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24 **Economic impact of lumpy skin disease and cost effectiveness of vaccination for the**
25 **control of outbreaks in Ethiopia**

26

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38

39 **Abstract**

40

41 Lumpy skin disease (LSD), an infectious viral disease of cattle, causes considerable financial
42 losses in livestock industry of affected countries. A questionnaire survey with the objectives of
43 determining direct economic losses of LSD (mortality loss, milk loss, draft loss) and treatment
44 costs (medication and labour cost) per affected herd, and assessing the cost effectiveness of
45 vaccination as a means for LSD control was carried out in the central and north-western parts
46 of Ethiopia. From a total of 4430 cattle (in 243 herds) surveyed, 941 animals (in 200 herds)
47 were reported to be infected. The overall morbidity and mortality at animal level were 21.2%
48 and 4.5%, and at herd level these were 82.3% and 24.3%. There was a significant difference in
49 animal level morbidity and mortality between categories of animals. Over 94% of the herd
50 owners ranked LSD as a big or very big problem for cattle production. A large proportion
51 (92.2%) of the herd owners indicated that LSD affects cattle marketing. A median loss of USD
52 375 (USD 325 in local Zebu and USD 1250 in Holstein-Friesian local Zebu cross cattle) was
53 estimated per dead animal. Median losses per affected lactating cow were USD 141 (USD 63
54 in local Zebu cows and USD 216 in Holstein-Friesian local Zebu cross cows) and, USD 36 per
55 affected ox. Diagnosis and medication cost per affected animal were estimated at USD 5. The
56 median total economic loss of an LSD outbreak at herd level was USD 1176 (USD 489 in
57 subsistence farm and USD 2735 in commercial farm). At herd level, the largest component of
58 the economic loss was due to mortality (USD 1000) followed by milk loss (USD 120). LSD
59 control costs were the least contributor to herd level losses. The total herd level economic losses
60 in the commercial farm type were significantly higher than in the subsistence farm type. The
61 financial analysis showed a positive net profit of USD 136 (USD 56 for subsistence farm herds
62 and USD 283 for commercial herds) per herd due to LSD vaccine investment. It should be noted
63 that only the noticeable direct costs and treatment costs associated with the disease were

64 considered in the study. Generally, vaccination is economically effective and should be
65 encouraged.

66

67 **Keywords:** LSD outbreak; morbidity; mortality; economic loss; vaccination; Ethiopia.

68 **1. Introduction**

69

70 Lumpy skin disease (LSD) is a severe systemic disease of cattle caused by the lumpy skin
71 disease virus, which belongs to the genus *capripoxvirus*, family *poxviridae*. It is characterized
72 by fever, nodular lesions on the skin and mucous membranes and lymphadenopathy (Murphy
73 et al., 1999; Radostits et al., 2007). The morbidity during LSD outbreaks varies greatly from
74 5% to 100% depending on the immune status of the host and the abundance of arthropod vectors
75 (Woods, 1988; Tuppurainen and Oura, 2012). LSD mortality is generally low (usually less than
76 5%) but occasionally may reach 20% (Woods, 1988; Babiuk et al., 2008; OIE, 2010). LSD is
77 associated with reduction in milk production, temporary or permanent sterility in bulls and
78 cows, weight loss, draft power loss, abortion, damage to hides and death. Disease control and
79 eradication measures such as vaccination campaigns, removal of affected animals, biosecurity
80 are costly (Woods, 1988; Radostits et al., 2007; Babiuk et al., 2008; OIE, 2010; Tuppurainen
81 and Oura, 2012). For example in Israel the control of the initial LSD outbreak costed USD
82 750,000, and the indirect financial loss associated with compulsory animal movement
83 restrictions was also significant (AU-IBAR, 2013). The economic importance of the disease is
84 also due to convalescence of several months (Murphy et al., 1999). The World Organization for
85 Animal Health (OIE) categorized LSD as a notifiable disease because of its substantial
86 economic impact (Tuppurainen and Oura, 2012; OIE, 2015). Because of these considerable
87 financial losses and the international trade restrictions on live animals and their products, LSD
88 is one of the most important infectious diseases in countries where it is endemic.

89

90 Livestock is an important sector in Ethiopia's economy as it contributes 35.6% to the
91 agricultural Gross Domestic Product (GDP), equivalent to 16.5% of the national GDP
92 (Metaferia et al., 2011), and 37 to 87% to the household incomes (GebreMariam et al., 2010).
93 The contribution of livestock to the annual foreign exchange earnings amounts to 12% (NBE,

94 2014). Households keep cattle for multiple purposes: milk production, draft power, beef
95 production, manure for fuel and fertilizer, and breeding (GebreMariam et al., 2010; Negassa et
96 al., 2011). The total cattle population of Ethiopia is estimated to be about 57 million heads
97 (CSA, 2015). The benefit that cattle could have for the country is not attained for several reasons
98 and one important reason is animal disease. LSD stands among the major diseases that limit the
99 productivity of the cattle population (Gari et al., 2011; APHRD, 2012).

100 LSD was restricted to Africa and Middle East countries for decades, but recently it is spreading
101 unusually beyond its territory into Europe and other Asian countries and increasingly becomes
102 a risk for the livestock industry in these continents (Tuppurainen et al., 2015; Tasioudi et al.,
103 2016; WAHIS, 2016). In Ethiopia, LSD was first observed in 1981 in the north-western part of
104 the country (Mebratu et al., 1984). However, it has now spread to almost all regions and agro-
105 ecological zones of the nation with seroprevalence ranging from 23-31% at animal level and
106 26-64% at herd level (Gari et al., 2010; Gari et al., 2012). The infection was reported to cause
107 33.93% and 13.41% morbidity and 7.43% and 1.25% mortality in Holstein-Friesian cross bred
108 and local Zebu cattle, respectively (Gari et al., 2011).

109

110 Knowledge of disease impact is essential when deciding on the level of expenditure that can be
111 justified for a disease control programme (Knight-Jones and Rushton, 2013). The economic
112 impact of LSD can be largely influenced by the methods used to control and eradicate
113 outbreaks. In general, LSD prevention and control programmes are based on one or more of the
114 following three elements: routine vaccination, stamping-out and movement restriction (Davies,
115 1991; Carn, 1993; Horst et al., 1999). The main LSD prevention and control scheme in Ethiopia
116 is through vaccination. Vaccination costs depend on the number of animals vaccinated, vaccine
117 cost, vaccination frequency, and labour and distribution costs (Horst et al., 1999). In Ethiopia,

118 vaccination cost is borne by the government, i.e. vaccines are provided free of charge to the
119 livestock owners.

120 Disease impacts are generally easy to identify but may be difficult to quantify. Disease
121 outbreaks often have broad, long-term effects on livestock industry. The costs of animal disease
122 can roughly be divided into direct costs, which include losses related to animal illness, death
123 and less immediate impacts such as reduced fertility, and indirect costs, which encompass
124 control costs, losses in trade and other revenues (Rushton, 2009; Oxford-Analytica, 2012).
125 Understanding the impact of animal disease and assessing its losses is useful for policy makers
126 and farmers who may weigh the losses against the costs of disease control each at their own
127 level (Pritchett et al., 2005). There has been very limited work carried out on the financial
128 analysis of herd-level control of LSD. Therefore, the objectives of this study were to determine
129 the direct financial losses of LSD related to milk loss, draft power loss, mortality and indirect
130 losses due to treatment, and to assess the cost effectiveness of vaccination as a means of LSD
131 control.

132

133 **2. Materials and methods**

134

135 **2.1. Study design and population**

136

137 A questionnaire survey targeted to assess the economic impact of LSD was carried out in the
138 central and north-western parts of Ethiopia (Figure 1). In central part, it was undertaken in
139 Ada'a, Sebeta Hawas, Ambo, Dendi, Debrelibanos, Kuyu and Hidabu Abote districts in Oromia
140 National Regional State. In north-western part, the data were collected from Dejen, Gozamen,
141 Hulet Ejju Enessie and Jabitenan districts in Amhara National Regional State. Furthermore,
142 another five commercial dairy farms (Selale Dairy Development PLC at Muketuri, Aser at

143 Ecoefobabo, Sululta; Selam Children Village in Addis Ababa, Holeta dairy cattle genetic
144 improvement nucleus farm and Holeta agricultural research centre farm at Holeta) were
145 included in the study.

146

147 The livestock production systems in the study area can be classified into two broad categories:
148 subsistence crop-livestock production and commercial dairy production. In the subsistence
149 production system the small holding farms are mainly kept for draft power, milk and meat
150 production (Mengistu, 2003) and the composition of the herd is dominated by local Zebu cattle.
151 The commercial dairy farms are market oriented and include medium (10-50 animals) to large-
152 scale (>50 animals) farms of crossbred Zebu with Holstein-Friesian. They are mostly located
153 around peri-urban and urban areas practicing intensive and semi-intensive production
154 (Mengistu, 2003). Milk and calf production are the main source of income.

155

156 **2.2. Data collection**

157

158 The questionnaire survey was undertaken from October 2014 to May 2015. The time span for
159 the financial analysis was one year i.e. May 2014 to April 2015. A total of 243 herd owners
160 from 15 districts (comprising 34 kebeles and 5 farms) enrolled in the study, a number close to
161 numbers used in comparable studies (Jemberu et al., 2014; Jibat et al., 2016; Chenais et al.,
162 2017). Kebele is the smallest administrative division in Ethiopia. The districts were selected
163 based on the occurrence of an LSD outbreak and three kebeles were randomly selected from
164 each of 10 districts, four kebeles from one district, 2 farms from 1 district and 1 farm each from
165 the other 3 districts. From each kebele, five to eight herd owners that were willing to participate
166 were interviewed. The data were collected by face to face interview using the local language.

167 An oral consent to use the data for scientific research was obtained from each participating herd
168 owner before the interview started.

169 The questionnaire was designed primarily to record the magnitude of production losses,
170 mortality, and cost of control for LSD in several categories of bovines in a herd (a group of
171 cattle owned by a household or an organization), and perception of farmers on livelihood impact
172 and its influence on cattle marketing during the outbreak period. The farmer's ability to identify
173 LSD infection was cross-checked by enquiring about the main epidemiological and clinical
174 features of LSD. If the herd owner's description was consistent with the classical clinical signs
175 and epidemiologic features of LSD (nodular lesions on skin and mucosal surface, enlargement
176 of superficial lymph nodes, swelling of the limb or the lower body, discharge from eyes, nostrils
177 and mouth, reduced milk production in lactating cows, depression, morbidity varying from 5-
178 45% and mortality less than 10%) (FAO, 2010), they were considered to know the disease and
179 the interview was continued. Farmers were also asked to estimate the daily milk production of
180 their cattle before and after infection, the duration of infection, the milk price per litre, the
181 renting price of an ox, the market value of animal, labour time lost for an animal getting treated
182 and wage of a daily labourer. Commercial farms and some of subsistence herd owners estimated
183 the volume of the daily milk produced in litres. However, the majority of subsistence herd
184 owners estimated the volume of milk produced by each LSD affected cow using the local
185 container (gourds or bucket) which normally is used for milking. This was later converted to
186 litre after filling the container with water to the level indicated by the owner and measured using
187 a graduated jug. Additional information such as treatment and vaccination cost were collected
188 from veterinary practitioners. Financial information was collected first in Ethiopian currency
189 (Birr) and later converted to USD at an exchange rate of 20 Birr = USD 1 (8 October, 2014).

190

191 **2.3. Estimation of economic losses**

192

193 The economic impact of LSD was determined by an estimation of the direct (visible) production
194 losses such as milk loss, mortality loss, and draft power loss, and indirect impacts like control
195 costs (Knight-Jones and Rushton, 2013) using the method described in Jemberu et al. (2014).
196 However, due to information paucity, impacts of the other direct losses due to reduced
197 bodyweight, abortion, infertility, culling, and poorer hide quality were not considered in this
198 study. Only affected herds were included in the calculations. All costs are expressed as median
199 costs as the distribution is not Normal.

200

201 2.3.1. Mortality loss

202 The mortality loss was set equal to the market value of the animal that died. Thus, the economic
203 loss due to mortality per herd was calculated by considering the seven categories of animals
204 (calf, bull, heifer, dry cow, pregnant cow, lactating cow, and ox) that died and their
205 corresponding market price (Formula 1).

$$206 \quad MLSD_i = \sum_{j=1}^7 NMC_{ij} * PC_{ij} \quad [1]$$

207 Where $MLSD_i$ represents the economic losses due to LSD induced death of herd i ; NMC_{ij} is the
208 number of animals that died in each category j of herd i and PC_{ij} is the price of that animal.

209

210 2.3.2. Milk loss

211 LSDV infections in lactating cows cause milk yield reduction or cessation of milking for the
212 duration of the illness and sometimes beyond. The economic loss per herd due to loss of milk
213 production was estimated based on Formula 2.

$$214 \quad MilkLSD_i = NLSDCow_i * D_i * QMilkL_i * PMilk_i \quad [2]$$

215 where $MilkLSD_i$ represents the economic losses due to milk loss for herd i ; $NLSD_{cow_i}$ the
216 number of LSD infected lactating cows in herd i ; D_i the average duration of illness in days of
217 affected lactating cows; $QMilkL_i$ the average quantity of milk lost in litres per affected cow per
218 day, and $PMilk_i$ the price of milk per litre for herd i .

219

220 2.3.3. Draft power loss

221 In Ethiopia, the traditional agricultural system depends heavily on animal draft power to
222 cultivate crops. A diseased draft ox cannot plough or provides less draft power. The loss from
223 draft power reduction can be captured from effective working days lost (Formula 3).

$$224 \quad \text{DraftLSD}_i = \text{NoxenLSD}_i * \text{DDraft}_i * \text{PDraft}_i * \frac{65}{365} \quad [3]$$

225 where $DraftLSD_i$ represents the economic loss due to draft power loss for herd i ; $NoxenLSD_i$
226 the number of oxen affected in herd i , $DDraft_i$ the average duration of illness in days of an
227 affected ox, $PDraft_i$ the price of draft power rent of an ox per day and $65/365$ is an adjustment
228 factor for effective working days - a draft ox in Ethiopia works for about 65 days in a year (Goe,
229 1987). Farmers whose draft oxen are affected with LSD have to rent, purchase a replacement
230 ox or borrow animals for cultivation. An ox can be rented from a farmer owning surplus oxen
231 on cash or grain basis.

232

233 2.3.4. LSD control costs

234 LSD control costs were considered to consist of vaccination, diagnosis and medication costs
235 and extra labour costs for seeking treatment for sick animals. Many herd owners in Ethiopia
236 use public veterinary services to get their animals vaccinated which is free of charge for
237 contagious and transboundary animal diseases like LSD. However, clinical treatment of LSD

238 affected animals was at the farmers' own expense. Hence, the economic cost of LSD treatment
239 is calculated as per Formula 4.

$$240 \quad TrCost_i = (NTr_i * PTr_i) + (NhoursL_i * Pdl_i) \quad [4]$$

241 where $TrCost_i$ represents the treatment cost for affected herd i ; NTr_i the number of animals
242 treated; PTr_i the average per head expenditure to LSD treatment; $NhoursL_i$ the average number
243 of working hours lost for seeking treatment for sick animals, and Pdl_i the average payment rate
244 of a replacement labourer per hour in the locality of herd i .

245

246 2.3.5. Total economic losses

247 The total economic costs (TEC) due to LSD infection per affected herd were obtained by adding
248 losses arising from draft power loss, milk production loss, mortality and treatment expenditure
249 (Formula 5).

$$250 \quad TEC_i = MLSD_i + MilkLSD_i + DraftLSD_i + TrCost_i \quad [5]$$

251

252 2.4. Partial budget analysis for LSD vaccine use

253

254 The cost effectiveness of LSD control through vaccination was evaluated using partial
255 budgeting analysis technique, which quantifies the economic consequences of a specific change
256 in farm procedures (Dijkhuizen et al., 1995). The economic concept of partial budgeting is
257 important for cost–benefit analysis of disease control measures (Rushton, 2009). A partial
258 budget format with four parts (additional returns gained, reduced costs, returns foregone, and
259 extra costs experienced as a consequence of the change) was employed as described by
260 Dijkhuizen et al. (1995) and Dijkhuizen and Morris (1997). Costs were estimated in scenarios
261 with and without vaccination. The base plan was no vaccine use by the herd owners, and the
262 alternative plan was LSD vaccine use. The cost for purchase and administration of the LSD

263 vaccine was considered the extra cost of the alternative plan, though it is borne by the
264 government. The profitability of vaccine use in LSD control was calculated on a herd basis
265 using Formula 6.

$$266 \quad \text{Net Profit} = (\text{Additional returns} + \text{Reduced costs}) - (\text{Returns foregone} + \text{Extra costs})[6]$$

267 A positive net result indicates that LSD vaccination is desirable from an economic point of view
268 (Dijkhuizen et al., 1995; Dijkhuizen and Morris, 1997; Young et al., 2013). Moreover, the
269 marginal rate of return (MRR) was calculated as the net benefit divided by the total cost incurred
270 due to vaccine use to further scrutinize the adoption of the change (Gari et al., 2011).

271

272 **2.5. Statistical analysis**

273

274 Descriptive statistics were used to calculate the morbidity and mortality at animal and herd
275 level. A Chi-square test was used to evaluate the differences in morbidity and mortality between
276 categories of animals and between districts. Kruskal–Wallis equality-of-populations rank test
277 was used, as the economic losses were not normally distributed, to compare the differences in
278 herd level economic losses among districts and between farm types. A p-value less than 0.05
279 was considered as significant. Stata version 14 was used for all analyses.

280

281

282 **3. Results**

283

284 **3.1. Herd size and structure**

285

286 A total of 243 herds with 4430 heads enrolled in the study. The study population comprised
287 18.4% calves, 22.7% heifers, 8.9% bulls, 37.1% cows and 12.9% oxen. Herd size varied from

288 1 (n=3) to 643 (n=1) animals. About 90% of the herds consisted of less than 25 animals. The
289 mean herd size in commercial farms was 56 heads and 10 heads in the subsistence farms. The
290 majority of the farms (81.9%) involved in the study were small holder subsistence farms, but
291 they hold only 44.3% of the study animals; 78.6% of the herds were managed extensively.

292

293 **3.2. LSD morbidity and mortality**

294

295 All herd owners approached were able to describe LSD in terms of its key epidemiologic
296 features and symptoms. Based on the farmer's response, a total of 941 out of 4430 (21.2%)
297 animals and 200 out of 243 (82.3%) herds were declared affected by LSD (i.e. they had at least
298 one LSD positive animal) in the period May 2014 to April 2015. Mortalities at animal and herd
299 level were 4.5% (198/4430) and 24.3% (59/243), respectively. Case fatality amounted to 21.0%
300 (198/941). In most herds in which animals died it was restricted to 1 (n=36 out of 59) or 2 (9
301 out of 59) dead animals, however in one large herd (331 heads) 40 animals died. Differences in
302 morbidity and mortality between study districts, at both animal level and herd level, were
303 statistically significant ($P<0.05$). The highest animal level morbidity (37.9%) and mortality
304 (12.1%) were recorded in Jabitenan district and Selale dairy Dev. PLC, respectively (Table 1).
305 The morbidity per animal category varied from lowest 15.0% in dry cows to 26.9% in oxen,
306 whereas the mortality varied from 2.2% in dry cows to 6.0% in pregnant cows (Table 2). The
307 difference in animal level morbidity and mortality between categories was significant ($P<0.05$).

308

309 **3.3. Perception of herd owners on LSD impact**

310

311 From 243 herd owners interviewed in this study, 229 (94.2%) ranked LSD as a serious or very
312 serious disease. Economic losses most frequently mentioned were death, milk loss, draft power
313 loss, weight loss, abortion and hide quality loss (Figure 2). 224 (92.2%) of the herd owners
314 indicated that LSD outbreaks affect cattle marketing. A large proportion (n = 217, 89.3%) of
315 them witnessed that cattle selling is practiced during LSD outbreaks. Almost all herd owners
316 do not sell sick animals and 32 (13.2%) of them would like to sell unaffected animals from their
317 herds during LSD outbreaks mainly due to fear of the disease (n=30, 93.8%).

318

319 **3.4. Financial losses of LSD outbreaks**

320

321 The financial losses related to mortality, milk reduction, draft power loss, and control cost per
322 affected individual animal are presented in supplementary Tables 1–4, respectively. The overall
323 median financial loss per dead animal was estimated at USD 375; however, it was USD 325 for
324 local Zebu and USD 1250 for Holstein-Friesian local Zebu cross cattle. Category wise, the
325 median loss per head varied from USD 150 for calves to USD 1181 for milking cows, whereas
326 from breed perspective the highest loss (USD 2250) was recorded in cross breed cows and the
327 lowest (USD 59) in local Zebu calves. District wise, the median loss per dead animal varied
328 from USD 125 in local Zebu in Debrelibanos district to USD 1966 in cross breed cattle in Holeta
329 (Supplementary Table 1). Besides to the mortality loss, additional costs were incurred for
330 carcass disposal. For this a cost of USD 11.9 (ranging USD 5-20) per carcass was required, but
331 this was not included in the economic loss estimation due to the fact that expenditure for this
332 purpose is required in rare occasions as usually the carcasses are disposed or buried by the
333 villagers.

334 Almost all (n=240, 98.8%) of the herd owners knew the effect of LSD on milk production.

335 According to the information obtained from the herd owners, milk production reduced by 74%

336 for a period of about 2.5 months. The overall daily milk loss per affected milking cow was 4.0
337 litres. Breed wise, it was 1.7 litres in local and 7.2 litres in cross bred cows. Financially, the
338 overall median milk production loss per affected milking cow was USD 141, which was USD
339 63 in local Zebu cow and USD 216 in Holstein-Friesian local cross cow. The lowest and the
340 highest milk loss per milking cow reported were USD 27 in local cattle and USD 906 in cross
341 cow in Hulet Ejju Enessie and Debrelibanos districts, respectively (Supplementary Table 2).

342 Almost all (n=241, 99.2%) interviewees responded that LSD affects the traction power of
343 animals. The median number of effective working days lost per affected ox was 10 days (range
344 1–32 days) resulting in an overall median loss of USD 36 per affected ox (Supplementary Table
345 3).

346 More than 80% of LSD affected cattle got treated for secondary complications. The overall
347 median diagnosis and medication cost per affected animal was USD 5 (Supplementary Table
348 4). The cost of time lost for seeking treatment per affected animal could not be estimated as it
349 was common practice that a herd owner took several animals to a veterinary clinic at a time to
350 seek treatment and this complicated the estimation of per head cost.

351 The median total economic loss of an LSD outbreak at herd level was USD 1176. This figure
352 is based on 193 herds as in 7 herds the LSD positive animal(s) were not productive and were
353 not treated. A statistical analysis with Kruskal–Wallis equality-of-populations rank test
354 revealed significant differences ($P < 0.05$) in total economic loss among districts. The highest
355 and lowest economic losses were recorded in Selale dairy farm and in Sebeta Hawas district,
356 respectively (Table 3). At herd level, the largest component of the economic loss was due to
357 mortality (USD 1000) followed by milk loss (USD 120) and draft loss (USD 48). LSD control
358 costs were the least contributor to herd level losses (Table 3). The median economic loss by

359 farm type was USD 489 and USD 2735 in subsistence and commercial farms respectively per
360 affected herd ($P < 0.05$; Table 3).

361

362 **3.5. Partial budgeting**

363

364 The majority of the input parameters for the partial budget analysis were obtained from data
365 collected in this study; however, the remaining key parameters were taken from other sources
366 (Supplementary Table 5).

367

368 The results of the partial budget analysis indicated a positive net profit of USD 136 (USD 56
369 for subsistence farm herds and USD 283 for commercial herds) and marginal rate of return
370 (MRR) of 15.14 (11.29 in subsistence and 10.10 in commercial herd) per herd by vaccinating
371 the animals for LSD (Table 4). Thus, investment in vaccination to control LSD would reduce
372 the overall financial loss due to the disease by 11.6% per herd.

373

374 **4. Discussion**

375

376 The animal level morbidity (21.2%) and mortality (4.5%) recorded in this study is close to the
377 22.9% and 26% morbidity and 2.3 and 1.9 % mortality reported in central Ethiopia (Ayelet et
378 al., 2013) and Jordan (Abutarbush et al., 2015), respectively. However, it is much higher than
379 the 7.4% animal level morbidity reported in north-eastern Ethiopia (Hailu et al., 2014), 8.7% in
380 Greece (Tasioudi et al., 2016), 11% in Israel (Brenner et al., 2009), and 0.65% in Turkey (Ince
381 et al., 20016). Significantly different morbidity and mortality was observed between animal
382 categories with oxen showing the highest level of morbidity (26.9%). This might be attributable
383 to the stress and fatigue created during ploughing. The highest mortality was observed in
384 pregnant cows (6%) which might be related to physiological conditions of pregnancy that make

385 the animal more susceptible to disease (Kehrli et al., 2009). Generally, LSD morbidity varies
386 from as low as 5% to 100% (Woods, 1988) and mortality is generally low (usually less than
387 5%) but may sometimes reach 20% (Woods, 1988; OIE, 2010). Thus, the animal level as well
388 as the LSD morbidity and mortality levels per animal category reported in this study are within
389 the limits reported in previous works. Furthermore, a significantly different morbidity and
390 mortality was present between districts with highest morbidity in Jabitenan district (37.9%).
391 This might be related to the presence of many rivers, irrigated areas and higher temperature,
392 making the conditions in the district suitable for the replication of arthropods and propagation
393 of LSD (Davies, 1991).

394

395 Interview results indicated that LSD is a serious problem for cattle producers in the study area
396 as more than 94% of the interviewees considered LSD as a threat for their cattle. According to
397 the herd owners, the disease induces weight loss, reduced milk production, draft power loss,
398 mortality, market instability, infertility, abortion, culling, and hides quality losses. These
399 observations are in line with the impacts of LSD described in previous works (Woods, 1988;
400 Davies, 1991; Kumar, 2011; Abutarbush et al., 2015). The impacts of LSD in domestic as well
401 as international cattle market is complex and generally go beyond the immediate effects on
402 affected producers (Otte et al., 2004). In this study, more than 92% of the herd owners reported
403 that LSD outbreaks affects cattle marketing at domestic market in numerous ways including
404 lowering the demand and price of cattle during the outbreak period.

405

406 An overall median financial loss of USD 375 per dead animal recorded in this study is a big
407 loss for a farmer whose livelihood depends on crop-livestock or livestock production. The
408 mortality loss per head was highly variable between breeds, animal categories and districts. The

409 per head mortality loss of local Zebu cattle was low (USD 325) as compared to Holstein-
410 Friesian local cross cattle (USD 1250). The median loss per head categories varied from USD
411 150 for calves to USD 1181 for milking cows. These differences can be mainly attributed to the
412 high production potential of cross bred animals and animal's purpose.

413

414 The milk production loss of 74% for the period of about 2.5 months recorded in this study is
415 almost comparable to what has been reported in previous studies (Woods, 1988; Kumar, 2011;
416 Abutarbush et al., 2015). The median daily milk loss of 4.0 litres per affected animal is a big
417 loss for a nation that is an importer of dairy products (Negassa et al., 2011) by aggravating the
418 product scarcity. In most cases the affected milking cows did not produce milk for months. For
419 cows restarting milk production, it took months to regain their normal production level while
420 in some cases, especially for local cows, LSD caused complete drying off. LSD caused an
421 overall median loss of USD 141 per affected cow, being USD 216 in Holstein-Friesian local
422 cross and reduced to USD 63 in local Zebu. The loss indicated here is greater than the loss
423 induced by foot and mouth disease (FMD), which was USD 29 per affected cow in crop-
424 livestock production system and USD 26 in pastoral system (Jemberu et al., 2014).

425

426 In the current study the herd owners reported that LSD affected draft animals were not available
427 for field work for an average period of 59 days (ranging 7-180 days) which resulted in a median
428 loss of about 10 (ranging 1-32) effective working days. The lost working days, in turn, lead to
429 reduced crop production, either through reduced area that can be cultivated, or through lower
430 yields due to late planting (McDermott et al., 1999). The effective working days lost estimated
431 in this study is smaller than the 16 days reported by Gari et al. (2011). A farmer whose ox is
432 affected by LSD has to borrow, rent, or purchase replacement ox or request assistance from

433 relatives for cultivation. The translation of the effective working days lost into financial loss by
434 considering the daily renting price (cash basis) of an ox gave an overall median loss of USD 36
435 per affected ox, which is greater than the loss reported due to FMD (Jemberu et al., 2014). This
436 loss would have been larger if we had used 100/365 as adjustment factor (Yilma et al., 2011)
437 instead of 65/365.

438

439 The median total economic loss of USD 1176 per LSD affected herd recorded in this study is a
440 huge loss for a producer in a country with a gross domestic product per capita of USD 316
441 (Trading-Economics, 2015) and per capita income of USD 550 (World-Bank, 2015). Even the
442 median loss per affected herd in subsistence crop-livestock system (USD 489) is six times
443 higher than what Jemberu et al. (2014) reported for FMD, a disease which is on the top list for
444 its devastating economic impact worldwide (Knight-Jones and Rushton, 2013; Junker et al.,
445 2009). This supports the reports stating that LSD is economically more important than FMD in
446 some countries such as South Africa (Murphy et al., 1999). The reason for this is that mortality
447 in FMD is low and it occurs mainly in young age categories while LSD mortality is relatively
448 high compared to FMD and occurs in all age categories. Of all costs, 85% is due to mortality
449 although LSD induced mortality is low in cattle population as a whole (Woods, 1988). The
450 median total economic losses per affected herd of USD 2735 for the commercial farm were
451 significantly higher than the loss of USD 489 for the subsistence farm type. The higher loss in
452 affected commercial herds is the reflection of larger herd size, higher market value and
453 productivity potential of cross-bred animals.

454

455 As the study is undertaken retrospectively after certain months of LSD occurrence in the herd,
456 recall bias in relation to the duration of infection, the amount of milk produced during sickness,
457 working days lost and others might happened. Furthermore, the number of animals and herds

458 affected were reported based on the owners declaration and this might also lead to biased
459 number of cases. The recall bias and the diagnosis bias might have influenced the estimation of
460 the financial losses reported to some extent and can be taken as the weakness of the study.

461

462 Routine vaccination, stamping-out and movement restriction are important methods in LSD
463 control (Davies, 1991; Carn, 1993). Each control measure acts by reducing the transmission of
464 the agent in the population. However, Ethiopia is applying mainly vaccination to control the
465 disease. The economic benefit gained from controlling LSD with vaccination was measured by
466 taking the reduction in economic loss from the disease into account by comparison with the
467 level of expenditure for its vaccination. The result of the cost benefit analysis showed that a net
468 loss of about USD 136 per herd would be avoided and marginal rate of return (MMR) of 15.14
469 gained by using LSD vaccination. The estimates revealed that LSD control with vaccination is
470 economically beneficial by reducing the loss by 11.6% per herd. This result is less cost effective
471 as compared to the findings of Gari et al. (2011) who reported a positive net benefit of USD
472 680.71 and a MRR of 34 for LSD vaccine intervention. However, the existing LSD vaccine
473 provides incomplete protection against the disease (Ayelet et al., 2013). The vaccine is
474 efficacious in only 28% of the vaccinated animals (unpublished data) which was taken into
475 account in the partial budget analysis. More effective vaccines are needed to gain more from
476 the intervention. The partial budget analysis was restricted to the direct benefits arising from
477 the mortality and morbidity losses avoided and savings in the cost of LSD treatment. We did
478 not consider other control options like movement control due to their practical limitation in
479 Ethiopian situations.

480

481 It should be noted that only the noticeable direct costs and treatment costs associated with the
482 disease were considered in the study. The indirect impacts of the disease such as under

483 exploitation of the animal potential, animal welfare, international trade etc., were not
484 considered. Also the visible direct costs were not fully captured mainly due to information
485 paucity and difficulty to measure the loss in precise economic terms. Thus, the economic loss
486 estimation presented here should be seen as a conservative estimate of the loss due to LSD.

487

488 **Conclusion**

489

490 The LSD impact in terms of production losses and control costs was high, a median total
491 economic loss of USD 1176 (USD 2735 in commercial and USD 489 in subsistence herd) per
492 LSD affected herd. The losses were mainly from morbidity and mortality of cattle and were the
493 greatest in highly productive animals. The largest component of the economic losses was due
494 to mortality loss followed by milk loss and draft loss at both animal level and herd level losses.
495 LSD control costs were the least contributor for the herd level losses. Commercial farms which
496 hold more productive and more susceptible animals were more severely affected economically
497 than the subsistence crop related farms. Vaccination was found to be economically and
498 practically feasible choice to control LSD. The cost benefit analysis was restricted to the direct
499 benefits arising from the mortality and morbidity losses avoided and savings in the cost of LSD
500 treatment. Generally, vaccination is economically beneficial and should be encouraged.

501 **Conflicts of interest:** None

502

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663 Table 1. Lumpy skin disease morbidity and mortality in 243 cattle herds in 15 Ethiopian
 664 districts (2014/15).

District/Farm	No. of herds	No. of cattle	Herd size	No. of herds with sick cattle (%)	No. of cattle sick (%)	No. of herds with death (%)	No. of cattle died (%)
Ada'a	22	421	19.1	15 (68.2)	77 (18.3)	7 (31.8)	23 (5.5)
Sebeta Hawas	17	266	15.7	11 (64.7)	32 (12.0)	1 (5.9)	2 (0.8)
Ambo	15	345	23	11 (73.3)	94 (27.3)	3 (20.0)	26 (7.5)
Dendi	22	243	11.1	16 (72.7)	29 (11.9)	5 (22.7)	7 (2.9)
Debrelibanos	17	139	8.2	14 (82.4)	38 (27.3)	7 (41.2)	11 (7.9)
Hidabu Abote	23	157	6.8	17 (73.9)	30 (19.1)	6 (26.1)	6 (3.8)
Kuyu	18	205	11.4	18 (100.0)	42 (20.5)	3 (16.7)	3 (1.5)
Dejen	20	130	6.5	15 (75.0)	36 (27.7)	2 (10.0)	10 (7.7)
Gozamn	28	497	17.5	26 (92.9)	121 (24.4)	9 (32.1)	16 (3.2)
Hulet Ejjju Enessie	31	293	9.5	31 (100.0)	72 (24.6)	3 (9.7)	5 (1.7)
Jabitenan	25	256	10.2	21 (84.0)	97 (37.9)	9 (36.0)	22 (8.6)
Selam C.Vil.	1	46	46	1 (100.0)	9 (19.6)	1 (100.0)	2 (4.4)
Aser	1	48	48	1 (100.0)	5 (10.4)	0 (0.0)	0 (0.0)
Holeta	2	1053	526.5	2 (100.0)	171 (16.2)	2 (100.0)	25 (2.4)
Selale dairy	1	331	331	1 (100.0)	88 (26.6)	1 (100.0)	40 (12.1)
Overall	243	4430	18.2	200 (82.3)	941(21.2)	59 (24.3)	198 (4.5)

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666 Table 2. Lumpy skin disease morbidity, mortality and abortion per bovine category in 243
 667 cattle herds in Ethiopia (2014/15).

Category	Number (%)	Number infected (%)	Number died (%)	Number aborted (%)
Milking cow	1047 (23.6)	220 (21.0)	59 (5.6)	2 (NA)
Pregnant cow	364 (8.2)	69 (19.0)	22 (6.0)	12 (3.3)
Dry cow	233 (5.3)	35 (15.0)	5 (2.2)	
Heifer	1006 (22.7)	232 (23.1)	47 (4.7)	8 (NA)
Calf	813 (18.4)	137 (16.9)	37 (4.6)	
Bull	395 (8.9)	94 (23.8)	15 (3.8)	
Ox	572 (12.9)	154 (26.9)	13 (2.3)	
Overall	4430 (100)	941 (100)	198 (100)	

668 NA = Not applicable, since the denominator is specifically unknown

669 Table 3. Median total economic costs of lumpy skin disease per affected herd by district/farm
 670 and by farm type in USD in 193 cattle herds in Ethiopia (2014/15).

District/farm type	Farm type	Production loss			Control expenditures		Total economic cost
		Mortality losses Median	Milk losses Median	Draft losses Median	Medication expenditure Median	Extra labour cost Median	
Ada'a	subsistence	0	0	46.75	4	8	58.75
	commercial	1750	231	0	72.5	0	2053.5
Sebeta Hawas	subsistence	700	57.75	40.07	5	7	809.82
	commercial	0	0	0	11.5	0	11.5
Ambo	subsistence	150	28.95	66.78	5.88	7.5	259.11
	commercial	18275	1690.5	0	146.25	0	20111.75
Dendi	subsistence	400	82.5	16.03	4.75	0	503.28
	commercial	2200	240	0	88.25	0	2528.25
Debrelibanos	subsistence	400	315	33.72	2.5	1.5	752.72
	commercial	4000	1191.15	119.67	32	15	5357.82
Hidabu Abote	subsistence	150	22.5	46.75	2.5	2.25	224
	commercial	1500	421.88	37.40	8.5	0	1967.78
Kuyu	subsistence	350	60	38.73	1.95	13.63	464.31
	commercial	0	105	0	6.5	0	111.5
Dejen	subsistence	1422.5	84	32.05	1.5	0	1540.05
Gozamn	subsistence	212.5	89.44	80.14	2	3	387.08
	commercial	1611.36	171	53.42	10.75	0	1846.53
Hulet Ejju	subsistence	1000	87.26	41.40	3.15	3	1134.81
Enessie	commercial	0	81	0	14.65	2.5	98.15
Jabitenan	subsistence	425	184.5	105.18	2.53	3	720.21
	commercial	5400	540	0	4.5	0	5944.5
Selam C. Vil.	commercial	1700	1080	50.49	79.2	0	2909.69
Aser	commercial	0	516.38	0	125	0	641.38
Holeta	commercial	19350.48	2377.5	0	791.44	0	22519.42
Selale dairy	commercial	37850	5791.5	0	498.65	0	44140.15
Per farm type	subsistence	350	87.26	45.01	3	3.88	489.15
	commercial	2200	421.88	51.96	52.5	8.75	2735.09
Overall		1000	120	48.08	4.5	3.88	1176.46
% of total loss		85.00	10.20	4.09	0.38	0.33	100

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672 Table 4. The cost effectiveness of LSD vaccination per herd in 243 cattle herds in Ethiopia (2014/15).

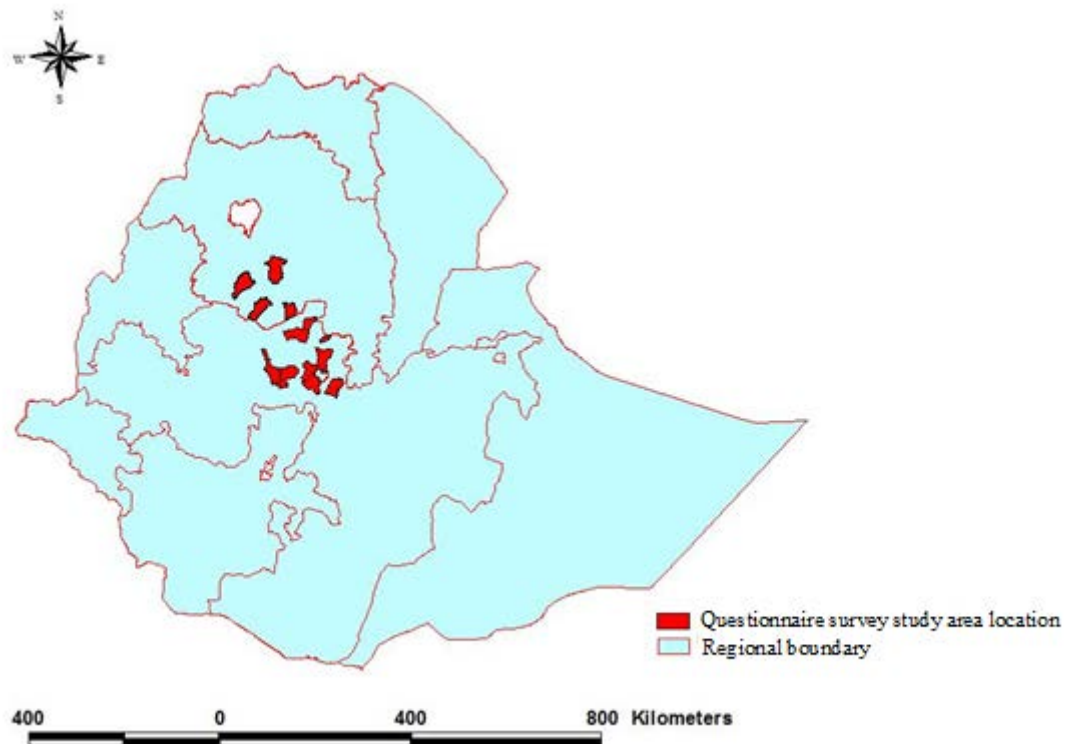
	Benefits per herd	Costs per herd	Net benefit	Marginal rate
	(USD)	(USD)	(USD)	of return (MRR)
(1) Additional returns	14.81* (10.96**, 47.94***)	(3) Returns foregone	0.00	
Milk loss saved	14.81 (10.96, 47.94)	None	0.00	136.25 (56.45, 282.80)
(2) Reduced costs	130.44 (50.49, 262.86)	(4) Extra costs	9.00 (5, 28)	
Replacement animal	123.46 (43.97, 250.00)	Vaccination cost	9.00 (5, 28)	
Draft power	5.94 (5.65, 5.90)			
Treatment cost saved	0.56 (0.38, 5.97)			
Labour cost for seeking treatment	0.48 (0.49, 0.99)			

673 *Over all

674 **Subsistence farm type

675 ***commercial farm type

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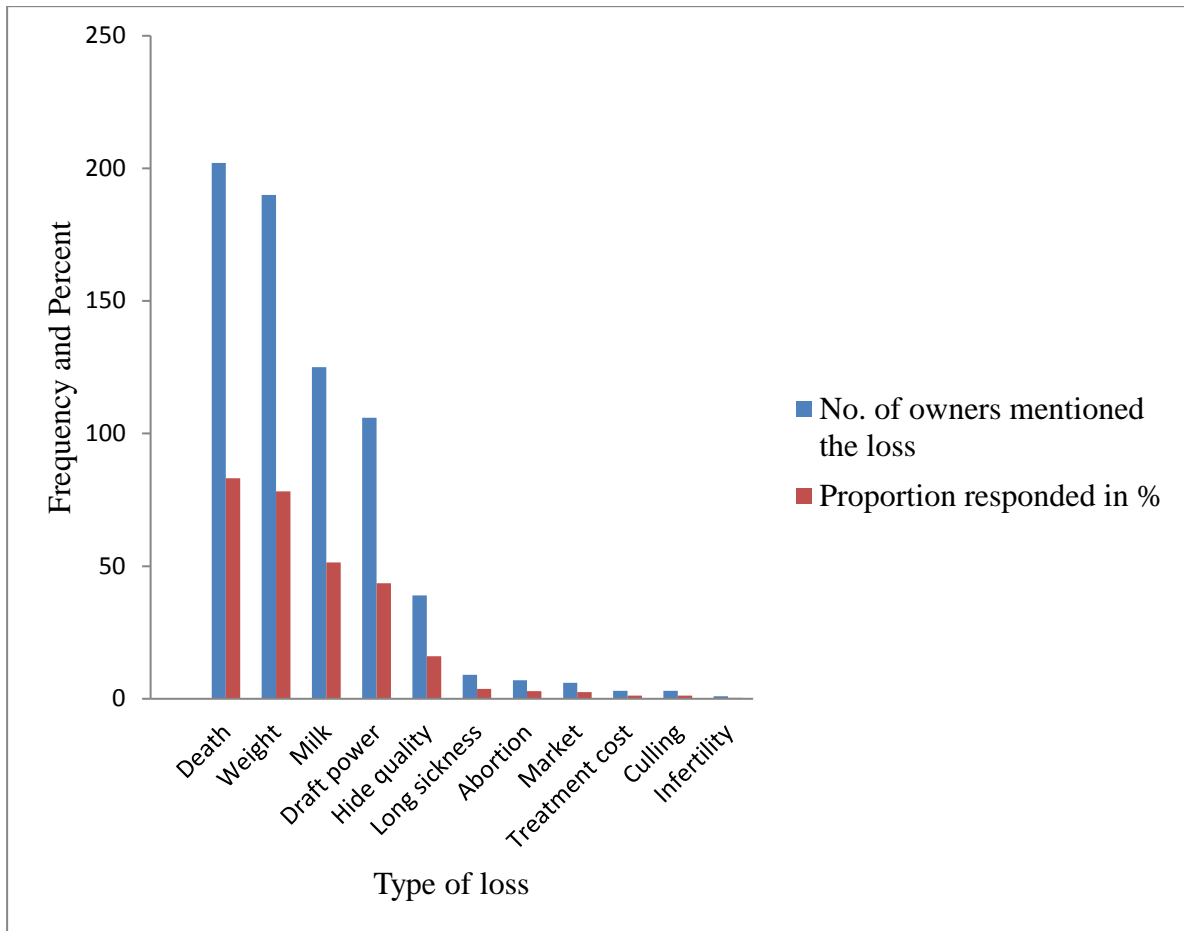


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Figure 1. Map of Ethiopia showing the area and the location of 243 cattle farms included in the study of the economic impact of lumpy skin disease (2014/15).

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699 Figure 2. Major losses induced by lumpy skin disease as listed by cattle herd owners (n = 243) in
700 Ethiopia (2014/15).

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713 Supplementary Table 1. Lumpy skin disease financial loss (USD) per head of cattle that died by breed, cattle category and district or farm in 193
714 herds in Ethiopia (2014/15).

District/Farm	Breed	Category							Median loss per animal
		Milking cow	Pregnant cow	Dry cow	Heifer	Calf	Bull	Ox	
Ada'a	cross	1481	2000	0	1200	750	0	0	1341
Sebeta Hawas	local	200	0	0	0	0	0	500	350
Ambo	local	0	0	0	0	0	150	0	150
	cross	1700	0	0	1658	133	1000	0	1329
Dendi	local	0	175	0	0	0	0	575	375
	cross	1500	0	0	0	150	0	1250	1250
Debrelibanos	local	200	0	0	0	0	0	400	300
	cross	2042	1667	0	0	0	0	0	1855
Hidabu Abote	local	150	0	0	0	0	100	0	125
	cross	2000	1125	0	0	0	0	1700	1700
Kuyu	local	350	0	0	0	0	0	400	375
Dejen	local	400	400	150	175	60	0	0	175
Gozamn	local	550	250	0	299	57	250	0	250
	cross	1181	0	0	0	200	0	0	691
Hulet Ejju Enessie	local	500	0	0	50	0	0	375	375
	cross	0	0	0	1000	0	0	0	1000
Jabitenan	local	400	350	350	0	0	225	438	350
	cross	1250	0	0	300	50	0	0	300
Selam C.Vil.	cross	0	0	0	850	0	0	0	850
Holeta	cross	1931	2250	2250	1594	233	2000	0	1966
Selale dairy	cross	1600	1750	0	900	400	0	0	1250
Median cost by breed	local	375	300	250	175	58.5	187.5	419	325
	cross	1600	1750	2250	1000	200	1500	1475	1250
Overall cost per animal		1181	1125	350	875	150	238	469	375

715 Supplementary Table 2. Economic losses (USD) due to milk loss per LSD affected milking cow by breed and district in 193 herds in Ethiopia
 716 (2014/15).

District/Farm	Bread	Daily milk yield (litre) before infection	Daily milk loss due to LSD (litre)	Days of LSD illness	Total quantity milk lost (litre)	Average milk price per litre	Economic losses per affected cow in USD
		Median (range)	Median (range)	Median (range)	Median (range)	Median (range)	Median (range)
Ada'a	cross	7.59 (6-18)	4.85 (3-18)	83.58 (30-120)	405.38 (90-900)	0.53 (0.5-0.55)	214.85 (45-472.5)
Sebeta Hawas	local	1.33 (1-2)	1.08 (0.5-2)	85 (30-120)	97.5 (15-180)	0.55	53.63 (8.25-99)
Ambo	local	2.08 (1-3)	1.24 (0.7-2)	57 (30-120)	55.8 (30-84)	0.5	27.9 (15-42)
	cross	13.10 (5-16)	9.76 (3.5-12)	30	292.89 (105-360)	0.61 (0.2-0.85)	178.66 (21-234)
Dendi	local	2	1	90	90	0.5	45
	cross	5	4	60	240	0.5	120
Debrelibanos	local	4	2	90	180	0.4	72
	cross	22.89 (9-25)	19.39 (5-25)	106.15 (60-150)	2058.33 (360-2647)	0.44 (0.4-0.45)	905.67 (153-1191.15)
Hidabu Abote	local	2 (2-2.5)	1.6 (1-2.5)	79.5 (7.5-180)	144 (15-375)	0.75	108 (11.25-281.25)
	cross	25	25	22.5	562.5	0.75	421.88
Kuyu	local	2.68 (1-5)	1.89 (0.5-3)	78.41 (7.5-120)	156.14 (7.5-300)	0.5	78.07 (3.75-150)
	cross	12.5 (10-15)	8.5 (7-10)	90 (30-150)	855 (210-1500)	0.5	427.5 (105-750)
Dejen	local	1.38 (1.3-1.5)	1.24 (1-1.5)	97.12 (90-120)	120.43 (117-135)	0.35	42.15 (40.95-47.25)
Gozamn	local	2.08 (1.5-3)	1.90 (1-3)	80.49 (30-150)	152.94	0.6	91.76 (30.6-180)
	cross	8 (7-10)	5.63 (4-10)	46.63 (30-60)	262.5 (240-300)	0.6	157.5 (144-180)
Hulet Ejju	local	2.25 (2-3)	2	30	60	0.45	27
Enessie	cross	5.38 (4-7)	4.63 (3-7)	43.93 (7.5-90)	188.57(45-300)	0.42 (0.38-0.45)	79.20 (40.5-118.61)
Jabitenan	local	2 (1.5-3)	1.86 (1.25-3)	126.01 (60-240)	234.38 (112.5 -480)	0.6	140.63 (67.5-288)
	cross	6.27 (5-8)	3.63 (3-6)	99.17 (60-120)	360	0.64 (0.6-0.75)	230.4 (216-270)
Selam C.Vil.	cross	10	10	60	600	0.9	540
Aser	cross	7	4.5	90	405	0.43	172.13
Holeta	cross	13.82 (8-16)	7.18 (5-8)	52.80 (30-150)	379.18 (240-750)	0.57 (0.5-0.63)	216.13 (120-472.5)
Selale dairy	cross	12	9	90	810	0.55	445.5
Per breed	local	2.04 (1-5)	1.73 (0.5-3)	82.75 (7.5-240)	132.22 (7.5-480)	0.50 (0.35-0.75)	62.82 (3.75-288)
	cross	10.00 (4-25)	7.18 (3-25)	60.00 (7.5-150)	405 (45-2647)	0.55 (0.2-0.9)	216.13 (18-1191.15)
Overall		5.38 (1-25)	4.00 (0.5-25)	80.49 (7.5-240)	240.00 (7.5-2647)	0.53 (0.2-0.9)	140.63 (3.75-1191.15)

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Supplementary Table 3. Financial loss from draft power reduction per LSD affected ox by district in 193 herds in Ethiopia (2014/15).

District/Farm	Duration of LSD oxen stayed out of work in days	Effective working days lost	Renting price (USD) for an ox for a day	Financial loss (USD) from effective working days lost per affected ox
	Median (range)	Median (range)	Median (range)	Median (range)
Ada'a	36 (30-60)	6.4 (5-11)	5.8 (5-7.5)	37.4 (26.7-62.3)
Sebeta Hawas	65 (30-120)	11.6 (5-21)	2.5	29 (13.4-53.4)
Ambo	55 (30-90)	9.8 (5-16)	5	49 (26.7-80.1)
Dendi	40 (15-90)	7.1 (3-16)	3	21.3 (8.0-48.1)
Debrelibanos	63 (30-120)	11.2 (5-21)	4.5 (3.5-5.6)	50.7 (21.4-119.7)
Hidabu Abote	56 (30-90)	9.9 (5-16)	3.5	34.7 (18.7-56.1)
Kuyu	42 (7-120)	7.5 (1-21)	3.3 (2.5-5)	24.8 (3.3-71.9)
Dejen	55 (7-90)	9.8 (1-16)	3	29.5 (4-5.1)
Gozamn	61 (30-90)	10.9 (5-16)	5	54.4 (26.7-80.1)
Hulet Ejju Enessie	74 (15-180)	13.1 (3-32)	2.5 (1.8-3.8)	32.2 (8.0-80.1)
Jabitenan	70 (15-120)	12.5 (3-21)	5.7 (5-7.5)	71.6 (15.0-160.3)
Selam C.Vil.	75	13.4	3.8	50.5
Overall	58.5 (7-180)	10.4 (1-32)	3.65 (1.8-7.5)	36.05 (4-160.3)

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726 Supplementary Table 4. Costs of treatment for LSD per affected animal by district in 193 herds in Ethiopia (2014/15).

District/Farm	No. of cattle affected	No. of cattle treated (%)	Medication cost per affected animal median (range) in USD
Ada'a	77	74 (96.1)	11.0 (2-50)
Sebeta Hawas	32	31 (96.9)	3.7 (1-10.5)
Ambo	94	83 (88.3)	4.2 (1-12.5)
Dendi	29	26 (89.7)	9.6 (1.3-50)
Debrelibanos	38	35 (92.1)	16.4 (1-34)
Hidabu Abote	30	28 (93.3)	5.4 (0.4-25)
Kuyu	42	36 (85.7)	1.6 (0.5-5.3)
Dejen	36	15(41.7)	1.1 (0.5-2.5)
Gozamn	121	42 (34.7)	2.4 (0.5-10)
Hulet Ejju Enessie	72	62 (86.1)	2.7 (0.5-15)
Jabitenan	97	56 (57.7)	3.4 (0.7-7.5)
Selam C. Vil.	9	9 (100)	8.8
Aser	5	5 (100)	25
Holeta	171	171 (100)	9.3 (3-15)
Selale dairy	88	88 (100)	5.7
Overall	941	761 (80.9)	5.4 (0.4-50)

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731 Supplementary Table 5. Partial budget input values and their sources.

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Inputs	Values	Data source
Total number of animals involved	4430	The current study
Number of herds	243	The current study
LSD prevalence at herd level per outbreak	44%	Gari et al., 2012; Hailu et al., 2014
Average vaccine cost per herd	9 USD	The current study
KS1 O-180 LSD vaccine efficacy	28%	LSD vaccine impact study (unpublished)
Average over all LSD loss per herd	1176.46 USD	The current study
Average milk loss per herd	120 USD	The current study
Average mortality loss per herd	1000 USD	The current study
Average draft loss per herd	48.08 USD	The current study
Average treatment cost per herd	4.5 USD	The current study
Average labour cost for seeking treatment per herd	3.88 USD	The current study

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