore attacks for two different sheep production systems: conventional, fenced-sheep farms and free-range grazing ("summer pasture") farms.

The paper is organized as follows: the Methods section describes the methods used for the survey, the econometric analysis and the cost calculations. This is followed by a Results section, a Discussion section, and an Implications section.

Methods

Survey

A survey was conducted with livestock holders in Sweden as a part of a governmental commissioned investigation of the costs of large carnivores to rural enterprises (Elofsson et al., 2015). The purpose of the survey was to identify quantifiable consequential costs for farmers from carnivore attacks and interference. From this survey, we have obtained a cross-sectional data set that describes sheep farms and their activities in 2013.

The sampling of farmers for the survey took into account the fact that sheep farms differ with respect to the abundance of large carnivores in the surroundings, in terms of whether the sheep have been subject to interference of attacks by carnivores, and with regard to their production practices. Four different groups of farmers were identified *ex ante*: First, farmers in areas with high densities of large carnivores, defined as municipalities with a documented presence of family groups of wolf and lynx, and of individuals of brown bear. Second, farmers in areas with low densities of carnivores, defined as municipalities with no stable presence of wolf or brown bear for at least the past five years, but with a possible occasional presence of lynx.[1] All municipalities with high densities of carnivores are located within the core area for wolf in Sweden and, hence, located inland, and can be characterized as mainly rural. Municipalities located inland with similar economic structure were selected for the control group in areas with low carnivore densities. The third category of interest is farmers who have experienced carnivore attacks. Finally, the fourth category of interest is farmers with summer pastures (“fäbod” in Swedish). Unlike other sheep farms, where sheep are kept within fences, the summer pasture farms apply free range grazing in the forest, implying that the risk of carnivore attacks is larger. The purpose of the stratification is to allow for comparisons of productivity and labor time across farm types that differ with regard to the risk for, and actual attacks from, predators.

For the survey, 200 sheep farmers in municipalities with low carnivore densities were randomly selected from the Swedish Farm Register. In municipalities with high densities of carnivores, there were only 140 sheep farmers in total, all of which were included in the survey. Only farms with more than 21 animals were included to avoid the inclusion of hobby farms, where production practices can differ from those at commercial farms. For the group that has

[1] There are no areas in Sweden, except the island of Gotland, which do not host any wolves, brown bears, and lynx.

experienced an attack, all sheep farmers who received wildlife damage compensation in 2013 were included, a total of 113 farmers across Sweden. All 201 farmers receiving summer pasture support through the Rural Development Program were included. At least 95% of those are located in areas with high densities of carnivores (Hedén, 2014). It is, therefore, not possible to compare summer pasture farmers in areas with low and high densities of carnivores, respectively. The analysis of summer pasture farmers is, therefore, restricted to those that have experienced a carnivore attack and those that have not reported any attack.

The survey included questions in five different areas: (1) General information about the production, (2) health and reproductive status of the animal stock, (3) grazing areas and agri-environmental support for natural grazing land, (4) labor time for different tasks and future prospects of the business, and (5) attacks and interference of large carnivores. Questions were developed, based on the literature, complemented by a postal enquiry to farmers' organizations on their members' experiences of the consequences of carnivore attacks that aimed to identify possible effects not described in the literature. From the different types of effects on animal health and productivity so obtained, the questions in the survey were restricted to effects that could be identified by the farmer and valued in monetary terms. The questions on labor time spent on different tasks were expressed as the number of man-days, defined as 8-hour days. The tasks included in the survey are typically performed by all livestock producers, but depredation or interference by large carnivores can imply additional time spent on them. Questions were asked about tasks in which additional labor could be the consequence of an attack, including time spent on searching for and retrieving lost animals, repairing fences damaged either by predators or by fleeing livestock, care of injured and sick animals, and time spent on contacts with public authorities. Questions were also asked about activities to prevent carnivore attacks, such as the time spent bringing the animals in for the night[2] and for monitoring. In addition, several farmers have set up so-called "carnivore fences," which are a reinforced type of electric fence requiring

[2] Bringing the animals in for the night is a common practice to avoid repeated attacks.

additional labor for installation and for cutting grass underneath the fence on a regular basis. Therefore, the survey therefore asked about the presence of such fences on the farm.

Questions on production, animal health, and labor time were demanded for the year 2013.[3] The survey also asked about carnivore attacks and interference of large carnivores in both the years 2012 and 2013 to account for possible delays in the effect of an attack, for instance, on reproduction, for delays in compensation payments, and for the possibility that not all farmers apply for compensation.

The survey was designed in a web-based survey instrument. Letters with login information were sent to the farmers, with two follow-up reminders, and farmers were supplied with a paper version upon request. In terms of validity, there was a potential risk that farmers may overstate consequences of carnivore attacks to signal the importance of the problem to policy makers (Pearson et al., 1992). To identify such a possible bias in the responses two different letters were sent out, so that two thirds of the respondents received an accompanying information letter saying that the purpose was to investigate the costs of carnivore attacks, and one-third received a similar letter saying that the purpose was to analyze productivity in farming. Survey questions were identical for all respondents.

A total of 214 sheep farmers replied to the survey, implying a response rate of 38%. For those farmers the number of livestock, the age of the farmer, and the distribution over different types of farms are very close to the national averages. Five farmers from municipalities with low densities of carnivores reported to have experienced carnivore attacks, and were categorized as such, while none of the farmers in areas with low densities reported interference by large carnivores. It was judged that the few farmers in areas with low carnivore densities who had

[3] Although time series data would have been useful, there is a risk of reporting errors when asking for retrospective data (Pearson et al., 1992).

experienced attacks were exceptions, in which the attack is made by wandering individuals of either wolf or brown bear. Descriptive statistics can be found in the Appendix, Table A.1.

In Table 1 the variables that reflect the possible consequences of carnivore attacks and presence are presented for the different farmer categories. A simple t-test indicated a statistically significant difference in reproduction and labor time between the groups for three of the tasks: fence maintenance, bringing the animals in for the night, and searching for and fetching lost animals. The t-test did not indicate any significant differences in the prevalence of mastitis,[4] time spent on care of damaged and sick animals, or time spent on contacts with public agencies.

[4] Several livestock holders have argued that there is a risk of deteriorating udder health due to stress induced by predators. Treated mastitis was included as a proxy for udder health.

Table 1

Animal health and labor time for different categories of farmers

Farmer category	Low carnivore densities	High carnivore densities	Herd attacked	Summer pasture, no attack	Summer pasture, attack
Fence maintenance (days)	6.8	7.6	8.4	8.6	11.1
Cutting grass under fences (days)	6.3	8.9	4.0	3.6	10.1
Bringing animals in for the night (% of farmers) [a]	14.6	10.0	44.0	66.7	71.4
Searching for and fetching lost animals (days)	1.6	0.4	4.7	3.3	10.7
Care of damaged and sick animals (days)	2.2	1.2	2.2	1.1	1.9
Contacts with public authorities (days)	2.6	1.7	1.8	1.6	6
Number of live born lambs per ewe	1.7	1.3	1.4		
Stillborn lambs (% of total)	7.3	9.2	7.4		
Aborted lambs (% of total)	0.5	0.7	1.5		
Mastitis (share of ewes in %)	2.1	1.6	4.3		
Slaughter weight (kg)	19.1	17.8	18.6		
Age at slaughter (months)	7.1	7.8	7.6		
Number of obs.	73	58	54	15	14

[a] The time spent on bringing the animals in for the night varies considerably, and can depend on other factors than carnivore presence. Also, the question has been interpreted by some of the respondents as the number of days that the animals have been brought in, instead of the number of 8-hour days. The variable is therefore transformed into a binary variable, where 1 indicates that the task has been carried out at least once during the last year, and 0 indicates that it has not been carried out.

Econometric approach

In this section, we present the econometric approach to estimation of the impact of carnivore abundance and attacks on reproduction and on farmers' work time. We thus chose to further analyze the variables in Table 1, for which a t-test indicated significant differences across farmer categories.[5] We regressed reproduction and labor time variables against farmer category and other relevant explanatory variables with an aim to determine whether farmer category has a statistically significant impact. To calculate the effect of farmer category, we compared sheep farmers who either have experienced carnivore attacks or are active in areas with high densities of carnivores with farmers in areas with low densities of carnivores.

The number of live born lambs per ewe is a measure that captures the overall reproductive health of the animals and is potentially sensitive to carnivore density because stress can result in impaired fertility, abortions, stillborn lambs, or complications at birth, with the consequential death of the lamb. As the number of live born lambs per ewe can depend on the breed (Löfquist, 2006), we controlled for sheep race categories, according to standards of the Swedish Association for Sheep Breeding (Elitlamm): meat breed, native breed, Gotland sheep (fur breed), and cross breed. Further, the number of lambs per ewe is lower in organic production than in conventional; this is because lambs in organic production are brought up solely on the ewe's milk (Johnson et al., 1998). We also controlled for whether the herd has been infected by the Schmallenberg virus (Afonsoa et al., 2014), which implies an increased risk of stillbirths and aborted fetuses.[6] In addition, the total number of sheep in the herd was included as a control to capture potential scale effects. Due to data limitations, summer pasture farms were not included in the analysis of reproduction.. The statistical model used is a generalized linear model that was estimated in the statistical software Stata.

[5] Multivariate regressions for other effects do not indicate any significant effects of farm category.
[6] In 2012, the virus spread to European countries, including Sweden.

To investigate whether farmers' labor time was affected by carnivore presence and attacks, we compared measures on reported workload for different labor time-consuming tasks across all five different categories of livestock producers. The aim was to identify whether there were statistically significant differences in labor time across categories when control variables were included.

We used separate models for all different work tasks in Table 1. For measures where we found a significant impact of farmer category (fence maintenance, searching for and retrieving lost animals, and bringing the animals in for the night), a more detailed analysis was carried out. Data on time for fence maintenance include routine maintenance, in addition to reparations. The distribution of the data for time spent on fence maintenance has an exponential shape (see Fig. A.1 in the Appendix). We therefore took the logarithmic value of the number of days reported for this task as the dependent variable, hence using a log-linear regression. This model performed better than did alternative specifications, such as Poisson regression and negative binomial regression, which are applicable with over-dispersed data. Outlier values above 50 days (five observations) were not included in the analysis, due to possible errors in reporting. Robust standard errors are used, as recommended by Cameron and Trivedi (2009), to control for mild violations of underlying assumptions.

In the second model, the dependent variable is the time spent searching for and retrieving lost animals. Here, 59% of the respondents reported this time to be zero. There is a large difference between the mean value of the variable (2.7 days) and the standard deviation (6.8). With this type of distribution, and when the dependent variable is count data (here: number of days), either a Poisson, a zero-inflated Poisson, or a negative binomial regression model is suitable. We ran the countfit test in Stata to compare these models and concluded that the preferred model is the negative binomial regression, although the results were similar for the different estimations. The model was estimated using a maximum likelihood model, with a log-likelihood function, and robust standard errors.

In the third model the dependent variable, bringing the sheep in for the night, was defined as a dummy variable, taking the value 1, if the farmer has performed the task at least once during the year, and 0, if the task has not been not carried out. Given the binary dependent variable, a probit model was used for the analysis.

In all three labor time models, we controlled for the total number of animals, including a cattle dummy for the farmers who have both cattle and sheep, since it was not possible to infer labor input for each type of livestock from the data. Further, we controlled for the percentage of carnivore fences. Such fences can require additional labor time, and may reduce the risk of livestock escaping, as well as the incentive for taking the sheep in at night. Finally, we controlled for whether the sheep are organically produced, as organically produced sheep have a higher value and the economic incentive for their protection could, therefore, be higher.

For each model, we estimated an alternative formulation, where we added a dummy variable indicating whether the respondent received a letter with information that the survey will be used to explore carnivore costs.

Cost calculations

Results from the econometric analysis were used to calculate the average effect of farm category on the dependent variables. The cost of reduced fertility was calculated by multiplying the value of one lamb with the estimated decrease in fertility rate in herds in areas with high carnivore densities, compared to herds in areas with low densities of carnivores. Costs were calculated for an average sheep herd of 31 ewes.[7] It was assumed that the value of an unborn lamb is 43 EUR,[8] which equals the wildlife compensation recommended by the Wildlife Damage Center, Swedish University of Agricultural Sciences (SLU), for an unborn lamb killed by a predator.

In order to calculate the expected prevalence of bringing the animals in for the night we calculated the marginal effects for each farm category. The difference between categories was calculated as the expected prevalence in a category minus the expected prevalence in areas with low carnivore densities. Time use for each category was calculated by multiplying the expected additional prevalence of the task by the yearly median number of days used for the task by all farmers that reported that they perform the task. So calculated, the median number of days was 10, corresponding to 80 hours per year in total. This can be related to the length of the grazing season, which is 60–150 days in our dataset, and where summer pasture farms have longer grazing seasons. During an average grazing season of 90 days, the labor spent on bringing the animals in for the night then corresponds to less than an hour a day, which seems reasonable. Based on the median in our dataset, we assumed that an average farmer used 10 days per year for bringing in the animals for the night, and, by comparing the difference between categories of farmers, we obtained a figure for the additional labor spent on the task. The labor cost was assumed to be 27 EUR per hour, which equals the compensation for labor recommended in 2015 by the Wildlife Damage Center. An 8-hour day of additional labor was then associated with a cost of 216 EUR.

[7] Average for sample as well as for national statistical data.
[8] Corresponding to 400 SEK, using the average exchange for 2015 from the Riksbank.

Results

Impact of farmer category on sheep reproduction

The statistical analysis revealed significant differences in the number of live born lambs per ewe between herds in areas with high and low densities of carnivores, as well as between herds that have been attacked and between herds in areas with low densities of carnivores (see Table 2). However, there was no significant difference between herds that have suffered an attack and herds in areas with high densities of carnivores. Sheep of meat breed had on average fewer lambs per ewe than did the native breed (reference category in our estimations), which was an expected result (see Löfquist (2006)).

Table 2

Regression results with the number of live born lambs per ewe as dependent variable

	Coefficient (standard error)	**Estimated value at means**	**Difference compared to areas with low carnivore densities**
Low carnivore densities	.	2.149	.
High carnivore densities	–0.529** (0.173)	1.620	–0.53
Experienced carnivore attack	–0.401** (0.164)	1.748	–0.40
Intercept	2.856*** (0.525)		
Schmallenberg virus	–0.0021 (0.271)		
Sheep of meat breed	–0.420** (0.160)		
Gotland/fur breed	–0.0936 (0.180)		
Cross breed	–0.252 (0.152)		
Other sheep breed	–0.585 (0.270)		
Organic production	0.209 (0.144)		
Total number of sheep in herd	–0.001 (0.001)		
Ram in herd	–0.166 (0.167)		
N obs	139		
F-test	5.59	Pr>|t|0.0047	
R2 (pseudo)	0.175		

*** indicates significance at the 1 % level, ** indicates significance at the 5 % level, * indicates significance at the 10 % level

The estimated number of lambs for each farm category was evaluated at the means of the other variables. Results then showed that the number of live born lambs per ewe was 0.53 units lower in herds in areas with high carnivore densities, and 0.40 units lower in herds that have experienced an attack, compared to herds in areas with low carnivore densities. Due to data limitations, it was not possible to analyze sheep fertility rates for summer pasture farms. Notably, we have not found any significant impact of carnivores on slaughter weight. Predator presence and attacks could potentially lead to a reduced weight gain in slaughter lambs. This is similar to the observation of Ramler et al. (2014) for calves. However, sheep producers typically compensate for this by delaying the slaughter, implying that the slaughter weight could be unaffected. We found no statistically significant effects of carnivores on either slaughter weight or slaughter age.

Impact of farmer category on labor time

The regression result on labor tasks indicated that the time spent on the three analyzed tasks was significantly higher in herds that have experienced a predator attack, compared to the control category (see Table 3). When control variables were included, there was no significant difference in labor time for fence management between areas with low and high carnivore densities. The share of carnivore fences was statistically significant in the fence management model, but all other control variables were insignificant. Fig. A.2 in the Appendix shows that the error terms are approximately normally distributed, which indicates that the model is correctly specified.

The results in Table 3 further show a significant positive effect of herd size, and a significant negative effect of carnivore fences, on the time spent on searching for and retrieving lost animals. Further, results revealed a significant effect of predator attack category and summer pasture farming on the propensity to bring the animals in for the night. The total number of animals had a significant negative effect on the probability of the task being performed, which can be explained both by less work being necessary to bring in a small herd and by a bigger herd discouraging carnivore attacks. Although the presence of cattle could also discourage attacks, the associated coefficient is not significant when included. Based on the levels of the Akaike

Information Criterion (AIC), the variable is dropped from the estimation of the third model. Our data do not reveal whether sheep and cattle graze together, which may explain the lack of significance of the variable in this model. Also, carnivore fence share has no significant effect on the probability of bringing the animals in for the night. The additional time spent on taking the animals in for the night was calculated as the marginal effect for each farm category, expressed in percentage terms, multiplied by the median number of days spent on this task for all farmers in the sample that performed the task. Marginal effects and the consequential number of eight-hour days for all labor tasks are shown in Table A.2 in the Appendix.

Although we find no effect of farmer category on the time spent on cutting and clearing under fences, it can be noted that respondents that have carnivore fences spend on average 5 more days per year on this task.[9]

[9] There are subsidies for putting up carnivore fences, but no subsidies for their maintenance, implying that maintenance can be considered as an uncompensated consequential cost of carnivore presence and attacks.

Table 3

Regression results, labor time on different tasks as a dependent variable. Farms in areas with low carnivore densities is used as a reference category. The table shows coefficients with robust standard error in parentheses.

Variable	**Fence maintenance (log of number of days)**	**Searching for and retrieving lost animals (number of days)**	**Bringing animals in for the night (dummy)**
High dens. of carnivores	-0.093	-0.842	-0.454
	(0.181)	(-0.548)	(0.413)
Attacked herd	0.311*	1.478***	0.750**
	(0.177)	(-0.459)	(0.357)
Summer pasture no attack	0.630*	1.101*	1.154**
	(0.353)	(0.653)	(0.618)
Summer pasture attack	1.020***	2.518***	1.624**
	(0.258)	(0.593)	(0.662)
Total number of animals	0.001	0.0066*	-0.007*
	(0.001)	(0.004)	0.004
Cattle	0.119	-0.214	
	(0.149)	(0.501)	
Organic prod.	-0.150	-0.620	-0.258
	(0.147)	(0.421)	0.328
Carnivore fence share	0.004**	-0.011**	0.004
	(0.002)	(0.005)	0.005
Constant	1.358***	0.166	-0.550*
	0.157	0.145	0.332
N obs	151	117	106
Test categories	F=5.45	Chi2=28.9	Chi2 = 16.70
Prob.	0.0004	0.0001	0.0022
F/Wald chi2	4.05	33.69	21.11
p-value	0.0002	0.000	0.0036
R-squared	0.133	0.062 (McFadden R2)	0.221 (Pseudo R2)

*** indicates significance at the 1 % level, ** indicates significance at the 5 % level, * indicates significance at the 10 % level

Impact of information on responses

The models in which we include a dummy for whether the respondent received a letter saying that the survey will be used to explore carnivore costs do not reveal any significant effect of the type of information provided. However, the response rate was higher among farmers who were informed about the true purpose of the survey.

Cost differences across farmer categories

The reduced reproduction and additional labor for different farm categories (compared to farms in areas with low carnivore densities) and the associated costs are found in Table 4. All results are calculated for an average sheep herd with 31 ewes. The estimated average additional cost for a farmer in a municipality with high densities of carnivores is over 700 EUR per year, while the additional cost for a farmer whose herd has been attacked by predators is about three times higher. The additional cost for summer farms that have not experienced an attack, compared to farms in areas with low carnivore densities, can be due to both carnivore presence and different production methods. In contrast, the difference between the two groups of summer pasture farms can be attributed to carnivore attacks. Hence, summer pasture farms that have suffered an attack have an additional labor cost of more than 3000 EUR per year, compared to other summer pasture farms.

Table 4

Consequential effects on labor and costs for average sheep farm with 31 ewes

		High carnivore densities	**Herd attacked**	**Summer pasture, no attack**	**Summer pasture, attack**
Fence maintenance	Additional days	-	1.9	3	7.9
	EUR	-	406	644	1 706
Search for and retrieving lost animals	Additional days	-	3.2	1.9	10.8
	EUR	-	691	410	2 332
Bringing animals in for the night	Additional days	-	2.6	3.3	3.9
	EUR	-	562	713	842
Number of live born lambs	Reduction (number)	16.7	12.7	-	-
	EUR	722	549	-	-
Total average cost	*EUR*	*722*	*2 208*	*1 767*	*4 882*

Discussion

We estimate the impact of carnivore abundance and predator attacks on reproduction and three different labor tasks: fence maintenance, searching for and retrieving lost animals, and bringing the animals in for the night. The impact and the associated cost are calculated by comparing farmers with different exposure to carnivores. The methodological approach has similarities to Ramler et al. (2014), but differs through the use of cross-sectional data, rather than panel data. Whereas Ramler et al. (2014) establish a significant relationship between carnivore attacks and slaughter weight, we cannot establish such an effect on sheep slaughter weight. This can be due to sheep farmers compensating for lower growth by delaying slaughter. Thus, although the net effect of a predator attack could be both reduced weight and delayed slaughter, the effect on each of those might be too small to be statistically significant. This suggests that future studies on the topic should pay further attention to compensatory measures by farmers that could reduce the impact on productivity. In contrast to Ramler at al. (2014), we find a significant impact of carnivore abundance on productivity in the absence of attacks, suggesting that reproduction is reduced by approximately the same amount by the mere presence of carnivores as it is when sheep are attacked. However, this result should be interpreted with some care, given that we are not able to fully control for all differences between farms located in areas with high and low carnivore densities. Farms located in municipalities with high carnivore densities are concentrated inland in central Sweden. We have attempted to select municipalities with low predator densities that are similar, not only with respect to the inland location and the economies being mainly rural but also to the presence of sheep production. These municipalities are found further south in the country. This could, hypothetically, imply that production conditions are different. However, we have not found any evidence that the number of lambs per ewe differs across Sweden. Typically, the shorter grazing season further north is compensated for by additional purchased feeding; thus, the location should not matter significantly for reproduction (Thellenberg, 2009). In addition, farm business calculation programs, such as Agriwise (2015), presume the same reproduction across the country for given sheep races. Further, the total production of sheep is higher in the southern parts, and transportation distances are shorter, implying that costs of purchased feed may be lower. On the other hand, higher land values imply that the opportunity cost of own produced feed is higher.

Our results on the impact of carnivore attacks on labor costs can be compared to results in Asheim and Mysterud (2004), where it is concluded that additional labor accounts for about half of the consequential costs for Norwegian sheep farmers. Summing up the consequential costs identified here, we find that additional labor time accounts for about 75% of the consequential costs for farmers that have experienced a predator attack. Notably, conditions for Swedish and

Norwegian sheep farming differ considerably, implying that the effects of carnivores on production could differ. For example, the Norwegian sheep industry is larger, and bear attacks are common, while most attacks in Sweden are made by wolves (Wolf Committee, 2013). Further research on carnivore impacts on sheep farm productivity and labor will potentially verify additional cost components that could alter conclusions about the relative impacts on productivity and labor.

There can be other consequential costs of carnivore presence and attacks, which have not been addressed in our study. These include secondary effects on value-adding activities, such as the production of own brands of cheese or on-farm meat sales, and on the time for the farmer to plan and administer the business. Further, the risk of carnivore attacks can discourage farmers from letting sheep graze all the land, which can lead to lost agri-environmental subsidies for the farmer. In addition, the risk of carnivore attacks can be a source of concern to the farmer for reasons other than purely economic ones. Although the true risk might be low, humans tend to focus on the worst-case scenario, rather than the expected loss (Naughton-Treves, 2003), which can contribute to severe distress in farmers.

Implications

The results indicate that there are additional costs associated with farming in areas with high densities of carnivores and for farmers having experienced either carnivore predation of livestock or interference by large carnivores, as compared to farming in areas with low densities of carnivores. A flat rate compensation for consequential costs, in addition to the compensation for direct costs, could complement the current wildlife damage policy. If consequential costs occur, for both livestock holders that have experienced a predator attack and those that have not but whose farm is in a carnivore dense area, it is not sufficient to apply a compensation ratio larger than one (where payments for livestock killed and injured are inflated to account for the additional labor and reduced productivity). Instead, a flat rate compensation per ewe in the sheep herd could be more appropriate. The use of a flat rate compensation would reduce transaction costs, compared to the current Swedish practice, with individually determined compensation for consequential costs. Such a flat rate compensation could also compensate the sheep industry in a more appropriate manner, as consequential impacts on the individual farm are not easily verified and, therefore, are seldom compensated for under the current practice. This could avoid a reduction in the sheep industry in carnivore dense areas. This could be advantageous if sheep production is considered important for environmental reasons, for example, because sheep grazing benefits biodiversity, or for the local economy. Potential drawbacks are the increased costs for wildlife compensation to taxpayers and the reduced incentives for livestock holders to undertake preventive measures (Bulte and Rondeau, 2005; Rollins and Briggs, 1996). The latter problem can be partly counteracted if compensation is conditioned on the use of preventive measures.

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Appendix

Table A.1

Descriptive statistics for the whole sample

Variable	Mean	Std. dev.	Min	Max
Organic production (dummy)	0.34	0.5	0	1
Total number of livestock	70.0	76.8	2	438
Number of sheep	59.4	70.1	4	438
Percentage carnivore fence	16.9	32.7	0	100
Farm with cattle (dummy)	0.28	0.45	0	1
Schmallenberg virus (dummy)	0.05	0.22	0	1
Meat breed (dummy)	0.25	0.44	0	1
Gotland/fur breed (dummy)	0.17	0.38	0	1
Native breed (dummy)	0.16	0.37	0	1
Cross breed (dummy)	0.37	0.48	0	1
Other breed (dummy)	0.07	0.26	0	1
Ram in herd (dummy)	0.59	0.49	0	1
Fence maintenance (d)	9.7	16.2	0	120
Cutting grass under fence (d)	5.3	7.6	0	50
Bringing animals in at night (dummy)	0.24	0.43	0	1
Care of damaged and sick animals, (d)	1.7	3.0	0	20
Contacts with public authorities (d)	2.1	3.5	0	20
Number of live born lambs/ewe [a]	1.6	0.8	0	6.9
Stillborn lambs (% of total)	0.08	0.08	0	0.44
Aborted lambs (% of total)				
Mastitis (% of all ewes)	0.03	0.11	0	1
Slaughter weight (kg)	19.3	5.6	0	48
Age at slaughter (months)	7.4	2.2	3	12.5

[a] The number of live born lambs per ewe is calculated as average number of lambs born per ewe > 1 year. Sheep reach fertile age at around 4 months, so even though there is a possibility that the ewe has not yet lambed, one year old ewes are, typically, reproductive.

Table A.2

Regression results, marginal effects, and number of days

	Fence maintenance		**Searching and fetching animals**	**Bringing animals in for the night**	
	Marginal effects	**Number of days**	**Marginal effects (days)**	**Marginal effects (%)**	**Difference**
Low carnivore densities	1.449	4.26	0.94	15.8	-
High carnivore densities	1.636	5.13	0.40	7.4	-
Herd attacked	1.815	6.14	4.1	40.4	25.8
Summer pasture, no attack	1.980	7.24	2.8	47.3	32.6
Summer pasture, attack	2.500	12.18	11.7	53.4	38.7
Model	OLS with logged dep.var.		Negative binomial regression	Probit	

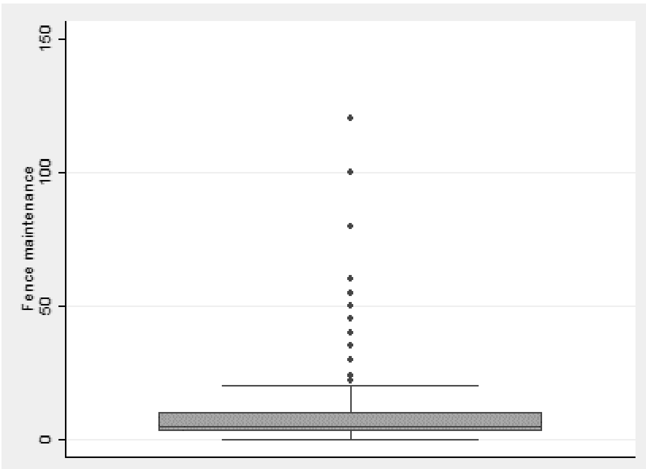

Fig. A.1 Distribution of the number of days spent on fence maintenance

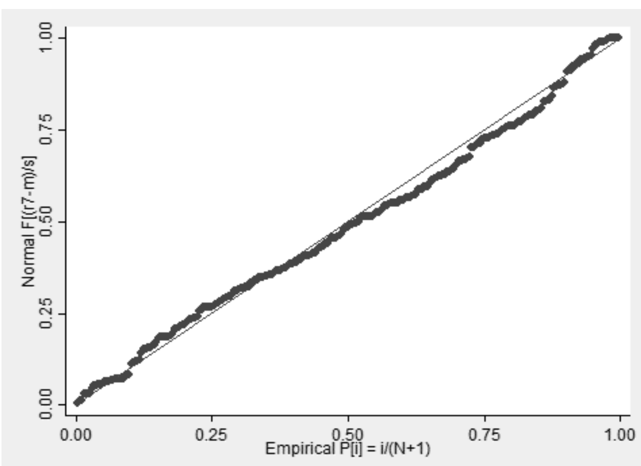

Fig. A.2 Distribution of residuals for fence maintenance

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