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Wild boars and farming in Sweden - an assessment of the costs

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Wild boars and farming in Sweden - an assessment of the costs

Abstract Wild boar is among the most wide spread mammal in the world and is known to cause serious damages for farmers in terms of crop losses and impacts on farm infrastructure. This study estimate farmers' cost of wild boar in Sweden, and how it is determined by land scape diversity, proxies for wild boar population, land ownership, feeding and protective measures by the farmer. Data are obtained from a survey of 3200 farmers, and the results indicate an average annual cost of SEK 28843/farm or SEK 305/ha, of which 62% arises from crop losses and 28% from adjustment and protection costs. However, 60% of the farmers reported no damage cost, and we therefore examined the determinants of the probability of damage cost and, when it occurs, the size. It was found that proxies of wild boar abundance and land scape diversity have significant and positive impact on the likelihood and magnitude of costs. Diversity in the landscape gives access to hiding opportunities for the pigs when searching for food in the agricultural fields. Share of area with forage, rented land, arable land, and protective measures all showed significant and positive effects on the size of the damage cost.

Key words: wild boar, farmers' costs, land scape characteristics, mitigation measures, Sweden

JEL codes: Q12, Q24, Q50

1. Introduction

Wild boar (*Sus scrofa*) is among the most widespread mammal in the world (Massei et al., 2015). Its natural range extends from Western Europe to East Russia, Japan and South-East Asia. They are difficult to control because they are difficult to trap, they are generalists and can adapt to most weather conditions, the females can produce 10-13 piglets per year, and they have few predators (Timmons et al., 2012). The wild boars have existed in Sweden over thousand years (Thamm 2004). They were eradicated in the end of the seventeenth century but reinstated in 1723 for hunting purposes on the island Öland. This caused protests among farmers and they were yet again eradicated in the end of 1770. Once again minor populations were kept within fenced areas but some individuals escaped in the 1970's. However, the wild boar population was accepted as part of the Swedish fauna by the parliament in 1988. In Sweden, the wild boar population has the capacity to grow rather rapidly, with a mean growth rate during 2000-2010 of 48% (Lemel and Truvé, 2008; Jansson and Månsson, 2011). The same growth rate of 48 % was also obtained using traffic data for estimating the growth rate of the wild boar population in Sweden (Gren et.al., 2016). The study also revealed that landscape characteristics have a substantial impact upon the traffic accidents that indirectly provide a measure of the population of wild boars in the vicinity. However, despite the dispersal of the animal and associated costs there is, to the best of our knowledge, no study estimating the costs to farmers and examining the impacts of different variables, such as landscape conditions. The purpose of this study is to carry out such assessments, which is made by a survey to farmers in Sweden.

The costs to farmers arise from natural habitat selection and rooting behaviour by wild boar in the field layer and soils during foraging (e.g. Frederick, 1998; Rao et al., 2002). Other costs to farmers are associated with mechanical damage to agricultural machinery due to wild boar bedding behaviour in fields and quality damage to silage due to admixture of soil. Crop damages on arable land constitute an evidence of the presence of the species, and a few studies have estimated associated costs. Pimentel et al. (2005) is a relatively early study which reported a cost of USD 800 million of wild boar in the US based on the assumption of a cost of USD 200/pig. Later studies of wild boar in the US report an annual costs of USD 15554/farm in Georgia (Mengak, 2012) and of USD 4333/farm in Louisiana (Tanger et al. 2015). The share of crop loss corresponds to 2/3 and

4/5 of total costs in the Georgia and Louisiana study, respectively. Laurent et al. (2007) examined damages caused by wild boars in Luxembourg over a 10 year period. Corn and forage were found to be the crops most susceptible to damage. According to the study 50.1 % of the forage area was damaged and 30.2 % of the acreage of corn. Wheat was also affected but, to a lesser extent with 11.7 % of the acreage damaged. In Sweden, a survey conducted in the area of Sörmland indicated mean crop losses amounting to 279 SEK/hectare (1 USD = 8.63 SEK July 20, 2016) for farms with wild boar damages (Swedish Board of Agriculture, 2010). For farms with dairy production the corresponding cost amounted to 467 SEK/hectare. According to Lemel (1999) field peas is the crop that is most vulnerable to damage. The explanation is that the crop is highly attractive for wild boars subsequent to drilling and the damages might be excessive.

The damages of wild boars may vary widely with the nature of the landscape (Schley et al.: Lindblom 2010; Persson 2010; Statistics Sweden 2016). Lindblom (2010) found that the probability of damage decreases with increasing distance to the forest and potential bait stations. Consequently, extensive damage is less likely in areas with open fields and few landscape elements. Lindblom (2010) examined economic losses in an area with a considerable population of wild boars. The loss per hectare varied from 66 SEK for barley to 253 SEK for wheat. Similar results were obtained by Statistics Sweden (2016) from a survey in 2014 to around 5000 farmers with different stratas depending upon type of crop (Statistics Sweden, 2016). The empirical results are consistent with findings by Schley et al. (2007) and Lindblom (2010) and the extent of losses vary considerably between regions in Sweden where the nature of the landscape appears to play a vital role. The study by Statistics Sweden (2016) is also consistent with the findings by Schley et al. (2007) where winter wheat reveals the highest percentage of damaged crops although substantially lower than 50 %.

The damages are also affected by farmers' protective actions such as construction of fences, of adjustment actions by altering the cropping system and by hunting practices. These factors are included in this study when estimating the likelihood and levels of costs of wild boars to farmers in Sweden. To the best of our knowledge, there is no study that simultaneously considers, crop losses, cropping system, rapier and mitigation costs, feeding, adjustment and protection strategies. The paper is organized as follows. First we present the simple theoretical model of farmer decision making which underlies the empirical analyses. Next, the data retrieval is presented, which is followed by the econometric analyses. The study ends with a brief summary and conclusions.

2. Modell

In order to design the econometric regression equations we construct a simple dynamic model of a representative farmer behavior in response to wild boars. We then assume cultivation of several crops, where π^i is unit profit of crop with *i=1,..,n* crops without any wild boar visits, which is assumed to be constant over time. The yield of each crop is assumed to depend on the area of land allocated to it, $Q^i(L_t^i)$ where L_t^i area of land allocated to crop *i* in time *t.* In case of wild boar visits, a share of the crop yield, $0 \le d_t^i \le 1$, is damaged.. Other costs than those from crop losses may arise due to damages of machinery and other infrastructure on the farm, c_t. The costs can be mitigated by adjustment and protection measures, A_t^r where *r=1,..m* practices such as reparation of fields destroyed by the pigs, creation of open areas, construction of fences, and fright by humans or dogs. The damage is also affected by given landscape characteristics, K, which we consider as a measurement of diversity of landscape elements at the arable land. As discussed in the introduction, more diversified landscape elements and fields attract wild boar because of hiding opportunities. We then have that the damage on crops and infrastructure depends on the wild boar population, W_t, protection measures, and landscape characteristics; $d_t^i = d^i(W_t, A_t^1,.., A_t^m; K)$ and $c_t = c(W_t, A_t^r; K)$ where $d_W^i \ge 0, d_A^i \le 0$ and $d_K^i \ge 0$ with similar marginal impacts on infrastructure costs.

Land owners who enjoy to hunt wild boar may undertake feeding in order to increase the number of animals available for hunting. It is therefore assumed that the development of wild boar population depends on the growth function $g(W_t)$, hunting, S_t, and feeding, F_t which is written as:

$$\frac{\partial W}{\partial t} = g(W_t) - S_t + f(F_t) \qquad (1)$$

The farmer obtains a unit profit of crops, π^i, unit value from hunting of wild boar, π^S, and faces a cost for protective measures, c^r per unit A_t^r. Hunting of wild boar could be considered as a protective measure although it is separated from the *r=1,..,m* measures in our model.

The total discounted profit to be maximized by the choice of crops, protective measures, and hunting is then written as:

$$\pi = \int_0^\infty \left(\sum_i \pi^i (1 - d^i (W_t, A_t^1,.., A_t^m; K_t) Q^i (L_t^i) + \pi^s S_t - c(W_t) - c^F F_t - \sum_r c^r A_t^r\right) e^{-\rho t} dt \qquad (2)$$

$$\text{s.t. eq (1) and } \sum_i L_t^i \le \bar{L},$$

where ρ is the discount rate and $\bar{L}$ is the total area of arable land.

The maximization problem is solved by constructing the current value Hamiltonian as:

$$H = \pi_t + \mu_t (g(W_t) - S_t - f(F_t)) + \lambda_t (\bar{L} - \sum_i L_t^i) \qquad (3)$$

where $\pi_t = \sum_i \pi^i (1 - d^i (W_t, A_t^1,.., A_t^m; K_t) Q^i (L_t^i) + \pi^s S_t - c^F F_t - \sum_r c^r A_t^r$. The first-order conditions are then given by:

$$\frac{\partial H}{\partial L_t^i} = \left(\pi^i (1 - d^i) + \lambda_t\right) \frac{\partial Q^i}{\partial L_t^i} = 0 \qquad (4)$$

$$\frac{\partial H}{\partial S_t} = \pi^s - \mu_t = 0 \qquad (5)$$

$$\frac{\partial H}{\partial A_t^r} = -\frac{\partial d^i}{\partial A_t^r} \pi^i Q^i - c^r = 0 \qquad (6)$$

$$\frac{\partial H}{\partial F_t} = -c^F + \mu_t \frac{\partial f}{\partial F_t} = 0 \qquad (7)$$

$$\frac{\partial \mu_t}{\partial t} = \rho \mu_t - \frac{\partial H}{\partial W_t} \Rightarrow \frac{\partial \mu_t}{\partial t} = \mu_t (\rho - \frac{\partial G}{\partial W_t}) + \sum_i \pi^i \frac{\partial d^i}{\partial W_t} Q^i (L_t^i) + \frac{\partial c}{\partial W_t} \qquad (8)$$

Condition (4) shows that total land area is allocated so that marginal value of product is equal for all crops and corresponds to λ_t. Optimal protective measures occur where marginal cost equals profits from increased crops due to the marginal decrease in wild boar damage. The conditions for S_t and F_t show that the unit of profit from hunting or cost of feeding, respectively, shall correspond to the user cost of the wild boar. The optimal development of the user cost, in turn, is revealed by eq. (8), and is determined by the discount rate, marginal population growth, and wild boar damage on crops. In steady state, $\frac{\partial \mu_t}{\partial t} = 0$ which implies that

$$\mu_t \rho = \mu_t \frac{\partial G}{\partial W_t} - \pi_t \frac{\partial d^i}{\partial W_t} - \frac{\partial c}{\partial W_t} \qquad (9)$$

Equation (9) shows the familiar condition that the marginal cost of increasing the population at the right hand side of (9) equals the marginal benefit as shown by the left hand side. When $\frac{\partial d^i}{\partial W_t} = \frac{\partial c}{\partial W_t} = 0$, which would occur for a farmer with no damages from changes in the wild boar, the population level is determined only by the discount rate and the growth rate. The farmer is then indifferent between eliminating another wild boar and investing the income to obtain the return ρ and not reducing the population which yields an increase in the population corresponding to $\frac{\partial G}{\partial W_t}$. When $\frac{\partial d^i}{\partial W_t} > 0$ and/or $\frac{\partial c}{\partial W_t} > 0$ additional benefits from reducing the population arise from reductions in damages on future crop and infrastructure.

However, the choice of crop allocation and the possibilities of implementing protective measures can be affected by the property rights to land which can be owned or rented. When land is rented, the tenant farmer seldom has the right to hunt on the land, but has the option to feed for protecting the agricultural land. The benefits from reducing the wild boar population are then reduced by the associated value of hunting, and the cost of protection measures can be increased from the deletion of hunting option (if this option is included in the optimal solution). This results in a higher population level and damage costs.

3. Description of data

Section 2 shows that data are needed on crop damage, crop unit profits, impacts and costs of protective and feeding measures, landscape characteristics, and wild boar population dynamics. Except for landscape diversity and wild boar population, all data are obtained from a survey to landowners/tenant farmers that farm tillable and pasture land. In total, there are approximately 67 000 operating farms in Sweden (Swedish Board of Agriculture, 2016). In order to obtain observations from regions where wild boar exist, and on different farm categories a stratified sampling technique is applied (Scott et al., 1975; Krosnick, 1990). The dispersion of wild boar is mitigated by cold climate since the piglet face difficulties surviving cold winters. Wild boars therefore are rare in the five most northern counties of Sweden. They are not prevalent in Gotland because it is an island located some distance from the main land in south Sweden. The pigs are populated in all other 15 counties, see map in Figure B1.

The survey was developed and tested on approximately 13 farmers in February-May 2014 that were selected on the basis that they should be well aware of the problems associated with the wild boar population as well as having substantial knowledge concerning various forms of mitigation strategies apart from hunting. The responses were in general favorable to the proposed survey but had opinions on the question related to feeding. In general, feeding of wild boar is regarded as a problem by neighboring farmers, and a question on feeding by the respondent might result in a less truthful answer despite the anonymity of the survey. Therefore, questions on feeding were formulated in terms of existence of feeding in the neighborhood irrespective of who is responsible.

Swedish Board of Agriculture (SBA) administered the survey and the questionnaire was sent to a sample of 3200 farmers that were stratified by county. The survey was distributed to the 15 counties with wild boars and 200 farmers were selected in each county apart from the geographically substantially larger areas such as “Skåne” and Västra Götaland”. In the latter regions 300 farmers were selected. All farmers were selected by a stratified random sampling approach where the probability of selection depended upon the acreage farmed by each farmer (Scott et al., 1975; Krosnick, 1990). This approach was motivated by the need to obtain consistent measures on damages on land farmed as opposed to damages to the specific farm operator. A total of 3200 questionnaires were sent out in April and the initial response rate amounted to around 35 %. A reminder was sent to 2109 farmers in May 2015. In a second reminder in the beginning of June the survey was sent to 1527 farmers and supplementary survey was sent to 825 farmers. Altogether a total of 4025 farmers obtained the survey and the final response rate amounted to 61.9 %. A follow up study of the non-respondents showed that the most common reasons were forgetfulness (32%), questionnaires were answered but did not reach SBA (35%), and minor problems with wild boar (18%). We do not expect any systematic bias of the non-respondents since most of them are due to forgetfulness and problems with the post system. However, some responses were deleted because of the inconsistency in the response, such as reported area affected by wild boar is larger than the total area at the farm. In total, the data set then contains 2484 observations.

In order to further validate the representativeness of the sample a comparison with the aggregate population of farms is conducted. Table 1 reveals that for the counties that participated in the survey the average farm size amounted to 42.5 hectares of tillable land in 2014. The sample average farm size in the sample amounts to 109.4 hectares but given the nature of the stratified sample with weights attached to each observation the weighted average of the sample reveals a farm size of 51.4 hectares which is close to the farm size in the entire population of farms during 2014 according to Statistics Sweden (2015 a). However, there is tendency towards larger farms being more inclined to respond to the survey. Another crucial variable is the tenancy ratio that measures the ratio of tillable land that is rented. This variable is important since the hunting rights typically do not belong to the farmer that rents land. The share of rented land amounts to 37. 6 % which is slightly lower than the weighted average of the survey, which amounts to 42.9 % . This may partly be explained by the fact that the farms in survey are slightly larger and the tenancy ratio typically tends to increase with farm size (Andersson, 1995). Another explanation is that farmers that operate larger share of rented land may be more vulnerable to crop losses due to wild boar damage and therefore face an added incentive to participate in the survey. Finally, the percentage of forage crops, typically grown for ruminants, amount to 42.2 % in the counties surveyed but the weighted average according to the survey amounts to 37.1 % which may indicates that farmers that do not operate livestock may be slightly more inclined to respond to the survey. However, in general the deviations between the population statistics and the weighted average of the sample are quite small which suggests that the sample is reasonably representative for the population of farms in the counties surveyed.

Table 1: Comparison between survey data and corresponding variables for the entire population of farms within the counties surveyed

Source	**Tillable acreage per farm**	**Share of rented land, % of total land**	**Share of forage crops, % of total land**
Statistics Sweden (2015a)	42.5	37.6	42.2
Survey, unweighted average	109.4	48.5	35.6
Survey, weighted average	51.4	42.9	37.1

With respect to costs, the survey contained questions concerning the farmer´s subjective perceptions regarding the losses from crop losses, and adjustment and protection costs. Crop losses were calculated from impacts on four major crop categories; grain and oilseeds, forage and fodder crops, potatoes and sugar beets and finally miscellaneous crops such as field grown vegetables, bio-energy crops etc. The respondents were requested to grade the damage incurred in terms of losses inflicted upon land with at least 5 % of the physical crop affected by extensive damages due to rooting behavior or simply forming habitats in the field. Upon the area affected the respondents were provided with 11 alternatives for damage assessment ranging from 0- 5 % up to more than 50% of the assessed crop value. In addition, a check question was introduced indicating "no damage to the crop" as to examine the consistency of the answers. This question was motivated by the fact that some of the farmers in the initial test group raised the issue of possible "overreporting" of damage incurred. Costs from crop losses were calculated based on the responses in the survey and on data on unit profits in the region (see appendix A).

Two questions were formulated in order to obtain data on other costs associated with wild boar. In one of them, famers where asked to report number of labour hours needed to mitigate damages from wild boar Costs were then calculated as the average labour cost per hour times the reported hours. The other question asked for expenditures associated with repairs of machinery damages.

The survey showed that 39% of the respondents experience any of the three types of costs of wild boar, and the average cost of wild boar amounts to 29.44 thousand SEK (9.54 SEK = 1 Euro, 8.63= 1 USD). This cost is below the estimates made for some US states, but the allocation of costs due to crop losses and damage on infrastructure is relatively similar (Mengak, 2012; Tanger et al. 2015). The main part, 63%, of the total cost is due to crop losses, 9% to machinery damage, and 28% to adjustment costs. However, the total cost is unevenly distributed among counties, see Figure 1.

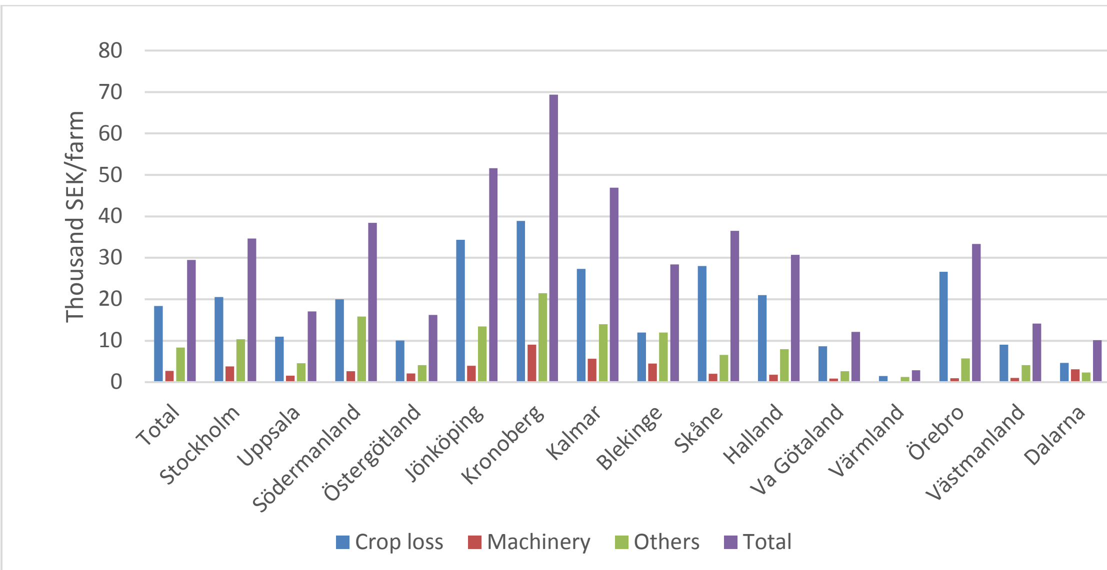

Figure 1: Allocation of costs per farm of wild boar among counties.

The costs per farm range between 2870 SEK and 69370 thousand SEK among the counties. They are highest in the counties located in the southern part of Sweden, where relatively large populations of wild boar have been documented (Jansson and Månsson 2011; Gren et al., 2016). Common to all counties is the high cost of crop losses compared with the other types of costs. When we calculate the average costs only for the farmers with wild boar damage, it increases to 71480 SEK, and the range among counties is between 43710 (Värmland) and 102710 (Skåne) SEK (Figure B2).

The pattern of allocation of costs among the counties remains the same when we instead compare the costs per hectare, which on average amounts to SEK 175/ha for crop losses, SEK 101/ha extra costs, and SEK 29/ha for machinery repair costs. The estimated average cost of crop losses is close to results obtained by other studies on costs of wild boar in Sweden. As mentioned in the introduction, the crop loss can range between SEK 66/ha and 479/ha depending on type of crop (Lindblom, 2011).

However, when we compare cost/ha arable land solely for farmers that incurr losses from wild boar, the allocation becomes more even, see Figure B2 The average cost of only farmers with losses amounts to SEK 931/ha, of which 61% arises from crop losses and 30% from adjustment costs. The total cost/ha ranges between SEK 511/ha (Uppsala) and SEK 1186/ha (Södermanland). We can notice that the costs of farmers affected by wild boar in the counties with few pigs (Dalarna and Värmland) are in the same order of magnitude as the costs in counties where the pigs have been established.

With respect to feeding practices this can be made for luring the pigs away from the agricultural land but also for concentrating them to an area where they are relatively easy to hunt. Wild boar are difficult to hunt in other ways since they are active during night and have excellent hearing. The survey includes two questions on feeding. One pertains to the frequency, which includes six choices ranging from feeding less then every month to instantaneous feeding. The other question concerns the spatial frequency, which, in turn, is divided into two alternatives; number of feeding plots/area unit or number of farmers with feeding plots in the vicinity. However, since it is difficult to disentangle the impacts on damages from these types of feeding categories, we constructed a composite feeding index, $Feeding_{COMP}$, by means of principal component analysis. This is constructed as

$$Feeding_{COMP} = \sum_h a_h x_h \qquad (10)$$

where $h=1,..,n$ are the different feeding choices, and a_h are the weights applied to each of the choice (see e.g. OECD 2008 for a further description). The weights are obtained from principal component analysis and chosen where at least 70% of the total variance is explained (Table B1).

The survey also contained questions with binary responses on five different protection measures; hunting of piglets in the agricultural field, creation of open fields around the agricultural land, frightening the pigs, construction of fences, and others. Similar to feeding, we constructed a composite $Protection_{COMP}$ index by means of principal component analysis. The results from the principal component analysis are displayed in Table B2.

Information concerning hunting rights on the land farmed is available in the survey. As discussed in Section 2, this information can be of importance since the right to hunt typically does not belong to the tenant farmer. The survey contained questions on area of rented agricultural land. The share of rented agricultural land in relation to total land is used as an explanatory variable.

Data on landscape characteristics were gathered through SAM 2015, which is a database that contains detailed information regarding the nature of the farm operation and serves as the foundation for the application for direct income payments as part of the CAP payment program (Swedish Board of Agriculture 2016b). For the sample of farmers data concerning their cropping system for the year of 2015 was gathered and linked to the observations. This data contains detailed information concerning type of, and area of, crops grown, livestock operations and additional data regarding the configuration of agricultural land. A measure relating to the configuration of land are the number of “blocks”. A “block “ is at tract of land which is defined by natural borders such as roads, forest land, pasture land, rivers, ditches, trenches or other landscape elements. Consequently, the number of blocks, and area per block, provides indirect information regarding the nature and diversity of the agricultural landscape. This information was found to be of importance in the study by Gren et.al. (2016). The results from the survey show that the average number of blocks per farm is 27.746 (Table 1).

A main challenge with respect to data retrieval is to obtain data on wild boar populations at the local level, which do not exist. Instead, there are data on wild boars shot per unit area at the municipality level (Viltdata, 2016). We would expect a positive relation between harvest and population size in a given period of time, and we therefore use hunting/ha as a proxy for the population size. The variable may therefore indicate a positive relation with farmers’ total cost, but also a negative when hunting is used as a protective measure. On average, the number of wild boar/ha amounts to 8.038/ha, but it can vary considerably and in the extreme case amount to 52 (Table 2). We also constructed a variable where the number of eliminated wild boars are divided by the number of hunters in the municipality. There are no data on active hunters, and we instead used number of hunting licenses as an approximation of hunting effort. By dividing the number of killed animals with the number of hunting licenses we obtain a measurement similar to catch or harvest per unit of effort, which is commonly used as a construct of population abundance (e.g. Maunder et al. 2006). The average killed animal per effort amounts to approximately 0.70, but can be 4.3 in some municipalities where the farmer lives (Table 1).

Table 2: Descriptive statistics, n=2484

Variable	Mean	Standard deviation	Min	Max
Costs, thousand SEK/farm:				
Crop loss	18.243	91.889	0	3488.386
Adjustment cost	7.990	27.072	0	360
Machinery repair	2.602	14.926	0	450
Total	28.842	106.006	0	3488.366
Land use, ha/farm:				
Grain and oil seeds	58.001	84.315	0	1115.610
Potatoes and beets	2.607	12.309	0	363.380
Forage	38.979	54.023	0	1250.620
Total arable land	109.556	112.354	5.02	1662.020
Number of blocks on arable land	27.746	25.909	1	252
Share of rented land	0.385	0.347	0	1
Wild boar killed/1000 ha in the municipality	8.038	7.383	0	52.69
Animal killed/hunting license in the municipality	0.689	0.704	0	4.300
Cost, dummy for cost>0	0.397	0.489	0	1
Feeding$_{COMP}$, composite index	0.096	0.153	0	0.680
Protection$_{COMP}$, composite index	0.101	0.140	0	0.750

4. Econometric analysis and results

As shown in the descriptive statistics Table 2, approximately 60% of the respondent face no cost at all from wild boar, but the cost can amount to 3.5 million SEK at some farms. However, these large costs are treated as outliers in this analysis and most of the costs are typically below 0.5 million SEK (Figure 2).

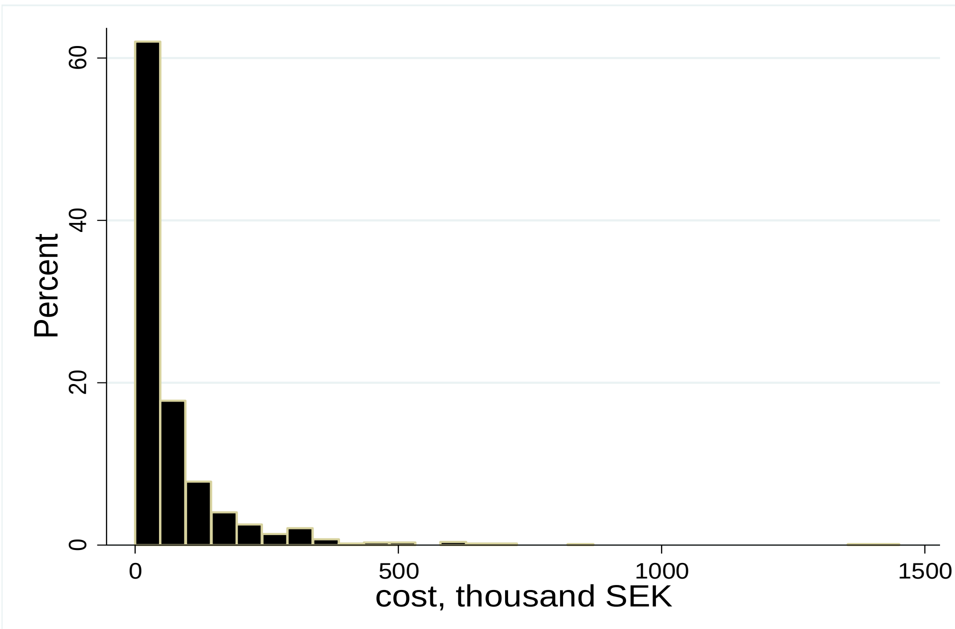

Figure 2: Percentages of farmers at different cost levels

The skewed allocation of costs among the farmers with a large number of zero damages from wild boar requires appropriate econometric approaches. One is the hurdle method which includes estimations of probabilities of damages and, given that damage cost occurs, estimation of the explanatory power of different independent variables. However, one of the explanatory variables, *wild boar/1000 ha* or *wild boar/hunting license,* is likely to be endogenous and depend on feeding and hunting as shown in Section 2. We therefore used the probit model with endogenous covariates for the regression of the likelihood of damage occurrence and the instrumental variable method for the regression of magnitude of costs as dependent variable. Tests were made for endogeneity in the regressions of the likelihood and size of damages from wild boar. The results showed that the hypothesis of exogeneity can be rejected at the 1% level. We included *Hunting License*, *Municipality area,* and *Protective hunting* and *Feeding* as instruments, which turned out to be valid and strong enough instruments. The Hansen J statistic indicated that the hypothesis of exogenous instruments could not be rejected on the 1% level, and the Cragg-Donald Wald F statistic amounted to 11.02. When estimating the power of the variables to explain the magnitude of costs, we use log of costs as dependent variable. These two regression models are used for each of the explanatory variables on wild boar abundance. Test results revealed heterogeneity and we therefore make all estimates with robust standard errors.

We also estimated regressions with dummies for each county except for Stockholm, but none of the dummies were significant and the results showed a lower statistical performance as measured by AIC and BIC. We therefore present regressions without county dummies, and the results are presented in Table 2.

Table 3: Results from regressions with Loss or no loss and *lnCost* as dependent variables with endogenous covariates[a] and robust standard errors.

Variable	**Loss =1 or 0 as dependent variable, Probit model, n=2391**		***lnCost* as dependent variable, IV method, n=1029**	
	Model 1	**Model 2**	**Model 1**	**Mosel 2**
Constant	-1.642*** (0.000)	-1.489*** (0.000)	0.716 (0.230)	1.135** (0.017)
Wild boar/1000 ha	0.151*** (0.000)		0.065* (0.059)	
Wild boar/hunting license		1.533*** (0.000)		0.401** (0.010)
Grain and oils seed area/total area	-0.156 (0.253)	-0.026 (0.845)	-0.342 (0.489)	-0.433 (0.383)
Potato and beets area/total area	-4.235*** (0.000)	-1.722*** (0.000)	1.316 (0.358)	1.906 (0.137)
Forage area/total area	0.308 ** (0.042)	0.221 (0.234)	1.367*** (0.003)	1.183** (0.010)
Number of blocks on arable land	0.015*** (0.000)	0.008*** (0.000)	0.011*** (0.000)	0.009*** (0.000)
Agriculture area	-0.602-3** (0.021)	-0.2-3 (0.421)	2.149-3*** (0.000)	2.249-3*** (0.000)
Rented land/total land	-0.098 (0.205)	0.022 (0.767)	0.586*** (0.000)	0.628*** (0.000)
Feeding$_{\mathbf{COMP}}$	0.080 (0.636)	0.014 (0.946)	0.314 (0.257)	0.329 (0.226)
Protective$_{\mathbf{COMP}}$	0.601 (0.096)	0.339 (0.521)	1.305*** (0.002)	1.422*** (0.000)
Dummy for cost>1500 thousand SEK			3.142*** (0.000)	3.112 *** (0.000)
AIC	18177.19	7156.68	3785.86	3749.967
BIC	18321.68	7301.167	3840.042	3804.150

[a]The explanatory variables wild boar/ha and wild boar/hunting license are endogenous with Hunting Licenses in municipality, municipality area, and binary variables for feeding and hunting license at farm as instruments

The results show that the variable *wild boar/hunting license* gives the best statistical fit as measured by AIC and BIC for both the probit and IV model, and there are small differences in results. Common to both models is that *wild boar/1000 ha* and *wild boar/hunting license* are positive and significant. Wild boar abundance increases the probability and the magnitude of damage cost, which would be expected. This is also true for *Number of blocks on agriculture land*. The hiding opportunity for the pigs contributes to the occurrence and size of damage.

Irrespective of choice of wild boar abundance variable, a larger share of potatoes and beets has a significant and negative effect on the likelihood of damage, but the share of forage shows a significant positive effect on damage. This result may be partly due to that these specialty crops are typically grown in more open and favorable field conditions. The results also show that neither $Feeding_{COMP,,}$ *Rented land/total agricultural land* nor $Protective_{COMP}$ has any significant effect on the probability of damage cost, but the latter two have significant and positive effects on the magnitude of the damage cost. We would expect that the *Rented land/total agricultural land* contributes to the damage cost because of the limited options to hunt and manage land to avoid damages. However, the positive and significant effect of $Protective_{COMP}$ is unexpected. One reason can be that protective measures are implemented at farms with relatively high cost and are thus endogenous. Therefore, we estimated an IV model with *Wild boar/hunting license* and $Protective_{COMP}$ as dependent variables. However, it should be noticed that the variable wild boar/hunting license may be associated with some measurement problems since it is quite common that hunters do hunt in other areas apart from the municipality where their hunting license is registered Furthermore, a three stage least square model was estimated with these two dependent variables in addition to *logCost.* The results showed that $Protective_{COMP}$ is positive and significant in both these regression models, see Table B3.

A reason for this positive effect can be explained by the formulation of one question to the farmers as ‘What is the costs attributable to wild boar that are not associated with crop loss or machinery repair?’ This question may give information regarding protection costs, and we therefore estimated the IV model without this cost component. Further, hunting of piglets at the fields is included as a choice of protection measure, but it can be interpreted as hunting in general. We therefore excluded this option and conducted a principal component analysis of the remaining three options (fright, open field, and fencing). This analysis showed that fright and open field explains the same share of the variance and we therefore treated fences and fright measures as explanatory variables. Regression were estimated with either the composite index, $Protection_{COMP}$, or the separate *Fright* and *Fences* variables. The results showed that neither $Protection_{COMP}$ nor the separate protection measures *Fences* and *Fright* had any significant impact on the costs excluding the adjustment cost not related to changes in crop allocation (Table B4). The estimates of the other variables remained similar to both level and significance of the coefficients.

In order to obtain some insights into the role of the different significant variables for the probability of damage occurrence and magnitude of costs we calculate the effects of a 10% increase in the mean values of the significant variables in Table 3, but exclude protective measures. However, since it is not possible to increase share variables by one unit we evaluate a marginal impact of 0.1.

Table 4: Calculated marginal impacts in each significant variable from Model 2 in Table 2 on probability and size of damage costs.

	Wild boar/ hunting license	**Blocks on arable land**	**Share of rented arable land[a]**	**Share of potatoes and beets[a]**	**Share of forage[a]**	**Arable land**
Probability	0.607	0.003		-0.068		
Cost, SEK/farm	11548	259	1108		3407	722

[a]Increase by 0.1

The marginal effect of *Wild boar/hunting license* on the probability and magnitude of costs are relatively large. However, the average level is 0.69 and an increase by one animal would constitute an increase by 145%. .

5. Summary and conclusions

This study has calculated the costs of wild boars to farmers in Sweden by collecting data from a survey to a sample of 4025 respondents, who constitute 5% of the total number of farmers in Sweden. The response rate was 61%, and the results showed that a majority, approximately 60%, of the respondents did not face any costs from wild boar. The average damage cost amounted to 28842 SEK per farm, or 323 SEK/ha. The average value added/farm was approximately 175000 SEK in 2014, and the estimated damage can thus be considerable

(Swedish Statistics, 2016). The main part of the cost, 63%, is attributed to crop losses, 9% to machinery damages, and 28% to other losses such as adjustment costs due to wild boar. The cost of crop loss per ha estimate is within the range of the few other studies on costs of wild boar to farmers in Sweden.

With respect to the determinants of damage costs of wild boar, our dynamic theoretical model of a representative farmer facing wild boar incursion points out potential impacts of wild boar abundance, hunting preferences of wild boar, adjustment and protection options and costs, landscape diversity, and ownership in terms of rented or owned land. In order to test the explanatory power of these variables we needed to consider that 60% of the respondents reported no damage costs. Therefore, we applied a two-step approach where we first examined the impact of the variables on the probability of a damage and then regressed the effects on the magnitude of the costs. Another aspect to consider was that our constructs of wild boar abundance (killed wild boar/1000 ha or killed wild boar/hunting license in the municipality) are endogenous.

Using instruments to account for the endogeneity for both regression steps robust results were obtained where wild boar abundance and landscape diversity contribute to higher probability and larger damage cost. Share of rented land, area of agricultural land, and protective measures did not revealany significant effect on the occurrence of a damage, but had significant and positive effect on the size of the damage cost. Except for protection measures, these effects were expected. Since protection measures can be regarded as a response to high damage costs, we carried out regression with these measures as dependent variable, but the results remained the same. However, when excluding the reported adjustment cost, which may include costs for protection measures, the effect was not statistically significant. The estimates of the coefficient signs of the other explanatory variables remained unchanged.

Our results with respect to effects of wild boar abundance, and diversity on arable land thus appear quite robust. An increase in the wild boar abundance by one unit as measured by wild boar/hunting license increase the damage cost by approximately 11500 SEK per farm as evaluated at the mean cost. Similarly, the landscape diversity, as measured by the number of fields separated by different landscape elements contributed to increased damages. This points out a cost of providing diversity in the agricultural landscape which, to the best of our knowledge, has not been identified in any other study. An increase in the number of blocks by 10% raises the damage costs by SEK 725/farm. It is also noteworthy that being a tenant farmer raises the damage cost, because of the limited options to exercise adjustment and protection measures.

As mentioned in the introduction, wild boar are excellent survivors and it is not likely that the population will decrease unless the hunting pressure increases. According to a choice experiment study carried out by Engelmann et al. (2016) hunters' value of a wild boar amounts in average to 346 SEK/wild boar. Gren et al. (2016) calculated that the wild boar population in Sweden amounted to approximately 200 000 animals, which gives an average value of approximately 1030 SEK/farm which is far below the estimated damage cost. In order to reduce the wild boar population hunters might need compensation. Our results indicate that the farmers' losses from wild boar are large enough to provide room for compensation payments.

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Appendix A: Calculation of damages on crops

The assessment of crop losses is based upon the expected value of the harvested crop. For grain and oilseeds as well as potatoes, sugar beets etc. a three year average of the market price is calculated for every crop in each of the production areas. In order to obtain the net market value of the crop per kg drying costs and transportation costs are deducted from the market price (Agriwise, 2015). For rape seed (fall variety) non hybrid varieties are assumed to represent this crop. The expected revenue per hectare is calculated as the expected harvest in the local area times the net price. Information on expected harvest is based on Statistics Sweden

(2015b) which provides data for each local production area (SKO, “skördeskadeområde”). The partition of tillable land in Sweden into SKO´s is based upon historical data from a crop disaster insurance program dating back to the 60´s. The local areas, or SKO´s, are partitioned in such a manner that they ought to represent rather similar yield conditions

In terms of potatoes the market price for “winterpotatoes” is used since this type of potatoes represent the majority of potato volume consumed. Finally, for sugar beets market price during fall is applicable. With respect to forage, no market value typically exists. Hence, the opportunity cost, or more precisely, the Lagrangean multiplier for the forage constraint in an optimization problem involving ruminants and forage production (Liljegren , et.al. 1983). The opportunity cost, OC_f is calculated as:

$$OC_f = (C_f + GM_a)/ Y_f \tag{A1}$$

where C_f is production cost per hectare of forage, GMa is gross margin per hectare of the alternative crop, and Y_f is the yield per hectare of forage (drymatter)

The opportunity cost OC_f is calculated for each production area using data from Agriwise (Agriwise, 2016). The calculated opportunity cost for forage a harvested as silage ranges from 1.49 – 1.79 SEK(/kg drymatter. In, addition a substantial acreage of tillable land is harvested as pasture for grazing. Largely due to grazing regulations for livestock, no specific yields are reported by Statistics Sweden for this harvest system but the yield as estimated to be approximately 60% of the yield for silage (Statistics Sweden, Pers. Communication Lindell, 2016). The corresponding opportunity costs for pasture on tillable land amounts to 0.96- 1.59 SEK/kg drymatter.

Appendix B: Tables and figures

Table B1: Principal component analysis of dummy variables for feeding

	Eigen value	Cum. probability	Loadings: Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8
Comp1	1.203	0.10	Feed1	**-0.53**	0.27	-0.38	-0.28	-0.24	-0.04	-0.10	0.01
Comp2	1.175	0.198	Feed2	0.25	0.28	0.23	0.02	0.45	-0.38	-0.23	0.48
Comp3	1.133	0.292	Feed3	0.27	0.09	-0.12	-0.14	0.27	0.59	**0.56**	0.07
Comp4	1.106	0.385	Feed4	-0.02	-0.34	0.19	0.17	0.25	0.37	-0.53	-0.42
Comp5	1.071	0.472	Feed5	0.06	-0.36	0.01	0.25	0.08	**-0.42**	0.37	-0.14
Comp6	1.030	0.560	Feed6	0.23	-0.04	0.18	0.29	**-0.58**	-0.13	0.19	-0.10
Comp7	1.021	0.645	Feed7	0.32	-0.06	**-0.66**	0.10	0.11	-0.08	-0.10	0.01
Comp8	0.996	0.728	Feed8	-0.48	0.05	0.37	-0.08	0.29	-0.07	0.35	-0.11
			Feed9	0.16	0.17	0.35	-0.03	-0.39	0.33	-0.13	0.33
			Feed10	0.17	-0.39	0.09	**-0.63**	-0.11	-0.10	-0.07	0.07
			Feed11	0.16	**0.62**	0.05	0.16	0.01	-0.04	-0.04	-0.46
			Feed12	-0.33	-0.16	-0.12	0.53	-0.01	0.21	-0.02	**0.48**

Feed1 instant feeding; Feed2 >1 feeding/week; Feed3 1 feeding/week; Feed4 2 feeding/month; Feed 5 1 feeding/month; Feed6 <1 feeding/month; Feed7 1 plot/100 ha; Feed8 1 plot/500 ha; Feed 9 1 plot/1000 ha; Feed 10 1 plot/3 land owners; Feed11 1 plot/6 land owners; Feed12 1 plot/>6 land owners

Table B2: Principal component analysis of protection measures

	Eigen value	Cum. probability	Loadings: Variables	Comp1	Comp2	Comp3
Comp1	1.687	0.338	Frighting	**0.54**	-0.26	0.08
Comp2	1.228	0.582	Open area	0.49	-0.26	**-0.74**
Comp3	0.758	0.735	Hunting of piglets	0.48	-0.32	0.64
			Fences	0.33	**0.63**	0.16
			Others	0.36	**0.60**	-0.12

Table B3 Regression results with three stage least square, Probit and IV estimates with both *Wild boar/hunting licenses* and $Protection_{COMP}$ as dependent explanatory variables.

Variable	**Three stage least square, dependent variable:**			**Wild boar/license and Protectivecomp as endogenous**	
	Lncost	**Wildboar/ licence**	**$Protection_{COMP}$**	**Probit model**	**IV model**
Constant	0.611 (0.285)	1.105*** (0.000)	0.078*** (0.000)	-2.055*** (0.000)	0.881 (0.114)
Wild boar /hunting license	0.522*** (0.004)			2.187*** (0.000)	0.431*** (0.009
Grain and oils area/total area	-0.422 (0.314)			0.021 (0.922)	-0.606 (0.256)
Potato and beets area/total area	2.089*** (0.054)			-2.667*** (0.000)	2.035 (0.115)
Forage area/total area	1.204*** (0.002)			0.134 (0.516)	1.148** (0.018)
Number of blocks	0.015*** (0.000)			0.011*** (0.000)	0.008*** (0.000)
Agriculture area	2.276-3*** (0.000)			-0.171-3 (0.607)	2.147-3*** (0.000)
Rented land/total land	0.637*** (0.000)			0.156 (0.155)	0.612*** (0.000)
$Feeding_{COMP}$	0.215 (0.440)			0.259 (0.268)	0.244 (0.389)
$Protective_{COMP}$	5.408* (0.084)			0.616 (0.253)	3.152* (0.072)
Dummy for cost>1500 thousand SEK	3.062*** (0.001)			1.491 *** (0.000)	3.321*** (0.000)
Dummy for pigs>50				-7.744*** (0.000)	
Feeding, dummy		-2.777*** (0.000)	-0.016* (0.087)		
Hunting license at farm, dummy		-0.010 (0.820)	0.025*** (0.001)		
Hunting licenses in municipality		-0.610-3*** (0.000)	0.021*** (0.008)		
Municipality area		0.591-3*** (0.000)	-0.068-3 (0.541)		
AIC		4340.499		8841.936	3782.39
BIC		4443.937		9010.709	3836.575

Table B4: Regression results from the IV model with *lnCostb* as dependent variable which excludes adjustment costs for two different specifications of protection measures, n=834

Variable	**Dummy of *Costb*>0 as dependent variable**		**LnCostb as dependent variable**	
	Model 2a	**Model 2b**	**Model 2a**	**Model 2b**
Constant	-1.264*** (0.000)	-1.328*** (0.000)	0.579 (0.246)	0.578 (0.244)
Wild boar/hunting license	1.523*** (0.000)	1.508*** (0.000)	0.445*** (0.005)	0.434*** (0.007)
Grain and oils seed area/total area	-0.051 (0.695)	-0.047 (0.723)	-0.164 (0.741)	-0.164 (0.739)
Potato and beets area/total area	-1.827*** (0.000)	-1.788*** (0.000)	0.541 (0.741)	0.695 (0.675)
Forage area/total area	-0.042 (0.754)	-0.015 (0.914)	1.716*** (0.000)	1.730*** (0.000)
Number of blocks on arable land	6.915-3*** (0.000)	7.489*** (0.000)	9.543-3*** (0.000)	9.309-3*** (0.000)
Agriculture area	-0.22-3 (0.346)	-0.245-3 (0.299)	3.372-3*** (0.000)	3.391-3*** (0.000)
Rented land/total land	0.059 (0.429)	0.072 (0.346)	0.598*** (0.000)	0.596*** (0.000)
$\text{Feeding}_{\text{COMP}}$	-0.104 (0.581)	-0.027 (0.885)	0.291 (0.255)	0.273 (0.285)
$\text{Protective}_{\text{COMP}}$		0.118 (0.790)		0.271 (0.530)
Frighting	0.025 (0.793)		-0.014 (0.897)	
Fences	-0.202 (0.286)		0.328	
Dummy for cost>1500 thousand SEK			2.957** (0.020)	2.918** (0.019)
AIC	7426.868	7302.206	2895.365	2893.342
BIC	7582.925	7446.703	2951.08	2945.334

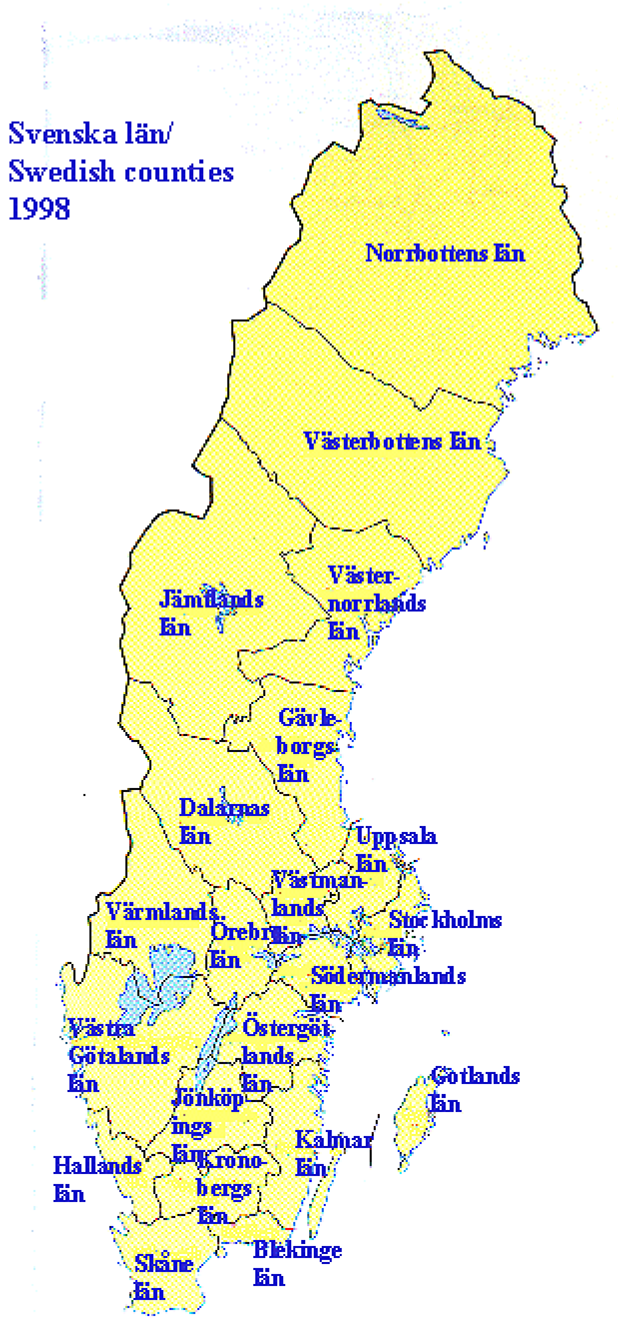

Figure B1: Counties in Sweden

Source: http://www.hhogman.se/swe_counties_map_eng.htm

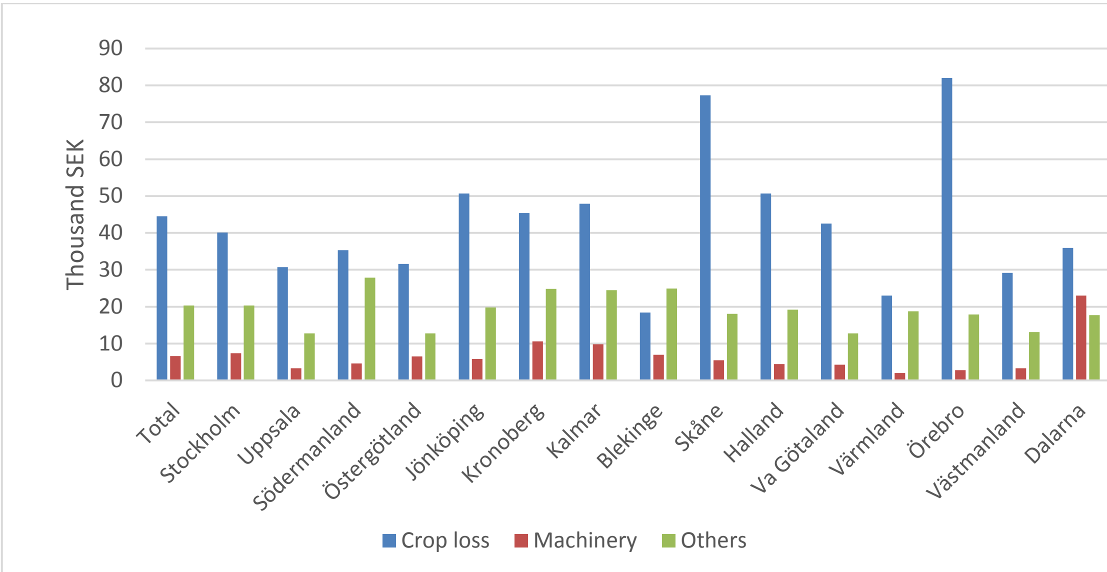

Figure B2: Damage cost/farmer for farmers with damage, average for different counties and for Sweden

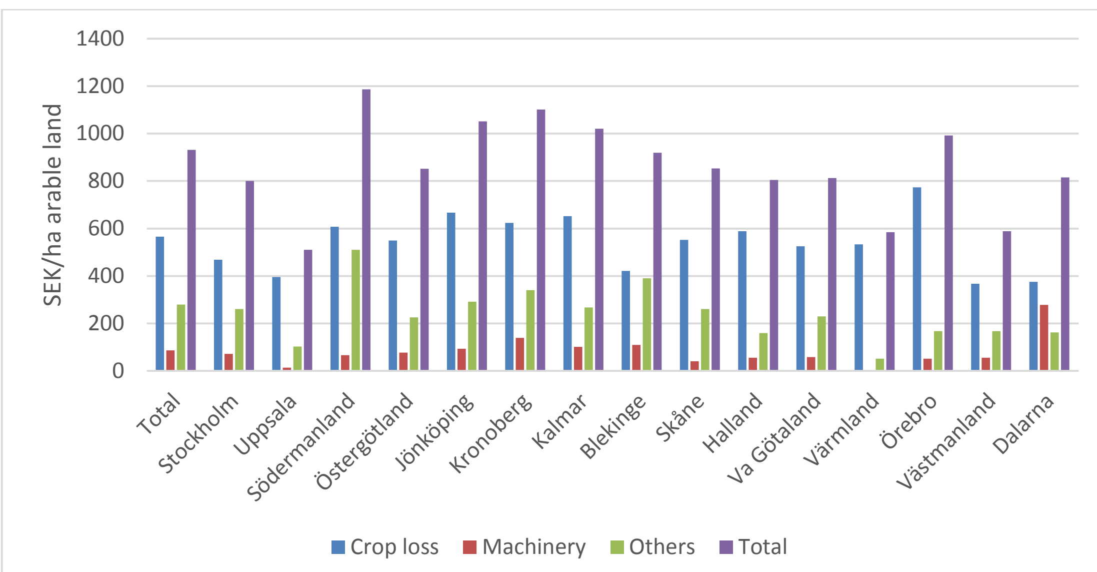

Figure B3: Damage cost/ha for farmers with damage, average in different counties and totally in Sweden.

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