

# *A review of the financial impact of production diseases in poultry production systems*

Article

Accepted Version

Jones, P. J., Niemi, J., Christensen, J.-P., Tranter, R. B. and Bennett, R. M. (2019) A review of the financial impact of production diseases in poultry production systems. *Animal Production Science*, 59 (9). pp. 1585-1597. ISSN 1836-0939 doi: <https://doi.org/10.1071/AN18281> Available at <https://centaur.reading.ac.uk/78999/>

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To link to this article DOI: <http://dx.doi.org/10.1071/AN18281>

Publisher: CSIRO Publishing

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1 **A review of the financial impact of production diseases in poultry production**  
2 **systems**

3

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5

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13 **The financial impact of production diseases in poultry production systems**

14

15 **Abstract**

16 Whilst the academic literature widely asserts that production diseases have a significant  
17 financial impact on poultry production, these claims are rarely supported by empirical  
18 evidence. There is a risk, therefore, that the information needs of poultry producers  
19 regarding the costs associated with particular diseases are not being adequately met.

20

21 A systematic literature review of poultry production diseases was undertaken, first to  
22 scope the availability of studies that estimate the financial impacts of production diseases  
23 on poultry systems and second, based on these studies, estimates were generated of  
24 the magnitude of these impacts. Nine production diseases, selected by a panel of  
25 stakeholders as being economically important in the EU, were examined.

26

27 The review found that the poultry disease literature has primarily an epidemiological  
28 focus, with very few publications providing estimates of the financial impacts of  
29 diseases. However, some publications quantified the physical impacts of production  
30 diseases and control interventions, e.g. using measures such as output volumes,  
31 mortality rates, bacteria counts, etc. Using these data in standard financial models,  
32 partial financial analyses were possible for some poultry production diseases.

33

34 Coccidiosis and clostridiosis were found to be the most common production diseases in  
35 broiler flocks, with salpingoperitonitis the most common in layers. While the financial  
36 impact of untreated diseases varied, most uncontrolled diseases were estimated to make  
37 flocks loss-making. However, in all cases, interventions were available that significantly  
38 reduced these losses. The review reinforces the concern that the available academic

39 literature is not providing sufficient information for poultry producers to decide on  
40 financially-optimal disease prevention and treatment measures.

41

42 Keywords: Poultry diseases; financial impacts; systematic literature review.

43

## 44 **1. Introduction**

45 There have been major changes in food consumption patterns in Western countries in  
46 the last 20 years, driven by increasing disposable incomes, changing food tastes and  
47 evolving health concerns (Traill, et al., 2014; European Commission, 2015). While egg  
48 consumption has remained fairly static (FAO, 2016a), there has been substantial  
49 growth in demand for poultry meat. Poultry meat is now the largest single source of  
50 meat-based protein in the diets of some countries, for example constituting 31% of all  
51 meat consumption in the UK and 43% in the USA in 2011 (FAO, 2016b). The chicken  
52 meat sector has responded to this increased demand by intensification of broiler  
53 production systems, involving more vertical integration, increases in production scale,  
54 use of new technologies and higher rates of input use, including higher stocking rates  
55 (FAO, 2016c).

56

57 A negative side of increasing production intensity has been a rise in the prevalence of  
58 so-called 'production diseases' in poultry systems. These usually originate from a  
59 complex interaction of pathogens, animal genetics and environment, including  
60 deficiencies in housing, nutrition and management. Production diseases constitute  
61 various infections, but also physical conditions, such as ascites, caused by genetic  
62 developments designed to increase physical performance, and physical damage  
63 caused by objects, or chemical irritants, in the rearing environment. What these  
64 diseases have in common is that, while they may be endemic, even in the wild, they  
65 can become increasingly problematic with the intensity of the production system and  
66 failures in management (Liverani, et al, 2013).

67

68 Production diseases compromise animal health and welfare and generate production  
 69 inefficiencies, which can reduce profitability, and increase both environmental footprint  
 70 and levels of antibiotic use. Bennett (2012) has provided a conceptual understanding of  
 71 the way in which production diseases impact the economics of poultry production  
 72 systems, i.e. through:

73 1. Economic impacts internal to the farm:

- 74 • a loss of capital (i.e. animal mortality);
- 75 • reduction in the level of marketable outputs;
- 76 • reduction in (perceived or actual) output quality; and
- 77 • waste of, or higher level of use of, inputs.

78 2. Economic impacts both internal, and external, to the farm:

- 79 • resource costs associated with disease detection, diagnosis, prevention  
 80 and control;
- 81 • negative animal welfare impacts (i.e. animal suffering) associated with  
 82 disease;
- 83 • international trade restrictions due to disease and its control; and
- 84 • human health costs associated with diseases or disease control.

85 3. Economic impacts external to the farm such as effects on rural economies  
 86 and tourism.

87 With producer margins being squeezed by increasing costs and limited opportunity to  
 88 transmit extra costs to consumers due to lack of market power, plus fierce competition  
 89 from international suppliers, the response of the poultry industry has been to drive  
 90 down those production costs that can be controlled, including disease costs (Narro et  
 91 al., 2008). To allow the industry to prioritise the most financially beneficial disease  
 92 prevention and control measures, robust empirical data are required on: the risks  
 93 posed by various production diseases; the financial impacts of different diseases; and  
 94 the efficacy of, and financial benefits from, different disease control measures.

95 It might be assumed that data to permit financially rational disease management  
96 decisions are available in the scientific literature. Much literature on poultry diseases  
97 exists, but data for individual diseases is seldom extensive and often lacking a financial  
98 dimension. Ubiquitous claims in research papers that particular poultry diseases lead to  
99 'significant' financial impacts are seldom supported by empirical evidence.  
100 Consequently, data on the scale of financial losses associated with particular  
101 production diseases and the financial case for using control measures, are often  
102 lacking. Therefore, unless more informative industry data is available, there may be  
103 many poultry producers who are not implementing financially optimal disease  
104 prevention and treatment practices through lack of appropriate information. For  
105 example, in Denmark, vaccines are widely used to control salpingoperitonitis infections  
106 in layers without robust evidence of their efficacy (Christensen, 2016).

107

108 The study reported here undertook a systematic literature review to: determine the  
109 availability of data on the financial impacts of poultry production diseases; and a  
110 synthesis of this data to estimate the financial impacts of a number of production  
111 diseases and, where possible, the financial benefits of selected measures to control  
112 them. The study also had three sub-objectives. First, to show the relative risks  
113 presented by different production diseases, from data on their incidence. Second, to  
114 map the nature and distribution of disease costs, by showing where, in the production  
115 process, losses are occurring. Finally, to identify gaps in the literature on the financial  
116 impacts of poultry production diseases, to help guide future research.

117

## 118 **2. Method**

### 119 2.1 The choice of production diseases

120 To reduce the scope of the study, the most important production diseases were  
121 selected for analysis by a panel of 29 European animal scientists collaborating on the  
122 EU-funded PROHEALTH project. These came predominantly from veterinary medicine

123 or animal science backgrounds. Nine production diseases were identified as the most  
124 important by virtue of rates of incidence, revenue losses, or control problems, i.e.  
125 respiratory diseases (Ascites; Infectious bronchitis), enteric (Coccidiosis; Clostridiosis),  
126 locomotory (Tibial dischondroplasia; Foot pad dermatitis; Keel bone damage),  
127 reproductive (Salpingoperitonitis) and other disorders (Injurious feather pecking).

128

129 2.2 The systematic literature review -

130 2.2.1 Introduction

131 A systematic review was undertaken to identify studies reporting financial or  
132 productivity impacts of these nine production diseases/conditions. As a first step, a  
133 Web of Science search was undertaken using a tailored search term with keywords to  
134 capture:

- 135 (i) economic (or financial) studies;
- 136 (ii) poultry as study subjects;
- 137 (iii) specific production diseases;
- 138 (iv) exclusion of topics appearing in searches but not relevant to the review;
- 139 (v) exclusions to remove studies based on non-intensive production systems;
- 140 and
- 141 (vi) exclusions by text language, research domain, document type and  
142 publication prior to 1995.

143

144 Abstracts found through the search were examined to exclude: duplications, those with  
145 no physical performance measures or financial data, or were based on modelling  
146 studies or reviews. This yielded 64 original studies. To supplement this list, additional  
147 publications were found by: reviewing the reference lists of publications already  
148 identified; a secondary web search using Google Scholar; website searches of  
149 organisations with an interest in poultry health, such as the FAO; and reference lists  
150 from recent poultry health research projects. This secondary search yielded a further



151 65 studies, making 129 in total. These publications encompassed peer-reviewed  
152 journals and conference proceedings, as well as 'grey' literature. Few publications  
153 assessed financial impacts, with most falling into the three categories shown in  
154 Sections 2.2.2 through 2.2.4.

155

#### 156 2.2.2 Surveys of disease incidence and severity

157 A few studies surveyed the incidence of production diseases. Incidence, which is the  
158 number of (new) disease incidents (or outbreaks) over a specified period of time, can  
159 be viewed as an indicator of risk. Incidence might be reported for a particular flock, or  
160 as an average across flocks (e.g. average annual incidence). In the studies reviewed,  
161 flocks were generally only deemed to have experienced a disease outbreak when  
162 symptoms met a given severity criterion i.e. they either exhibited clinical symptoms, or  
163 where subclinical disease resulted in financial impacts. As we were only interested in  
164 disease episodes that cause financial losses, the analysis of incidence here was limited  
165 to those surveys where this criterion was explicitly used.

166

#### 167 2.2.3 Studies exploring the impact of uncontrolled diseases on production

168 In this type of experimental study, birds could be deliberately exposed to a disease in  
169 either a controlled, or uncontrolled way. In the latter case, ambient levels of disease  
170 prevailed and therefore disease prevalence or severity was sometimes not elevated at  
171 all. Some of these studies employed a protected (or disease free) control group, while  
172 others did not.

173

#### 174 2.2.4 Studies exploring the efficacy of measures to control production diseases

175 Intervention studies were the most common type of study in the reviewed literature.  
176 These involved trials of wide-ranging scale, from a few dozen birds to tens of  
177 thousands of birds across many poultry businesses. These studies had a variety of  
178 formats, depending on the:

- 179 • presence of a control group;
- 180 • presence of replicates;
- 181 • the number of interventions tested; and
- 182 • the level of control of environmental (rearing) conditions.

183 Studies with no control groups were excluded from the assessment. Where there were  
184 replicates of trials, averages over the replicates were calculated. When multiple,  
185 similar, interventions were used, for example several types of vaccine, an average over  
186 these interventions was taken. When multiple interventions were very different, for  
187 example contrasting a vaccine against a dietary nutrient, they were treated as separate  
188 interventions. When studies manipulated environmental conditions, in addition to target  
189 interventions, such as wetness of litter, then an average for the intervention over the  
190 multiple environmental conditions was estimated.

191

### 192 2.3 The standard financial models

193 Because financial data were rarely provided, the costs of diseases were estimated from  
194 data on changes to productive parameters (i.e. FCR, mortality and output volumes),  
195 using spreadsheet-based standard financial models for poultry enterprises. These were  
196 based on published data for market returns and production costs for EU 'average'  
197 conventional broiler and layer enterprises for 2013 (Appendix A).

198

### 199 2.5 Weighting of data

200 Recognizing that greater confidence can be placed on trials conducted on larger  
201 populations of birds, a weighting system was used in estimating averages across  
202 replicate trials. As studies often didn't state the exact number of birds in a trial, the  
203 value of the weights increases with size ranges using a geometric progression with a  
204 common ratio of two. By this means, data from experiments with up to 1,000 birds were

205 given a weight of one, 1,001-10,000 birds had a weight of two, 10,001-25,000 birds a  
 206 weight of four, and more than 25,000 birds a weight of eight.

207

208 **3. Results**

209 3.1 The number of relevant studies identified from the systematic literature review  
 210 Table 1 lists the number of relevant studies identified for the nine study production  
 211 diseases, classified by the type of intervention used. Studies reporting no interventions  
 212 in Table 1 either examined the impacts of the uncontrolled disease, or were surveys of  
 213 disease incidence.

214

215 Table 1. The number of publications found reporting the impacts of poultry production  
 216 diseases and/or impacts of interventions to control them.

	Type of prevention/control intervention					Total studies <sup>2</sup>
	None	Anti-microbials <sup>1</sup>	Vaccination	Housing	Other <sup>3</sup>	
<b>Respiratory diseases</b>						
Pulmonary hypertension syndrome (ascites)	1	-	-	-	9	10
Infectious bronchitis (IB)	14	-	5	-	-	19
<b>Enteric diseases</b>						
Coccidiosis	1	7	8	-	-	16
Clostridiosis ( <i>C. perfringens</i> , <i>C. septicum</i> )	1	10	3	-	1	15
<b>Locomotory diseases</b>						
Tibial dischondroplasia	3	-	-	4	7	14
Foot pad dermatitis	3	-	-	-	12	15
Keel bone damage	10	-	-	3	5	18
<b>Reproductive disorder</b>						
Salpingoperitonitis syndrome, (colibacillosis)	9	1	-	-	-	10
<b>Other disorders</b>						

Injurious feather pecking	7	-	-	4	1	12
<b>Total</b>	<b>45</b>	<b>18</b>	<b>16</b>	<b>11</b>	<b>35</b>	<b>129</b>

217

218 <sup>1</sup> For either prophylactic or curative treatment.

219 <sup>2</sup> Some studies had multiple interventions, so the total number of studies may not equal the number of  
 220 interventions.

221 <sup>3</sup> 'Other' usually involves changing parameters in the rearing environment, such as temperature, or  
 222 humidity.

223

224 **3.2 Disease incidence**

225 This data came from studies ranging from large-scale surveys to small-scale laboratory  
 226 trials. Because of the dominance of small-scale studies in the literature, the estimates  
 227 in Table 2 should be treated with caution. Coccidiosis and clostridiosis would seem to  
 228 be present in 90 - 100% of poultry flocks (Williams, 1998; Miller et al., 2010). There is a  
 229 far greater incidence of the subclinical forms of these diseases, but these are only  
 230 included in the incidence estimates where they cause productivity losses. The lowest  
 231 reported disease incidence (at 5%) was reported for ascites, but most production  
 232 diseases appear to have a reported incidence of over 30% of flocks.

233

234 Table 2. The incidence of production diseases and sources of this data

	<b>Incidence (% of flocks)</b>	<b>Sources of data</b>
Ascites	5	Hassanzadeh et al. (2005); Hassanzadeh et al. (2008); Maxwell and Robertson (1998)
Coccidiosis	90-100	Williams (1998, 1999) <sup>1</sup>
Clostridiosis	90-100	Miller et al. (2010) <sup>1</sup>
Footpad dermatitis	41.1	Allain et al. (2009); de Jong et al. (2014); Pagazaurtundua and Warriss (2006)
Tibial dyschondroplasia	35.6	Edwards (1990); Edwards and Sorensen (1987); Leeson et al. (1995); Lilburn and Lauterio (1989); Lui et al. (1992); Petek et al. (2005); Trablante et al. (2003); Yalcin et al. (2007)
Salpingoperitonitis	49.5	Fossum et al. (2009) <sup>2</sup>

---

Injurious feather pecking	35	Lambton et al. (2013)
---------------------------	----	-----------------------

---

235

236 <sup>1</sup> Exact estimates of incidence for coccidiosis and clostridiosis are unavailable but sources indicate these  
 237 infections are close to ubiquitous.

238 <sup>2</sup> Estimate of incidence of colibacillosis i.e. e-coli infections.

239

240 **3.3 Mortality rates**

241 Financial impacts resulting from elevated bird mortality comes from: loss of sales;  
 242 expenditure on housing, feed and health care for birds that subsequently die; and the  
 243 cost of disposal of carcasses. Once a disease is present in a flock, mortality rate is  
 244 determined both by the severity of the disease challenge, and other factors such as the  
 245 type of bird, breed, age at end of productive life-cycle and housing and production  
 246 system, e.g. free-range. In an average commercial setting, with 'standard' disease  
 247 management practice, cumulative mortality in layers, from all causes, ranges from 6 -  
 248 11%, with an average of 7.7% (van Horne, 2014; Weber et al., 2003; Merle et al.,  
 249 undated; Vitse et al., 2005; and Bell, 2012). Cumulative mortality in broilers is  
 250 somewhat lower, ranging between 4 - 6% with an average of 4.7% (Havenstein et al.,  
 251 2003; ACP, 2006; Gocsik et al., 2014; and van Horne and Bont, 2014). Table 3 shows  
 252 the change in rate of mortality resulting from uncontrolled production diseases that are  
 253 classified in studies as severe, i.e. where they have measureable financial impact. Also  
 254 shown are the range of mortality values (in parentheses) found in the literature, where  
 255 more than one usable estimate is available.

256

257 Table 3. Impact of severe uncontrolled production disease on flock mortality rates

---

	<b>Mortality change (%) (range %)</b>	<b>Sources of data</b>
<b>Broilers</b>		

---

Tibial dischondroplasia	+1	Morris (1993)
Acites	+36.3 (15.2 – 68)	Acar et al. (1995); Arce-Menocal et al. (2009); Camacho-Fernandez et al. (2002); Izadinia et al. (2010)
Clostridiosis	+336 (45.4 – 1500)	Lovland and Kaldhusdal (2001); Miller et al. (2010); Tactacan et al. (2013); Zhang et al. (2010)
Footpad dermatitis	+12.7 (-1 – 87.5)	Bilgili et al. (2009); Cengiz et al. (2011); de Jong et al. (2014); Ekstrand et al. (1997); Martland (1985); Mayne et al. (2007); Taira et al. (2013); Wang et al. (2010)
<b>Laying flocks</b>		
Keel bone damage	+71.5 (65.1 - 77.8)	Nasr et al. (2013); Petrik et al. (2015);
Salpingoperitonitis	+57	Jordan et al. (2005); Medina (2008), Thøfner et al. (2015)

258

259 Note: Change in mortality is the change to the base, or 'normal', mortality rate resulting from uncontrolled  
260 disease.

261 Note: Coccidiosis, Salpingoperitonitis and Injurious pecking are omitted from the table due to lack of data.

262

263 Mortality impacts vary considerably between, and within, production diseases, and  
264 disease-driven mortality rates much higher than those in Table 3 have been observed  
265 in commercial practice. However, the headline observation is the paucity of studies on  
266 the mortality impacts of specific diseases in the literature. This problem is compounded  
267 by methodological weakness that affect the available data, i.e. some studies either  
268 have no experimental control, or they have a disease-challenged control, rather than a  
269 true (disease free) control. The lack of robustness in the available data is exemplified  
270 by the mortality impacts estimated for keel bone damage, which are considerably  
271 higher in the studies cited than have been observed by the authors in commercial  
272 farming practice.

273

### 274 3.4 Loss of physical outputs

275 Production diseases can lead to financial losses through reductions in the physical  
276 output from flocks (see Table 4). In broilers this can take the form of reduced terminal

277 weight (or rather, a longer growing period to reach the desired weight, requiring more  
 278 feeding and less efficient utilization of resources). In layers this would mean reduced  
 279 egg numbers, but also impairment of output quality. Loss of quality in broilers means  
 280 broken bones, damaged or discoloured muscle, or skin burns, leading to carcass  
 281 downgrades, or trimmings. In layers, this is experienced as smaller or mishapen eggs,  
 282 thin shells and colour change, resulting in downgrades or rejections.

283

284 Reviewed studies report reductions in terminal body weight in broilers range from zero  
 285 for ascites (although Swayne, 2013, suggests some weight loss is possible), to a high  
 286 of 17.7% for coccidiosis. There is a relatively high reported loss of body weight from  
 287 tibial dyschondroplasia. This effect is likely due to the fact that the condition can cause  
 288 considerable pain, and birds in pain move less and consume less food.

289

290 Table 4. Impact of severe and uncontrolled production disease on physical outputs

<b>Broilers</b>	<b>Live-weight (% change) (range)</b>	<b>Carcass downgrades (% change) (range)</b>	<b>Sources of data</b>
Tibial dischondroplasia	-10	<1	Burton et al. (1981); Edwards and Sorensen (1987); Morris (1993)
Acites	0	N.A.	Acar et al. (1995); Arce et al. (1992); Arce-Menocal et al. (2009); Camacho-Fernandez et al. (2002); Izadina et al. (2010); Kalmar et al. (2013); Khajali et al. (2007); Maxwell and Morris (1992); Rincon (2000); Robertson (1998)
Clostridiosis	-1.24	N.A.	Lovland and Kaldhusdal (2001)
Coccidiosis	-17.7 (-17.3 - -18.1)	N.A.	Abdelrahman et al. (2014); Li et al. (2005)
Footpad dermatitis	-7.3 (0.8 – -14.6)	<1	Cengiz et al. (2011); de Jong et al. (2014); Martland (1985)
<b>Laying Flocks</b>	<b>Egg numbers</b>	<b>Egg weight</b>	<b>Egg quality</b>

Keel bone damage	-3.5 (-1.2 - -5.7)	-3.2		Nasr et al. (2012); Nasr et al (2013)
Infectious bronchitis	-32.9 (-3 - -50)	-8.7 (-7.3 - -11.36)	N.A.	Bisgaard M. (1976); Muneer et al. (1986); Muneer et al. (1987); Ignjatovic and Sapats (2000); Muneer et al. (2000)
Salpingoperitonitis	N.A.	N.A.	<1	Bisgaard and Dam (1981)
Injurious feather pecking	-5.1 (-2.6 - -7.5)	0	0	Glatz (2001); Hagger et al. (1989); Peguri and Coon (1993); Leeson and Morrison (1978)

291 Note: N.A. means that suitable data are not available.

292

293 Disease impacts on laying flocks (number of eggs) range between 3.5% and 32.9%,  
 294 although greater losses may be observed in commercial practice. The impact of keel  
 295 bone damage and injurious pecking on egg production should be low, unless birds  
 296 contract secondary infections. In the case of feather pecking, feather loss means  
 297 elevated loss of body heat, so that birds must eat more food to regulate body  
 298 temperature and continue normal egg laying. While the impacts of infectious bronchitis  
 299 can be severe, these effects last for only a small part of the productive life of a hen,  
 300 typically 1-8 weeks. If a disease does not kill a hen, it will recover, and so, typically, will  
 301 the laying percentage, although productivity may not always recover to pre-disease  
 302 levels (Ignjatovic and Sapats, 2000; and Bisgaard, 1976). Based on available data,  
 303 infectious bronchitis has the most significant impact on egg downgrades.

304

### 305 3.5 Impaired feed conversion ratio

306 All production diseases, if severe enough, impair birds' FCR i.e. they lower feed  
 307 conversion efficiency. Where the bird cannot compensate by eating more, this can lead  
 308 to loss of physical output. Where additional food is available and the bird has the  
 309 capacity to consume it, physical outputs need not be reduced, but financial losses will  
 310 still be experienced due to elevated feed consumption. Reductions in FCR ranged from  
 311 zero for ascites to reductions of 25.9% for severe feather pecking (Table 5).



312

313 Table 5. Impact of severe, uncontrolled, production disease on the feed conversion  
 314 ratio (FCR)

	Reduction in FCR (%) (range)	Sources of data
<b>Broilers</b>		
Acites	0	Acar et al. (1995); Arce et al. (1992); Arce-Menocal et al. (2009); Camacho-Fernandez et al. (2002); Izadinia et al. (2010); Kalmar et al. (2013); Khajali et al. (2007); Maxwell and Robertson (1998); Morris (1992); Rincon, (2000)
Clostridiosis	16.4 (-3.7 – 70.5)	Lovland and Kaldhusdal (2001); Miller et al. (2010); Tactacan et al. (2013); Zhang et al. (2010)
Coccidiosis	17.7	Abdelrahman et al. (2014); Li et al. (2005)
Footpad dermatitis	3.3 (1.06 – 4.35)	Cengiz et al. (2011); de Jong et al. (2014)
<b>Laying flocks</b>		
Injurious feather pecking	25.9 (-5.1 - -49.7)	Glatz (2001); Leeson and Morrison (1978); Peguri & Coon (1993)

315 Note: Suitable data are not available for Tibial Dischondroplasia, Keel bone damage, Infectious bronchitis  
 316 and salpingoperitonitis.

317

318

319 3.6 Financial impacts of uncontrolled production diseases

320 The financial impacts of these diseases were estimated by applying percentage

321 changes in physical outputs to the standard broiler and layer financial models

322 (Appendix A). On the few occasions where data were available from the studies on

323 changes to input costs resulting from the diseases, or interventions, these were also

324 used in the financial models. For six of the diseases there were sufficient data to

325 undertake financial analyses, while for three there were not. In Figures 1 and 2, the

326 darker shaded bars represent the financial losses per bird, averaged over the flock,

327 arising from the uncontrolled diseases and the lighter bars show the losses that would

328 be incurred after applying the best available interventions to control them. Not

329 surprisingly, average losses for layers are higher than broilers because layers have a  
330 longer productive life (around 56 weeks (RSPCA, 2016) and thus generate more  
331 revenue. Broilers are usually slaughtered around 6-7 weeks in the EU and USA (EFSA,  
332 2010; National Chicken Council, 2016), depending on growth rates and desired  
333 slaughter weights.

334

335 Uncontrolled clostridiosis caused the greatest reported losses, at around €0.32 per bird  
336 averaged over the flock, while losses from uncontrolled coccidiosis amounted to €0.21  
337 per bird. Based on the financial model used here, confirmed by anecdotal industry  
338 evidence, the net (profit) margin for a typical commercial broiler enterprise in the EU in  
339 2013 was low, at around 10 Euro Cents per bird. With margins as tight as this, all of the  
340 production diseases costed here would, when unconstrained, make affected flocks  
341 loss-making.

342

343 Based on the standard financial model, laying hens typically generated a margin of  
344 around €6 per bird in 2013. Figure 2 shows that, among the studied diseases, keel  
345 bone damage causes the largest financial losses in laying hens, at around €3.5 per bird  
346 averaged over the flock. However, this result should be treated with some caution in  
347 view of the doubts raised above over the scale of mortality losses reported for this  
348 disease.

349

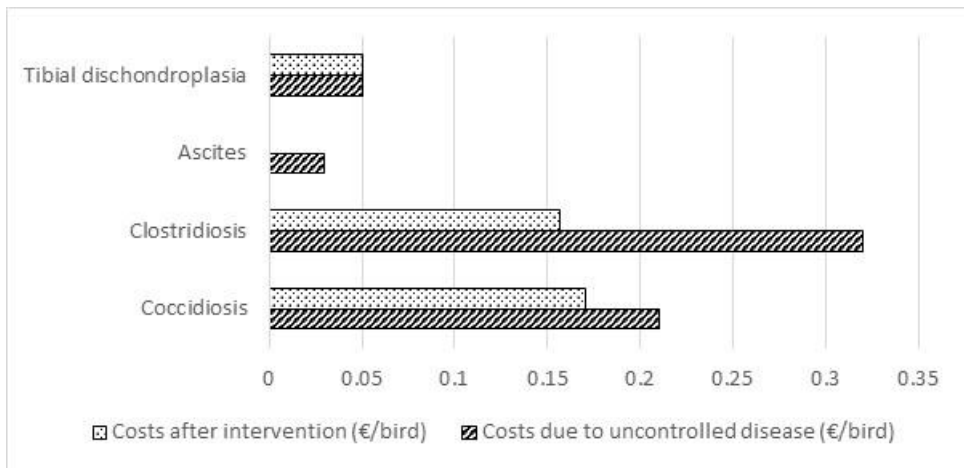
350 A number of possible disease costs have not been accounted for, due to lack of data.  
351 Typically, there are no data available from most disease impact studies on labour, vet  
352 and medicine costs, additional carcass disposal costs, or costs associated with the  
353 disruption of normal husbandry practices resulting from diseases, such as delays to  
354 thinning and depopulation to allow extra time for broilers to reach target weight. Also  
355 not reported are losses from increased heterogeneity of broiler weights in a cohort,  
356 meaning that a greater proportion of birds would fail to meet buyer requirements for

357 permissible weight range and would have to be sold at lower prices, often through  
 358 alternative marketing channels.

359

360 Figure 1. Financial losses due to four production diseases (controlled and uncontrolled) in  
 361 broiler flocks.

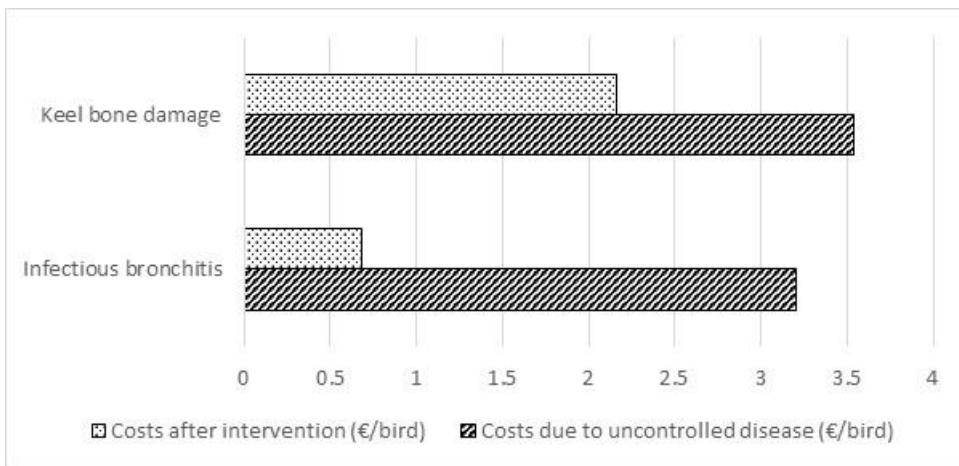
362



363

364

365 Figure 2. Financial losses due to two production diseases (controlled and uncontrolled) in  
 366 laying flocks.



367

368

369 3.7 The efficacy of interventions

370 Interventions to control production diseases in poultry are of two types, both adding to  
 371 production costs: treatment and prevention measures. Once a disease outbreak has  
 372 occurred, producers react with one or more courses of treatments, often with veterinary  
 373 support. Because many diseases are endemic, and difficult or expensive to control

374 once established, producers sometimes deploy preventive measures to try to reduce  
375 the risk of outbreaks and/or their severity. The cost of therapeutic treatments can be  
376 reduced if treatment begins early in a disease outbreak and so, producers may also  
377 increase expenditure on health monitoring to identify early signs of disease.

378

379 As Table 6 shows, many types of intervention have been evaluated in the literature,  
380 although there are few studies for any particular intervention. There is some  
381 heterogeneity within type of intervention studied for each disease. For example, in the  
382 anti-microbial category, treatments might be dietary supplements, probiotics,  
383 bacteriophage therapy, or antibiotics, with variation within these categories based on  
384 compounds or brands used, and concentrations of active ingredients. The data  
385 presented in Figures 1 and 2 represent the single most efficacious intervention  
386 reported in the literature for each disease. These estimates provide a sense of the  
387 higher end of the achievable levels of control that might be expected in a commercial  
388 setting.

389

390 Figures 1 and 2 show that there are considerable differences between these diseases  
391 in terms of both the financial losses caused when uncontrolled, and the extent to which  
392 interventions can reduce these losses. Tibial dyschondroplasia, for example, causes  
393 relatively small financial losses, but these are relatively difficult to eliminate.

394 Conversely, diseases such as clostridiosis and infectious bronchitis, while resulting in  
395 very high financial costs when uncontrolled, can be reduced effectively through  
396 interventions. The diseases that would seem most problematic are those, such as keel  
397 bone damage, which lead to high financial costs when unconstrained and which resist  
398 attempts to control them. Based on this analysis, coccidiosis appears to fall into this  
399 class, with lower efficacy of interventions than for other diseases. However, producers  
400 report that both vaccines and anti-microbials offer significant means of disease control  
401 in a commercial setting.

402

403 Table 6. Types of intervention to control production diseases from the literature review.

	<b>Class of measure</b>	<b>Types of intervention and data sources</b>
<b>Broilers</b>		
Tibial dischondroplasia	Prevention	Manipulation of nutrients (Edwards, 1990) Manipulation of feed consumption (Edwards and Sorensen, 1987; Onbasilar et al., 2007) Manipulation of egg incubation temp. (Yalcin et al., 2007)
Acites	Prevention	Feed restriction – full rearing period (Arce et al. 1992; Camacho-Fernandez et al., 2002; Rincon 2000) Feed restriction – early weeks (Acar et al., 1995; Arce et al., 1992; Khajali et al., 2007)
Clostridiosis	Treatment	Antibiotics (Tactacan et al., 2013; Zhang et al., 2010) Bacteriophage therapy (Miller et al., 2010) Other antimicrobials (Tactacan et al., 2013)
Coccidiosis	Prevention	Vaccines (Lee et al., 2009; Li et al., 2005; Miguel et al., 2008; Shirley et al., 1995; Sou et al., 2006; Vermeulen et al., 2001; Williams et al., 1999; Williams and Gobbi, 2002) Probiotics (Abdelrahman et al., 2014) Herbal treatments (Miguel et al., 2008) Anticoccidials (Abdelrahman et al., 2014; Lee et al., 2009; Li et al., 2005; Miguel et al., 2008; Sou et al., 2006; Williams et al., 1999; Williams and Gobbi, 2002)
Footpad dermatitis	Prevention	Manipulation of litter moisture (Cengiz et al., 2011; de Jong et al., 2014; Ekstrand et al., 1997; Martland, 1985; Mayne et al., 2007; Taira et al., 2013; Wang et al., 2010) Variation of litter materials (Bilgili et al., 2009)
<b>Laying flocks</b>		
Keel bone damage	Prevention	Switch from unenriched to enriched cages (Petrik et al., 2015; Sherwin et al., 2010; Wilkins et al., 2011)
Infectious bronchitis	Prevention	Vaccines (Cook et al., 1999; Faramarzi et al., 2014; Jones et al., 2005; Tarpey et al., 2006; Tawfik et al., 2013)
Salpingoperitonitis	Prevention	Probiotics (Shini et al., 2013) Inoculation (Reid and Bocking, 2003) Vaccination (Gregersen, et al., 2010)
	Treatment	Antimicrobials (Balevi et al., 2001; Nahashon et al., 1996; Willis and Read, 2008)
Injurious feather pecking	Prevention	Housing (Fossum et al., 2009) Beak trimming (Craig and Lee, 1990) Enriched environment (El-Lethey et al., 2000; Lambton et al., 2013) Reduced stocking rates (Nicol et al., 1999) Feed modification (Ambrosen and Petersen, 1997)

404

405

406 There are two possible explanations for the discrepancy between the results of the  
407 scientific trials and real-world experience. First, that the few studies available are  
408 simply generating unrepresentative results and, second, and perhaps more likely, that  
409 the reviewed studies are capturing sub-clinical disease impacts. Observation of

410 commercial practice suggests that coccidiostats, such as ionophore antibiotics, while  
411 effective at controlling clinical disease, are seemingly less effective at controlling  
412 subclinical impacts, leading to losses through reduced feed intake and feed conversion  
413 efficiency (Christensen, 2016).

414

#### 415 **4. Discussion**

416 Our study found that there is an almost complete absence of published studies  
417 generating data on the financial impacts of these nine poultry production diseases.  
418 Generalising from this, it might be supposed that the entire poultry disease literature  
419 has very much an epidemiological, rather than financial, focus.

420

421 To estimate the financial impacts of the nine poultry production diseases, and control  
422 interventions, it was necessary to apply data on changes to productive parameters to  
423 standard financial models (for broilers and layers) in order to monetise them. However,  
424 there are significant gaps, even in the data on the impacts of diseases on productive  
425 parameters, a case in point being salpingoperitonitis, where there are insufficient data  
426 to permit any estimation of financial impact. This is perhaps explicable in view of the  
427 tendency for salpingoperitonitis to occur in conjunction with other E. Coli-induced  
428 conditions, such as airsacculitis, and secondary infections such as septicemia.

429

430 There is great heterogeneity of research objectives and methodology in the reviewed  
431 studies, with some focusing on disease incidence, others on disease severity, others  
432 seeking to capture the physical impacts of the disease itself, while others are  
433 concerned only with the efficacy of control interventions. As a consequence of this,  
434 together with the few studies, there is little or no replication in the literature and,  
435 sometimes, essential data are only available from a single study. This limitation affects  
436 the level of confidence that can be placed in the available data when generalising to  
437 the whole sector.

438

439 The lack of focus on financial impacts in studies means that, even if data on changes to  
440 productive parameters are available and can be monetised, impacts on some cost  
441 categories, such as vet and medicine costs, still cannot be captured. With very little  
442 data on the impact of production diseases on the quality of outputs, the full financial  
443 impact of downgrades to carcasses or eggs cannot be accounted for, and so disease  
444 impacts may be underestimated. The lack of data on the cost of interventions means  
445 that the estimates of the financial savings resulting from using them may be over-  
446 estimated in our study.

447

448 Different studies often show a wide range of severity of impacts for the same disease.  
449 More extreme impacts than estimated here might occur in commercial practice for a  
450 number of reasons, including variations in: rearing environment; breed; management  
451 quality; and the pathogenicity of infections. An additional cause of variation is the  
452 occurrence of secondary infections. Most studies do not report data where secondary  
453 infections are known to have occurred, on the grounds that such data would bias  
454 impact estimates for the individual production diseases themselves. However, it must  
455 be acknowledged that part of the set of negative consequences arising from the  
456 occurrence of production diseases is an elevated risk of secondary infections from  
457 other diseases.

458 For the reasons identified above, it is concluded that there are deficiencies in the  
459 literature (and in the underlying reported research) resulting in data which are difficult  
460 to use. Thus, the financial impacts estimated for the production diseases examined  
461 here should be treated with some caution. Despite this, the claims made by many  
462 authors in the poultry disease literature that production diseases can have significant  
463 financial impacts would appear correct, even though these authors seldom supply any  
464 empirical financial evidence supporting these claims.

465

466 While poultry farms with elevated levels of production diseases can make substantially  
467 less profit than farms with low disease levels, these losses can be significantly reduced  
468 by a range of prevention measures, such as vaccinations, or improved litter  
469 management, nutrition and hygiene, as well as curative treatments. The financial  
470 benefits of interventions to control production diseases vary greatly according to  
471 disease and the intervention chosen. The losses associated with diseases such as  
472 clostridiosis, for example, can be significantly reduced through use of antimicrobials,  
473 but others, such as keel bone damage, present a greater challenge.

474

475 The reliance of the poultry industry on the use of antimicrobials to control infectious  
476 diseases highlights the risks to the financial sustainability of the sector from the  
477 continuing growth in farm bacterial reservoirs with resistance to antimicrobial  
478 treatments (Aminov and Mackie, 2007; Sykes, 2010, EFSA and ECDPC, 2016).

479

480 These risks occur on three fronts. First, some antibiotics commonly used for the  
481 treatment of diseases may lose their efficacy. Second, government action plans, such  
482 as the EU Action Plan Against the Rising Threats from Antimicrobial Resistance (EU,  
483 2011), which are designed to drive more responsible use of antibiotics, may make  
484 some antibiotics less readily available. Third, although there have been few official  
485 bans on the use of selected antibiotics so far, such as the US ban on Fluoroquinolones  
486 (FDA, 2005), governments may adopt the 'precautionary principle', and issue complete  
487 bans on the use of some antibiotics.

488

## 489 **5. Conclusions**

490 In light of this growing threat, there is a pressing need for the poultry research  
491 community to help identify cost-effective alternatives to antibiotics which offer similar  
492 levels of disease control. These could include: novel substances to strengthen the



493 poultry immune response to bacterial infection; naturally occurring bacteriophages;  
494 novel vaccinations; and enhanced biosecurity measures on farm. Although some  
495 rigorous individual studies of alternative approaches have been undertaken, there is  
496 insufficient data across the literature to evaluate them. Failure to develop these  
497 alternatives could significantly, and negatively, impact the future financial sustainability  
498 of the global poultry industry.

499

500 There are strong hints in the literature that some interventions, particularly in relation to  
501 biosecurity measures, reduce disease incidence, prevalence and severity, for multiple  
502 production diseases simultaneously. The use of single interventions to control multiple  
503 diseases would be very advantageous for an industry faced with small profit margins,  
504 volatile markets, and the possibility of further regulation. The industry would, therefore,  
505 benefit from a more holistic effort from the research community to identify the most  
506 useful and cost-effective multi-functional interventions to reduce disease-related  
507 financial losses.

508

509 The analysis above has revealed a disconnect between the requirements of the poultry  
510 industry for data on the financial impacts of diseases and control measures and the  
511 goals of researchers in the non-commercial poultry disease research community. As a  
512 consequence, the value of such research, even if it targets relevant production  
513 diseases and interventions, is of less value than it could be. In view of this, the question  
514 might reasonably be asked, where are commercial producers and their advisors getting  
515 the data on which to plan their disease management programmes?

516

517 In order to meet the future informational needs of the poultry industry, the focus of  
518 academic poultry disease research needs to be changed. Studies need to generate  
519 data not only on the first-order physical impacts of production diseases, but also  
520 secondary and financial impacts, as is currently already being achieved commonly in

521 research on pig and dairy cow diseases. This means collecting data from abattoirs on  
522 the impact of diseases on product quality, as well as data from farm trials and lab-  
523 based experiments on changes to the levels of input use resulting from diseases and  
524 the interventions to control them. This would require a more inter-disciplinary approach  
525 to research, involving not just veterinarians or animal scientists, but also agricultural  
526 economists.

527

### 528 **Acknowledgement**

529 The work on which this paper is based was made possible by funding from the EU's  
530 DG Research Framework 7 Programme PROHEALTH project [http://www.fp7-](http://www.fp7-prohealth.eu/)  
531 [prohealth.eu/](http://www.fp7-prohealth.eu/)

### 532 **Conflict of interest**

533 The authors know of no conflict of interest in relation to the production or publication of  
534 this article.

535

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957 **Appendix A. Standard financial models for broiler and layer enterprises, 2013**

	<b>Broilers</b>	<b>Layers</b>
<b>Sales:</b>	<b>Revenues (€/ 100 kg live weight) <sup>6</sup></b>	<b>Revenues (€ / hen) <sup>6</sup></b>
Broilers, (2.276 g of meat per bird at €107.7/100 kg liveweight); Layers, 340 eggs at €7.6/100 eggs <sup>7</sup>	107.7	25.84
Spent hens	-	0.36
<b>Expenditure:</b>	<b>Production costs (€/ 100 kg live weight) <sup>10</sup></b>	<b>Production costs (€ / hen) <sup>8, 9</sup></b>
Day old chicks / pullets (17 weeks)	15.20	3.30
Mortality <sup>1</sup>	2.02	0.87
Feed	67.00	10.29
Medication <sup>5</sup>	1.40	0.09 <sup>4</sup>
Heating and electricity	2.20	1.41 <sup>4</sup>
Water	0.60	
Litter (incl. cleanout & disposal)	3.70	
Labour	3.40	1.10
Housing <sup>2</sup>	6.40	2.75
General <sup>3</sup>	1.00	0.41
Total costs	102.92	20.22
<b>Net margin</b>	<b>4.74</b>	<b>5.98</b>

958

959 <sup>1</sup> Mortality costs assumed to be 50% of total rearing costs per dead bird. Mortality rate  
960 for layers assumed to be 9%.

961 <sup>2</sup> Housing costs includes: poultry house and inventory.

962 <sup>3</sup> General costs include: insurance, office, consultancy, telephone, transport.

963 <sup>4</sup> Medication, heating and electricity, water and litter costs are equated with the 'Other  
964 variable costs' category of Van Horne (2014), which includes: heating, electricity, litter,  
965 animal health and catching.

966 <sup>5</sup> Medication costs for broilers taken from Cocsik et al. (2014); layers from RBR (2014).

967 <sup>6</sup> 2013 broiler meat and egg prices; Eurostat Median of EU28 prices (authors' own  
968 calculations)

969 <http://ec.europa.eu/eurostat/statistics->

970 [explained/index.php/Agricultural accounts and prices](http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_accounts_and_prices)

971 <sup>7</sup> Number of eggs produced per housed bird = 340 (source: van Horne, 2014), based  
972 on enriched cage system).

973 <sup>8</sup> Sources: Van Horne (2014); Agro-Business Consultants Ltd (2012); RBR (2014).

974 <sup>9</sup> 2013 prices (based on 2010 (Van Horne, 2014) prices adjusted for inflation using  
975 annual GDP deflators for the EU. Source: World Bank National Accounts Data & OECD  
976 National Accounts files 2010-2015)

977 <sup>10</sup> Sources: Van Horne (2014); Agro-Business Consultants Ltd (2012).

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