

Scotland's Rural College

## **Why are most EU pigs tail docked? Economic and ethical analysis of four pig housing and management scenarios in the light of EU legislation and animal welfare outcomes**

D'Eath, RB; Niemi, JK; Vosough Ahmadi, B; Rutherford, KMD; Ison, SH; Turner, SP; Anker, HT; Jensen, T; Busch, ME; Jensen, KK; Lawrence, AB; Sandoe, P

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1 **Why are most EU pigs tail docked? Economic and ethical analysis of four pig**  
2 **housing and management scenarios in the light of EU legislation and animal**  
3 **welfare outcomes**

4

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18

19 Short title: Tail docking – economic, legal and welfare aspects.

20 **Abstract**

21 To limit tail biting incidence, most pig producers in Europe tail-dock their piglets. This is  
22 despite EU Council Directive 2008/120/EC banning routine tail docking and allowing it  
23 only as a last resort. The paper aims to understand what it takes to fulfil the intentions  
24 of the Directive by examining economic results of four management and housing  
25 scenarios, and by discussing their consequences for animal welfare in the light of legal  
26 and ethical considerations. The four scenarios compared are: “Standard Docked”, a  
27 conventional housing scenario with tail docking meeting the recommendations for  
28 Danish production (0.7m<sup>2</sup>/pig); “Standard Undocked”, which is the same as “Standard  
29 Docked” but with no tail docking, “Efficient Undocked” and “Enhanced Undocked”  
30 which have increased solid floor area (respectively 0.9 and 1.0m<sup>2</sup>/pig, provision of  
31 loose manipulable materials (100g and 200g/straw/pig/day) and no tail docking. A  
32 decision-tree model based on data from Danish and Finnish pig production suggests  
33 that Standard Docked provides the highest economic gross margin with the least tail  
34 biting. Given our assumptions, Enhanced Undocked is the least economic, although  
35 Efficient Undocked is better economically and both result in a lower incidence of tail  
36 biting than Standard Undocked but higher than Standard Docked. For a pig, being  
37 bitten is worse for welfare (repeated pain, risk of infections) than being docked, but to  
38 compare welfare consequences at a farm level means considering the number of  
39 affected pigs. Because of the high levels of biting in Standard Undocked, it has on  
40 average inferior welfare to Standard Docked, whereas the comparison of Standard  
41 Docked and Enhanced (or Efficient) Undocked is more difficult: In Enhanced (or  
42 Efficient) Undocked, more pigs than in Standard Docked suffer from being tail bitten  
43 while all the pigs avoid the acute pain of docking endured by the pigs in Standard  
44 Docked. We illustrate and discuss this ethical balance using numbers derived from the

45 above-mentioned data. We discuss our results in the light of the EU Directive and its  
46 adoption and enforcement by Member States. Widespread use of tail docking seems  
47 to be accepted, mainly because the alternative steps that producers are required to  
48 take before resorting to it are not specified in detail. By tail docking, producers are  
49 acting in their own best interests. We suggest that for the practice of tail docking to be  
50 terminated in a way that benefits animal welfare, changes in the way pigs are housed  
51 and managed may first be required.

52

53 **Keywords:** swine, welfare, tail biting, tail docking, economic modelling

54

### 55 **Implications**

56 Widespread use of tail docking in the EU seems to be accepted mainly because the  
57 alternative steps (as regards environment and stocking densities) that producers are  
58 required to take before resorting to it are not specified in detail by EU legislation. In  
59 current indoor housing systems, the use of tail docking enables producers to limit the  
60 occurrence of tail biting and its economic and welfare impacts. For tail docking to be  
61 stopped in a way that benefits animal welfare, considerable changes in the way pigs  
62 are housed and managed may first be required.

63 **Introduction**

64 Tail biting is a problematic behaviour in pig farming. It has a considerable welfare cost,  
65 in terms of immediate painful consequences for the victims, and by injured tails  
66 becoming an entrance for infection resulting in further suffering. Also it may lead to  
67 partial or total carcass condemnation and consequent economic loss for producers.  
68 Tail biting often occurs in unpredictable outbreaks, and multiple factors are known to  
69 increase tail biting risk, although sufficient access to substrates for rooting and  
70 foraging, and to resources such as food are thought to be of primary importance  
71 (D'Eath *et al.*, 2014). Tail docking is known to reduce the risk and severity of tail biting  
72 but does not eliminate the problem (Sutherland and Tucker, 2011). Tail docking is an  
73 unsatisfactory 'solution' to tail biting: It is an acutely painful mutilation, which masks the  
74 underlying risk factors which lead to tail biting, which are in themselves harmful to  
75 other aspects of pig welfare. It has been argued that docking enables sub-optimal  
76 environments to be used (Valros & Heinonen 2015). For example, docked pigs can be  
77 reared in environments which lack sufficient space and substrate to fully occupy their  
78 behavioural need to root, chew and forage. However, tail biting does still occur in intact  
79 pigs in 'improved' environments, and often at a higher level (Hunter *et al* 2001;  
80 Forkman *et al.* 2010).

81  
82 The EU Directive (2001/93/EC amending Directive 91/630/EEC, now codified in  
83 Council Directive 2008/120/EC) which came into force in January 2003 states that tail  
84 docking must not "be carried out *routinely* but only where there is evidence that injuries  
85 ... to other pigs' ears or tails have occurred. Before carrying out these procedures,  
86 other measures shall be taken to prevent tail biting and other vices taking into account  
87 environment and stocking densities. For this reason, inadequate environmental

88 conditions or management systems must be changed” (italics added). It goes on to  
89 state that “...pigs must have permanent access to a sufficient quantity of material to  
90 enable proper investigation and manipulation activities, such as straw, hay, wood,  
91 sawdust, mushroom compost, peat or a mixture of such, which does not compromise  
92 the health of the animals.”

93

94 A person with little knowledge of the pig industry might assume that since routine tail  
95 docking is banned, except as a ‘last resort’, and improved environmental conditions  
96 and enrichment materials are required as an alternative, tail docking must now be a  
97 rare occurrence. However, despite this EU directive, tail docking is still widely applied  
98 in most countries in the EU, with the exception of Finland and Sweden (and non-EU  
99 countries Norway and Switzerland). Tail docking continues for 95% or more of pigs in  
100 Germany, Denmark, Belgium, France, Ireland, Netherlands and Spain, and it is at over  
101 80% in the UK (EFSA, 2007); and a recent slaughter study in Ireland found that 99% of  
102 pigs were docked (Harley *et al.*, 2012). This anomalous situation puts the EU pig  
103 industry in a difficult position in terms of public expectations and pressure for change.  
104 For example, in the Netherlands, a voluntary agreement has been reached between  
105 producers and government to phase out tail docking by 2023 (Spoolder *et al.*, 2011).

106

107 In this article we aim to understand the barriers standing in the way of the goal of the  
108 EU Council Directive 2008/120/EC: to stop or severely limit the use of tail docking in  
109 such a way that it will benefit the welfare of the affected pigs. To achieve this we  
110 develop an economic model of four management and housing scenarios, three without  
111 tail-docking and one with tail docking. In our analysis and discussion of these

112 scenarios we focus on legal frameworks, financial incentives, consequences for animal  
113 welfare and finally on ethical considerations.

114

## 115 **Materials and methods**

116 In this section we present an economic model that allows us to analyse the outcomes  
117 of four indoor housing scenarios for finishing pigs with different approaches to tail  
118 biting management.

119

### 120 *Financial analysis of four pig production scenarios*

121 The four scenarios are:

- 122 • Standard Docked: A standard housing scenario where pig tails are docked,  
123 0.7m<sup>2</sup>/pig of space is provided, the pen floor is 2/3 slatted and 1/3 solid or drained,  
124 and fixed enrichment materials such as pieces of wood attached to chains or in  
125 holders attached to the pen partition are provided, but no straw.
- 126 • Standard Undocked: As Standard Docked but with no tail docking.
- 127 • Enhanced Undocked: An improved housing scenario otherwise similar to Standard  
128 Undocked. No tail docking, and the environment is 'enhanced' by measures to  
129 reduce tail biting risk: increased floor area to 1.0m<sup>2</sup>/pig, pen floors which are 1/3  
130 slatted and 2/3 solid, and provision of straw at 200g/pig/day as the key measure to  
131 control tail biting.
- 132 • Efficient Undocked: An improved housing scenario similar to Enhanced undocked  
133 except with 0.9m<sup>2</sup>/pig and 100g/pig/day of straw, while achieving similar levels of  
134 tail biting control as Enhanced Undocked.

135 Standard Docked resembles current Danish production where 0.7 m<sup>2</sup>/pig is

136 recommended, even though the legal requirement is only 0.65 m<sup>2</sup>/pig; Standard

137 Undocked is based on current Danish production but without tail docking and  
138 consequently much higher levels of tail biting. Enhanced Undocked is also based on  
139 Danish production, but draws on some elements of many Finnish farms (Niemi and  
140 Karhula 2011) and with other undocked systems (see D'Eath et al 2014, Table 2).  
141 Efficient Undocked is based on Danish production, but has some similarities with the  
142 most efficient well-managed Finnish farms. We have good economic data on Danish  
143 and Finnish production, which were used to develop the scenarios, but our analysis is  
144 not intended to be a comparison of Danish vs. Finnish systems, as there are many  
145 more differences than those considered here (health status, liquid vs.solid feeding,  
146 genetics etc.). The model focuses on a specialist finisher farm where the cost of tail  
147 docking labour (docking takes place on the farrowing farm, we assume costs are  
148 passed on) or costs of extra measures to prevent tail biting are added to the other  
149 variable and fixed costs. Looking at the finisher stage simplifies our analysis and  
150 focuses on the period when losses from tail biting mainly occur (Schrøder-Petersen  
151 and Simonsen, 2001), but it ignores the possibility that some economic losses can  
152 occur as a result of tail biting in younger pigs (Zonderland *et al.*, 2008), meaning that  
153 the cost of tail biting may be underestimated somewhat. Although there are multiple  
154 interacting risk factors in tail biting (see e.g. EFSA, 2007; D'Eath *et al.*, 2014), to keep  
155 our model simple, our main focus is on efforts to reduce tail biting through increased  
156 space allowance and the use of straw, which are the main differences in practice  
157 between docked and undocked systems (see table 2 in D'Eath et al 2014). A further  
158 simplifying assumption is that docked tails are docked according to Danish rules (no  
159 shorter than half of the tail) and that this is short enough to reduce tail biting  
160 (Sutherland & Tucker 2011).

161



162 Finnish and Danish pigs differ in their slaughter weights and duration of the growing  
163 period. To be able to compare the scenarios solely from the tail biting management  
164 point of view, we have assumed similar live weight at entry (31.7 kg) and at slaughter  
165 (109.1 kg), carcass weight (81.8 kg), and duration of fattening period as well as similar  
166 prices of inputs and pig meat. Our simulation assumes that all four scenarios operate  
167 under market conditions and slaughter weights similar to those in Denmark in 2012.  
168 Table 1 illustrates qualitatively the main differences in the cost items between the four  
169 modelled scenarios.

170

### 171 *Financial inputs*

172 Production and price data for the four scenarios were gathered, and gross and net  
173 margins (€/pig) were estimated in the absence of any costs associated with tail biting  
174 (Table 2). The net margin for Standard Docked was based on Udesen (2013). The net  
175 margins for the three Undocked scenarios were calculated by differentiating the costs  
176 by the characteristics of production. The main differences between the scenarios are  
177 labour costs associated with docking tails (used only in Standard Docked), the material  
178 and labour costs of providing straw and enrichment materials (straw is provided only in  
179 Efficient and Enhanced Undocked) and fixed costs of buildings (cost of additional  
180 space per pig in Efficient and Enhanced Undocked). In Finland, a new Decree requires  
181 that at least two thirds of the pen floor area must be either solid or drained (i.e.  
182 perforations <10% of the area, in effect from 2013, except already existing pig houses  
183 for which it will become in effect 2028; Finnish Government, 2012), whereas in  
184 Denmark one third of the floor must be solid or drained from July 2015 (Danish  
185 Government, 2000). Hence, we have assumed that the two Standard scenarios have  
186 two thirds slatted and the Efficient and Enhanced Undocked have one third slatted

187 floor. Solid or drained floor is less expensive to build than slatted floor but is more  
188 labour intensive to keep clean. Differences in fixed costs, labour costs and materials  
189 needed are reflected in our calculations (Table 3).

190  
191 Should there be any tail biting in the pen, an extra net cost of €18.96 per victim was  
192 subtracted from the net margin. This cost is due to extra medicine, veterinary, labour  
193 and material costs, increased mortality, carcass disposal and carcass condemnations,  
194 reduced daily gain and extra feed consumption. This cost was an average calculated  
195 from published studies and from industry data, but in practice these numbers can vary  
196 both within and between farms and also over time. The breakdown and justification of  
197 these costs per item are presented in a Supplementary Table (Supplementary Online  
198 Materials). An important cost is that some bitten pigs suffer from infections and  
199 abscesses throughout the carcass which can lead to condemnation of part of or the  
200 entire carcass (Kritas and Morrison, 2007).

201  
202 It was assumed that in each scenario, there were 11 pigs per pen and that there is  
203 enough hospital pen capacity at the farm. Hence, potential extra fixed costs of hospital  
204 pens were not explicitly included although tail biting can increase the need for hospital  
205 pens. In our analysis, the extra costs per victim are weighed with the probability of  
206 occurrence according to the outbreak scenarios represented in the subsequent  
207 section.

208  
209 A pen size of 11 was chosen because tail biting data used in a key study originated  
210 from a farm where there were on average 11 pigs per pen. Although pig farms often  
211 have larger pens than this (e.g. 16 pigs per pen is the most common in Denmark),

212 extending the results to larger pens could have biased our parameters. However, there  
213 is no strong evidence suggesting large group size as a major risk factor for tail biting.

214  
215 Besides pen size, the farm size was also standardized: Data on production costs  
216 without the costs of tail biting was drawn from Danish farms having space for  
217 approximately 2,200 finishing pigs, which are housed in production batches in all-in-all-  
218 out compartments each of which has space for 314 pigs. The size of a farm was not  
219 considered as a risk factor for tail biting, because the comparison is made between  
220 four scenarios applied at similarly sized farms. We assume that our results could apply  
221 equally to larger farms. In our simulation, calculations were performed at the pen level,  
222 and standard deviation parameters represent variation in the occurrence of tail biting  
223 outbreak in different pens of a farm over two-year period.

224

#### 225 *Size of tail biting outbreaks*

226 In all four scenarios, outbreaks of tail biting can occur. In Standard Docked, the  
227 outbreaks are expected to be less likely to occur and to affect fewer pigs than in the  
228 three Undocked scenarios. This was based on evidence from experimental studies  
229 showing that tail docking is partially effective in reducing the incidence and impact of  
230 tail biting (e.g. Sutherland *et al.*, 2009; reviewed by Sutherland & Tucker 2011).

231 Industry figures from abattoirs can be difficult to interpret because scoring systems are  
232 not standardised across studies or locations (EFSA, 2007; Keeling *et al.*, 2012), but  
233 some studies compare pigs from different production systems delivering to the same  
234 abattoir. In a farmer system survey combined with abattoir data, docked pigs had 2-3%  
235 bitten tails, while undocked pigs had 6-8%, regardless of deep, light or no straw being  
236 provided (Hunter *et al.*, 2001). Data from a single Danish abattoir in which conventional

237 (tail docked; 0.5-1.5% bitten), ecological and free-range pigs (tail intact; 1-5% bitten)  
238 were slaughtered showed higher average and more variable levels of tail biting over a  
239 19 month period (Forkman *et al.*, 2010). These studies indicate that levels of tail injury  
240 are lower in docked pigs from standard environments than in intact-tailed pigs from  
241 enriched environments.

242  
243 It was stipulated that the magnitude of the expected tail biting outbreaks in a pen  
244 varies from zero (i.e. no outbreak) to small, medium and large outbreaks. The classes  
245 were:

- 246 - No outbreak, “no”
- 247 - Small outbreak (1 victim per pen), “S”
- 248 - Medium-sized outbreak (2.8 victims per pen, covering outbreaks with 2-4  
249 victims per pen), “M”
- 250 - Large outbreak (7.6 victims per pen, covering outbreaks with 5 or more victims  
251 per pen), “L”.

252

### 253 *Probability of tail biting outbreaks*

254 The probability of small, medium-sized and large outbreak was estimated based on  
255 data by Sinisalo *et al.* (2012) on the condition that the probability of no outbreak (“P<sub>no</sub>”)  
256 is given. These data cover daily animal-level health records on 6,812 fattening pigs  
257 raised in 2007-2008 in an experimental farm similar to Enhanced Undocked. Thus for  
258 Enhanced Undocked (and for Efficient Undocked which was assumed to have the  
259 same tail biting risk), the relationship between the probability of no outbreak and small  
260 or medium outbreak was estimated using monthly statistics about the frequencies of  
261 tail biting outbreaks (Table 4). Because the use of docking and the housing

262 environment affect tail biting, the probability of outbreak varies by scenario. The  
263 probability of no outbreak or of small, medium or large outbreaks in a pen for the two  
264 Standard scenarios was determined by extrapolation after consulting and synthesising  
265 data from various studies which give the total incidence (rather than individual pen  
266 data) in similar scenarios (Table 4). For Standard Docked, abattoir data suggest a  
267 prevalence of 0.5 to 3% (Hunter *et al.*, 1999; EFSA, 2007; Forkman *et al.*, 2010), but  
268 these are thought to underestimate the on-farm incidence (Busch *et al.*, 2004). For  
269 Standard Undocked, only small experimental studies are available (Van de Weerd *et*  
270 *al.*, 2005 and 2006; Zonderland *et al.*, 2008). In addition to the detailed data of Sinisalo  
271 *et al.* (2012), two further studies were available as a check of our estimated incidence  
272 for Enhanced Undocked and Efficient Undocked (Partanen *et al.*, 2012; Munsterhjelm,  
273 2013). Incidence as used here and throughout this paper is meant in the sense of the  
274 % of pigs that will be affected by tail biting injury at some point during their time on the  
275 farm, rather than prevalence which would be a snapshot of affected pigs at a given  
276 instant.

277  
278 A conditional probability was used to estimate the probability of small, medium-sized or  
279 large outbreak to occur. These conditional probabilities were eventually used in a  
280 decision tree model.  $P_i$  denotes the probability of outbreak in each size category  $i=(no,$   
281  $S, M, L)$ , and equations which determine  $P_S$ ,  $P_M$  and  $P_L$  are provided in the footnote of  
282 Table 4. Because  $P_{no}$  in each individual simulation run depends on random draws  
283 made during the simulations (see the following sections), also the values of  $P_S$ ,  $P_M$   
284 and  $P_L$  are adjusted accordingly, and they depend on the result of a random draw  
285 made for  $P_{no}$ . The values of  $P_i$  depend also on the housing scenario  $h$ .

286

287 *Decision tree model*

288 A decision tree model (Huirne and Dijkhuizen, 1997) presented in Figure 1 was  
289 developed using the input data gathered on margins, losses due to tail biting and  
290 estimated probabilities of outbreaks. The decision tree model was developed using  
291 Microsoft Excel software (Microsoft, 2010) and was run using TreePlan add-in  
292 simulation software (TreePlan, 2013). In the decision tree, the choice of housing  
293 scenario is represented by a square called a decision node, and the four branches  
294 represent the four scenarios. Chance events (state of nature) or outbreaks of tail biting  
295 are represented by four circles and are called chance nodes. Following each chance  
296 node there are four branches representing outbreak possibilities with certain  
297 magnitudes and probabilities. These branches include all possible outcomes assumed  
298 in this model and are mutually exhaustive.

299  
300 Expected Monetary value (EMV) for each decision option (i.e. housing scenario) was  
301 calculated by the decision tree using the following equation:

302

$$303 \text{EMV}(h) = \sum_{i,j} (P_i V_{ih})$$

304

305 Here h represents the decision options of housing scenarios (h=Standard Docked,  
306 Standard Undocked, Enhanced Undocked or Efficient Undocked), i represents  
307 outbreak events (the four magnitudes: no, S, M, L),  $P_j$  represents the probability of  
308 each outbreak, and  $V_{ih}$  denotes the monetary value of the outcome for the outbreak  
309 events for each housing choice and  $j$ th simulated pen.

310

311 When tails are not docked, there is a greater variation in the range of tail biting  
312 outcomes observed, i.e. the situation is more risky. To reflect this, the standard  
313 deviation for the three Undocked housing scenarios was set at 0.1 (according to the  
314 data of Sinisalo *et al.*, 2012) whereas for Standard Docked it was set at 0.05 as a  
315 smaller standard deviation is expected to be associated with a lower probability of tail  
316 biting outbreaks.

317

318 To capture the impact of the uncertainty about the probability of outbreaks and their  
319 magnitude on the optimal decision and on EMV, 10,000 model runs, each simulating  
320 one pen of pigs, were carried out under each of two different Risk Situations, RS1  
321 referring to a 'standard' situation and RS2 referring to a situation where there is  
322 increased uncertainty about the range of variation of  $P_{no}$  in the three Undocked  
323 scenarios. 'Probability of no outbreak' was allowed to vary using a normal distribution,  
324 the mean and standard deviation of which was defined in Table 5. Performance of  
325 10,000 runs meant we were able to ensure a smooth distribution of outcomes. A  
326 random sample of 5,000 runs from the 10,000 resulted in less than 0.03% error in both  
327 the average and standard deviation of EMV. The runs were performed using RiskSim  
328 in the TreePlan Excel add-in.

329

330 Under these simulations the mean of the distribution remained constant but the  
331 standard deviations were changed. The standard deviations of the three scenarios with  
332 undocked pigs were doubled under the hypothetical simulation RS2 which refers to the  
333 case where the decision-maker does not know the parameter values as well as in the  
334 case of RS1. Impacts on the net margins of each scenario and also the impacts on the  
335 optimal decision of the decision tree model were investigated.

336

337 Upon reporting the results, the simulation results for each individual pen were  
338 combined to represent one production batch of pigs housed in a single compartment  
339 with on average 314 pigs. Thus the variation in EMV per pig is reported so as to  
340 represent variation in the *mean* EMV of the batch. This was done to help interpretation  
341 of results at the farm level. As a default, it was assumed that the simulation results  
342 between the pens are correlated so that for instance the most severe tail-biting losses  
343 occur in pens at the same time. As an alternative, we also consider a situation where  
344 the occurrence of tail biting is not correlated across pens in the same compartment,  
345 and hence, each pen is to suffer from tail biting only due to incidental (non-systemic)  
346 reasons.

347

## 348 **Results**

349 Expected monetary values (EMV) of the considered costs in the four housing  
350 scenarios were simulated at –€14.2/pig for Standard Docked, –€16.8/pig for Standard  
351 Undocked, –€20.6 /pig for Enhanced Undocked and –€15.8/pig for Efficient Undocked.  
352 These average payoffs were determined by our initial assumptions and calculations  
353 and would also have been found if we had used a deterministic model. Based on these  
354 results and given the input data and assumptions used, Standard Docked resulted in  
355 the largest EMV. Although Standard Docked had slightly higher costs than Standard  
356 Undocked when excluding the costs of tail biting, the losses due to tail biting are  
357 expected to be approximately five times higher in Standard Undocked than in Standard  
358 Docked (17.3% rather than 3.1% incidence; Table 4). In contrast to this, Enhanced  
359 Undocked incurs larger fixed costs and higher labour costs caused by the increased  
360 use of straw and space than the Standard housing scenarios. Efficient Undocked, in



361 which we simulated a well managed farm, able to control tail biting with less space and  
362 straw than Enhanced Undocked, performed second only to Standard docked.

363 Enhanced Undocked and Efficient Undocked resulted in losses due to tail biting which  
364 are 63% lower than those in Standard Undocked.

365  
366 Simulation results showed that under RS1, the optimal choice of housing scenario to  
367 maximise EMV was almost always Standard Docked, and therefore, no decision was  
368 allocated to the other three scenarios. The expected monetary value of Standard  
369 Docked varied between -€13.4 and -€15.2/pig (mean -€14.2, SD €0.2), for Standard  
370 Undocked it varied between -€14.0 and -€21.0/pig (mean -€16.8, SD €0.8), for  
371 Enhanced Undocked it ranged from -€19.0 to -€23.4/pig (mean -€20.6, SD €0.6) and  
372 for Efficient Undocked it ranged from -€16.8 to -€18.2/pig (mean -€17.0, SD €0.6;  
373 Figure 2a). Hence, Standard Undocked had more uncertainty about the returns. Taking  
374 into account uncertainty about the probability of outbreak, Standard Docked was  
375 superior, because it was preferred over Standard Undocked in virtually all simulated  
376 pens (i.e. first-order stochastic dominance). The expected benefit from Standard  
377 Docked was €2.6/pig (SD 0.6) against Standard Undocked, €6.4/pig (SD 0.3) against  
378 Enhanced Undocked and €2.8/pig (SD 0.4) against Efficient Undocked. The numbers  
379 above represent a situation where the most severe tail biting losses occur at the pens  
380 systematically at the same time. In the situation where the occurrence of tail biting is  
381 not correlated across pens in the same compartment and batch and hence a tail biting  
382 outbreak in each pen is independent from outbreaks in other pens in the same  
383 compartment and batch, the mean results are the same as above. However, the  
384 standard deviations of simulated losses at the batch level are then only 18.9% of the  
385 standard deviations reported above, i.e. the standard deviations are less than €0.1,

386 €0.2, €0.1 and €0.1 for the four scenarios respectively. Hence, if tail biting occurs non-  
387 systematically within a batch and a compartment, it reduces the variation in EMV at the  
388 batch level. Possible risk factors for tail biting (D'Eath et al 2014) can occur at the room  
389 or farm level (e.g. feeder space, breed, changes in temperature or humidity, disease)  
390 but also at the individual level (e.g. individual susceptibility, sex, disease). Given also  
391 that the causes of any specific outbreak remain obscure, either of these two extremes  
392 (pen level risk 100% or 0% correlated in a batch) are plausible but the truth is probably  
393 intermediate.

394  
395 The results of the RS2 simulation, which had a greater variation in outcomes, showed  
396 that in 96.9% of the modelled batches, the optimal decision was in favour of Standard  
397 Docked, and 3.1% of the decisions were allocated to Standard Undocked (Figure 2b).  
398 Efficient Undocked was not selected as the optimal decision in competition with  
399 Standard Docked despite of its very close range and similar curve pattern to Standard  
400 Undocked. As found for simulation RS1, Enhanced Undocked was not selected as the  
401 best option under RS2. However, Enhanced Undocked had a higher EMV than  
402 Standard Undocked and Efficient Undocked, in more cases under RS2 than RS1.

403

## 404 **Discussion**

405 In this section we will first discuss how to interpret the results of the economic  
406 modelling, before placing our results in a wider context. We consider current EU  
407 legislation, knowledge about stakeholder perception and studies in welfare science  
408 before aiming to situate the result in the ethical discussion regarding how best in the  
409 future to produce pigs.

410

411 *How to interpret the results of the economic modelling*

412 The three undocked scenarios are financially less attractive than Standard Docked  
413 under the assumptions used for the probability and magnitude of outbreaks under each  
414 scenario. In essence, this is because docking is low-cost and relatively effective in  
415 preventing costly tail biting (Standard Docked vs. Standard Undocked) in comparison  
416 to the use of space and enrichment (Standard Docked vs. Enhanced Undocked). In the  
417 most efficient undocked systems, the financial returns are still less than those in  
418 Standard Docked systems but not by as much. The simulation results showed that the  
419 number of situations where Standard Docked would not be preferred is negligible when  
420 examined at the batch level.

421  
422 Simulation results suggest that Standard Docked had the most stable EMV whereas  
423 Standard Undocked had more variable returns (higher standard deviation) than the  
424 three other scenarios. For a pig producer deciding which scenario to adopt, more  
425 variation in EMV may be undesirable in itself. Farmers are typically risk-averse  
426 (Lassen and Sandøe, 2009) and prefer to avoid large variations in income. This means  
427 that the perceived negative impact of risk is more than just the probability of tail biting  
428 times the expected loss per biting incident. Thus, if the financial costs of not tail  
429 docking are uncertain, this could make the cessation of tail docking even less attractive  
430 to producers.

431  
432 Our results suggest that producers do not currently have an economic incentive to stop  
433 tail docking. To change this, the profitability of the Enhanced Undocked scenario would  
434 need to increase through reduced costs or increased income, and more producers  
435 would need to approach or exceed the success of our Efficient Undocked model

436 scenario. Production costs per pig in enhanced housing (and efficient housing) were  
437 estimated to be higher (due to increased space, labour and enrichment) even without  
438 the costs of tail biting than in the two standard scenarios (which were similar in cost).  
439 Costs could be reduced for the enhanced or efficient housing: for example automated  
440 delivery of enrichments to pigs would reduce labour costs of allocating straw. If the  
441 level of tail biting assumed for Enhanced and Efficient Undocked could be achieved in  
442 an even smaller space than that of Efficient Undocked (between 0.7 and 0.9m<sup>2</sup> per  
443 pig), there is a potential for cost reduction. Thus we calculate that each 0.1 m<sup>2</sup>  
444 reduction in pen space would decrease fixed costs by €1.07 per pig.

445 Increased income might be achieved by increasing slaughter weights in Enhanced  
446 Undocked, as the greater space allowance allows for this, as is the case in Finland  
447 when compared to Denmark. (For simplicity, our model assumes similar slaughter  
448 weights for all four scenarios). Niemi (2006) found that increasing the carcass weight  
449 from 80kg to 85kg increases net returns by ~€3.2 per pig, and when taking into  
450 account differences in the number of finishing days per pig, by €2.2 per pig space per  
451 year. Increased income for Enhanced or Efficient Undocked might be possible if the  
452 willingness of some consumers to pay for higher animal welfare products (Lusk et al.,  
453 2007; Arnoult *et al.*, 2011) could be translated into improved prices for the producer  
454 (e.g. through distinct labelling and marketing). According to meta-analyses, the  
455 willingness to pay a premium for animal welfare could be 10% to 15%, although this  
456 varies between countries (Cicia and Colantuoni, 2010; Lagerkvist and Hess, 2011).  
457

458 Finally, we have assumed that all scenarios have a similar level of productivity, but  
459 increased space allowance can improve both average daily gain (Gonyou and Stricklin,  
460 1998) and feed conversion ratio (Turner *et al.*, 2000). Meta-analysis suggests a linear

461 relationship between space and weight gain, but only up to a threshold after which  
462 further increases in space have no further effect (Gonyou *et al.*, 2006). Pigs in pens of  
463 1.0 m<sup>2</sup>/pig (Enhanced) do not reach this threshold before slaughter, while at 0.7m<sup>2</sup>/pig  
464 (Standard), pigs reach this threshold at around  $k=0.0317 - 0.0348$  (where area (m<sup>2</sup>) =  $k$   
465  $\times$  weight<sup>2/3</sup>), which equates to between 90.2kg and 103kg. After this threshold daily  
466 gain is reduced by 0.98% for each 0.001 of  $k$  (Gonyou *et al.*, 2006). If we take the  
467 upper estimate of 0.0348 and assume that daily gain is reduced by the amount  
468 suggested by Gonyou *et al.* (2006) after a threshold of 90.2kg, then this would result in  
469 a 0.94kg lower live weight at 90 days, which equates to 1.06 €/pig. This would reduce  
470 the difference between the scenarios, but not by enough to affect the conclusions of  
471 our model.

472  
473 Our economic analysis suggests farmers are unlikely to stop tail docking pigs for  
474 economic reasons. In the next section we consider whether existing legal requirements  
475 backed by sanctions might result in farmers stopping docking.

#### 476 477 *The legal status of tail docking in the EU*

478 As mentioned in the Introduction, Member States of the European Union must comply  
479 with the tail docking requirements of Council Directive 2008/120/EC laying down  
480 minimum standards for the protection of pigs. The Directive is not legally binding upon  
481 pig producers directly; it is binding upon the Member States, which are required to  
482 transpose the Directive into national legislation and to ensure implementation and  
483 enforcement. This allows for different approaches across Member States.

484

485 While appearing to constitute a ban on routine tail docking, closer reading of the  
486 Directive reveals considerable room for different interpretations by Member States and  
487 their enforcement agencies. Before docking, producers must have “evidence that  
488 injuries...to other pigs’ ears or tails have occurred” but it is not specified how severe or  
489 how recent this tail and ear biting must be to justify tail docking, or even how it should  
490 be documented. In practice, written advice from a veterinary surgeon that tail docking  
491 is necessary is accepted by most enforcement agencies.

492

493 The Directive requires that “other measures shall be taken to prevent tail biting and  
494 other vices, taking into account environment and stocking densities. For this reason,  
495 inadequate environmental conditions or management systems must be changed”  
496 (2008/120/EC, The Council of The European Union, 2008). However, no details are  
497 given. Are producers expected to go beyond the EU minimum requirements on space?  
498 What other aspects of environment should they consider? The most important risk  
499 factors (D'Eath *et al.*, 2014) such as a lack of provision of substrates and limited  
500 access to feeder space are not specifically mentioned. Elsewhere in the Directive  
501 (Annex 1, Chapter 1, 4), the requirements on substrate are vague on quantity:  
502 “permanent access to a sufficient quantity of material to enable proper investigation  
503 and manipulation activities”. The inclusion of wood on the list of acceptable materials  
504 has led to a preference by producers for the use of relatively indestructible thick  
505 wooden poles as these need to be replenished less often, and the loose destructible  
506 materials that pigs seem to prefer (Studnitz *et al.*, 2007; Van de Weerd and Day, 2009)  
507 are absent or used in small amounts (due to cost and incompatibility with existing  
508 slatted-floor slurry systems). The provision of materials such as solid wooden blocks  
509 on chains which have been widely accepted as sufficient to comply with the EU

510 Directive, can result in high levels of tail biting if docking is not also used  
511 (corresponding to Standard Undocked in our model).

512  
513 The lack of more precise requirements in the Directive makes room for national  
514 legislation which is vague and difficult to enforce. This apparently leads to widespread  
515 acceptance of (in effect) routine docking. Yet, it appears that the Member States, and  
516 their enforcement agencies, do not provide a proper implementation of the Directive if  
517 they do not ensure that tail-docking is only used as a last resort. However, it must be  
518 acknowledged that there is some level of discretion for the Member States as regards  
519 what kind of documentation or evidence that must be provided. To improve on the  
520 current ambiguous and uncertain situation, an improvement in enforcement of existing  
521 legislation, as well as improved guidance (or even a new or amended Directive) would  
522 be needed.

523  
524 *Producer perceptions and pig industry factors affecting the decision to tail dock*

525 Besides economics and legislation, other factors can contribute to pig producers'  
526 decisions on how to manage their herd. A study of pig producers' attitudes towards tail  
527 docking in the Netherlands, where docking is widespread (Bracke *et al.*, 2013) showed  
528 that conventional pig producers frequently agreed with the following statements:  
529 "docking is necessary to prevent tail biting" (mean 4.9 on a scale from 1 to 6), and "it is  
530 better to dock all tails than to run the risk of tail biting even if it concerns just one bitten  
531 pig" (mean 5.0). There was lower agreement with the statement "I know how to  
532 effectively treat tail biting when it arises" (mean 4.1). Thus, most producers who  
533 currently use tail docking perceive the risk of tail biting as very serious, and most know  
534 some actions they could take in case of an outbreak but do not feel they can handle an

535 outbreak of biting entirely effectively. These findings indicate that producers dislike tail  
536 biting not just because of the expected economic losses but perhaps also because  
537 they fear losing control over the situation. However, there is an absence of studies into  
538 producer attitudes to tail docking in countries where it has never been allowed or has  
539 been banned, and anecdotal reports suggest that farmers can learn to manage  
540 undocked pigs. It is also worth considering that factors other than production  
541 economics affect producer decision making. Farmers are conscious of potential conflict  
542 between production and animal welfare (Jääskeläinen et al 2014), thus farmers  
543 working with a system which they feel better meets the needs of pigs may enjoy  
544 greater job satisfaction, pride and a sense that they are promoting good animal  
545 husbandry.

546  
547 However, industry trends in at least some parts of the EU may be towards reducing the  
548 number of staff per pig, and/or the level of skill and training of staff. This would be likely  
549 to reduce the likelihood that staff will be able to spot tail biting early and act  
550 appropriately to prevent the worsening of an outbreak.

551  
552 In addition, some characteristics of the industry increase the motivation of producers to  
553 tail-dock. In many cases, production is split-site and specialist farrowing farms provide  
554 weaners to more than one specialist weaner-finisher farm. The decision to dock should  
555 then depend on the requirement of the second farm. From the perspective of a  
556 farrowing farm, it may even be unclear which farm a litter is destined for at the time  
557 when docking is carried out, so given the possible requirement for docked pigs from  
558 the recipient farm, docking seems the prudent overall choice.

559



560 *Welfare consequences of tail biting and tail docking*

561 A literature review of the evidence for welfare consequences of tail docking and tail  
562 biting can be found in Supplementary materials, but is briefly summarised here, to give  
563 some relevant background to the following ethical discussion. The responses of pigs to  
564 tail docking suggest it is acutely painful for at least a few hours (Sutherland et al 2008,  
565 2011). Behavioural changes include disrupted suckling, increased activity, lying apart  
566 from other piglets, tail wagging, and increased sitting including 'bottom scooting'. In  
567 one study, 'tail jamming' was elevated for 3 days following docking (Torrey et al 2009).  
568 Physiological changes reflecting psychological stress such as decreased skin-  
569 temperature and white blood cell counts, and elevated cortisol and/or ACTH have been  
570 reported in some (Sutherland et al 2008, 2011) but not all studies of docking  
571 (Marchant-Forde et al 2009). In comparison with studies of other painful procedures  
572 performed on piglets, tail docking appears to be less acutely painful than piglet  
573 castration and similar in painfulness to teeth resection or ear tagging (Marchant-Forde  
574 et al 2009). Identification of neuromas in healed docked pig tails (Herskin et al 2014)  
575 may indicate that docking causes chronic pain, but this has never been investigated  
576 (FAWC, 2011).

577  
578 Tail bitten pigs probably experience pain as evidenced by their vocalisations  
579 (Blackshaw 1981), avoidance of biting pigs and changes in tail posture (Zonderland et  
580 al 2009) although this has never been systematically quantified. As well as causing  
581 pain, inflammation and blood loss, tail wounds can get infected, and infection can  
582 spread to the spine (sometimes resulting in paralysis of the hind limbs) and to other  
583 organs including the lungs (Munsterhjelm et al 2013). Repeated tail bites resulting in a  
584 messy wound and partial or total tail loss must presumably be a more painful way for a

585 pig to lose its tail than by tail docking in a quick single event. Furthermore, suffering  
586 due to secondary infections (which are rare following tail docking) adds further to the  
587 negative welfare consequences of being tail bitten.

588

589 *The ethical balance concerning tail docking and tail biting*

590 In this section, we first consider a consequentialist (Broome, 1991) approach to ethics  
591 to evaluate the four scenarios in our economic model. Underlying this approach is an  
592 ethical assumption that each relevant consequence contributes to the goodness or  
593 badness of a scenario. The overall goodness of each scenario is then determined by  
594 weighing up all the good and bad features against each other, considering the number  
595 of individuals affected, enabling the scenarios to be compared.

596

597 Consider a very simple utilitarian framework for weighing up animal welfare, where the  
598 avoidance of pain and other suffering due to tail docking or tail biting are considered  
599 the only relevant features of animal welfare, with a neutral attitude to risk. Under this  
600 framework we can compare our four scenarios in terms of their expected total animal  
601 welfare, considered for all the pigs going through those scenarios. To make this  
602 comparison, we must know how the pain of being tail docked compares with the pain  
603 of being bitten, taking their entire duration into account, and then weigh each of these  
604 with the incidence of affected individuals. If  $U(D)$  denotes the pain of tail docking  
605 (multiplied by 100% assuming all pigs are tail docked) and  $U(B)$  the pain from being  
606 bitten, using the % values for overall incidence in Table 4, the overall pain is:

607

608 Standard Docked:  $100U(D) + 3.1U(B)$

609 Standard Undocked:  $17.3U(B)$

610 Enhanced (or Efficient) Undocked:  $6.3U(B)$

611

612 Standard Docked and Standard Undocked are equally good if  $100 U(D) = (17.3-3.1)$   
613  $U(B)$ , i.e.  $U(B) = 7.0 U(D)$ . In this example, tail docking would be better than not tail  
614 docking, if the total pain of being bitten (added up over time) were more than 7.0 times  
615 worse than the total pain of being tail docked.

616

617 The cost of choosing Enhanced (or Efficient) Undocked rather than Standard Docked  
618 from the point of view of animal welfare is an incidence of tail biting which is doubled,  
619 but the benefit is avoiding the pain of tail docking. These two scenarios are equally  
620 good, if  $100U(D) = (6.3-3.1)U(B)$ , i.e.  $U(B)= 31.3U(D)$ . That is, under these conditions,  
621 tail docking is better only if the pain of being bitten is more than 31.3 times worse than  
622 the pain of being tail docked. This is because, in this comparison, the total pain of tail  
623 docking of all pigs has to be balanced with the pain resulting from far fewer bitten pigs.  
624 In the previous section, we argued that tail loss through severe tail biting is  
625 considerably worse for welfare than tail docking. However animal welfare science is  
626 not able to give us a precise numerical value for how much worse, so this question  
627 remains a matter of judgement.

628

629 It could be argued, based on these calculations and plausible assumptions, that  
630 Enhanced (or Efficient) Undocked is better from the point of view of the pigs than  
631 Standard Docked, which in turn is better than Standard Undocked. Thus, it seems  
632 plausible that comparing Standard Docked and Enhanced (or Efficient) Undocked, a  
633 doubling of the risk of tail biting, where the tail biting is still at a relatively low level, is a  
634 price worth paying for avoiding tail docking, whereas it does also seem plausible that

635 comparing Standard Docked and Standard Undocked, an almost six fold increase in  
636 tail biting to a level of more than one out of six pigs being bitten is a too high price to  
637 pay for avoiding tail docking. However, this relies on the assumption that the pain of  
638 tail biting is not as much as 31 times greater than the pain of docking, and this  
639 judgement will depend on the degree of pain suffered by docked pigs compared to  
640 bitten pigs. If pain during docking were reduced by the use of refined methods or  
641 effective analgesia (Sutherland *et al.*, 2011), or pain resulting from being bitten were  
642 reduced for example by earlier detection and intervention (D'Eath *et al.*, 2014), the  
643 balance would be altered.

644  
645 These calculations are based on some crude assumptions which can be discussed.  
646 Tail docking affects all pigs on a farm, but tail biting affects an uncertain and variable  
647 number of pigs to an uncertain and variable extent. It will depend on breed,  
648 management and various aspects of the scenario (D'Eath *et al.*, 2014), and the actual  
649 outcome for any group of pigs will be uncertain. We have simplified this by using our  
650 modelled population averages. Some of the most plausible relaxations of the  
651 simplifying assumptions underlying this framework would be: instead of adding up  
652 pains, greater levels of suffering could be given greater weight. Or instead of the  
653 expected average value of incidence, the amount of variation around these expected  
654 values could be given greater weight (reflecting risk aversion on behalf of the pigs).  
655 Perhaps surprisingly, both of these relaxations would count in favour of Standard  
656 Docked.

657  
658 On the other hand, we may assume that the enriched and larger pens in Enhanced  
659 Undocked, and to a lesser extent Efficient Undocked, benefit all of the pigs in ways

660 other than reducing tail biting. For example these pens most likely provide a better  
661 outlet for foraging and exploratory behaviour, greater physical comfort with more  
662 choice of lying areas, greater capacity for physical exercise including play and  
663 improved social control due to the ability to associate with or avoid certain penmates.  
664 Thus these systems could provide a positive welfare benefit for all pigs to offset the  
665 negative 'pain' aspects for bitten pigs included in our calculations, which would weigh  
666 in favour of Enhanced and Efficient Undocked systems. It has been suggested that an  
667 intact tail has a function for communication between pigs (Kiley-Worthington et al  
668 1976), and to some, it matters that docking impacts on the 'animal integrity' of the pig  
669 (Sutherland and Tucker, 2011) either or both of which would also weigh in favour of  
670 Enhanced or Efficient Undocked.

671  
672 So far the discussion has focussed on consequences for pig welfare. From a human  
673 perspective, costs and benefits apply to different parties: The financial costs of  
674 implementing the four scenarios are borne by farmers (to some extent passed on to  
675 consumers) while the financial benefits are the availability of affordable pig meat  
676 products (a market good for consumers). Finally the benefits of improved welfare are a  
677 'non-market good' benefiting farmers and other citizens concerned for the pigs'  
678 welfare. An important aspect of weighing up good and bad features of the different  
679 scenarios is to ask whether there is the right balance between costs and benefits for  
680 humans and welfare consequences for the pigs. The question is whether Enhanced or  
681 Efficient Undocked systems represent an improvement in animal welfare to match the  
682 higher cost of production (compared to Standard housing), and whether society at  
683 large or a subset of consumers are willing to pay farmers to reflect this, or whether a  
684 lower financial cost of producing pig meat is a higher priority. Meta-analysis has shown

685 that a higher income is the strongest predictor of increased willingness to pay for high  
686 animal welfare products (Lagerkvist & Hess 2011). Thus the perception of the proper  
687 ethical balance between the pig and human perspectives is likely to be different for  
688 wealthy or poorer countries or individuals.

689  
690 It is important to stress that a consequentialist perspective which accepts the weighing  
691 up of consequences does not necessarily permit the acceptance of the best of these  
692 four alternatives. Even if (for example) Standard Docked is judged to have better  
693 overall consequences than presently known versions of Enhanced Undocked, it is still  
694 not necessarily justified. If a version of Enhanced Undocked could be devised, which  
695 cost roughly the same as Standard Docked and with similarly low levels of tail biting as  
696 this scenario, it would clearly be better, and Efficient Undocked is clearly a step in this  
697 direction. From a consequentialist ethical perspective, there is always a duty to look for  
698 better strategies. For example, genetic selection of pigs to reduce tail biting behaviour  
699 may be possible and could result in lower levels of tail damage in all four scenarios  
700 (Turner 2011; D'Eath *et al.*, 2014).

701  
702 Finally, there is reason to mention that, for some, this sort of weighing of ethical costs  
703 and benefits is not considered acceptable. From a deontological ethical perspective,  
704 avoiding a larger evil cannot normally justify a lesser evil (Nozick, 1974). Tail docking  
705 does not address the underlying welfare problem which is an important contributor to  
706 tail biting in the first place: that pigs bite due to an unmet motivational need to forage,  
707 root, investigate and explore (Taylor *et al.*, 2010). Hence, from a deontological  
708 perspective, tail docking can be considered wrong. It should also be considered wrong  
709 to have a form of production which makes tail docking necessary. Neither situation is

710 ethically acceptable. This deontological argument demands changes to housing and  
711 management to reduce tail biting to an acceptably low level without the need for  
712 docking (D'Eath *et al.*, 2014; Spoolder *et al.*, 2011).

713

## 714 **Conclusion**

715 Our analysis suggests that by continuing to dock their pigs in systems specified by  
716 current EU pig housing standards, pig producers are acting in a risk-averse way which  
717 is in their economic best interests. From a legal standpoint, there appears to be a  
718 discrepancy between the requirements of the EU Directive (to end 'routine' tail docking  
719 and provide manipulable materials) and the practices in the Member States, partly due  
720 to a lack of clarity in the Directive. Various ethical concerns about tail docking remain:  
721 it is a painful mutilation, fails to respect animal integrity and does not address the  
722 underlying deficiencies in the environment that increase the risk of tail biting in the first  
723 place. A total ban on tail docking in current systems, without any changes in housing  
724 and management, would likely lead to an increase in tail biting, with a negative impact  
725 on farm economy and, other things being equal, also on welfare, if we assume that  
726 being tail bitten is more than 7 times more painful for a pig than being tail docked.  
727 Hence, a new management pattern is needed, considering changes to improve the  
728 housing environment to reduce tail biting risk. This also has the potential to improve  
729 pig welfare in other ways, although it would increase the cost of housing. Thus to  
730 achieve the goal of improvement of animal welfare through a ban on tail docking, our  
731 analysis suggests that production system changes (perhaps alongside genetic  
732 selection to reduce tail biting) may be needed, provided that customers are willing to  
733 pay the increased costs.

734

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747

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912 **Table 1.** Comparison of cost items of the modelled scenarios in relation to tail biting management practices.

	Standard Docked	Standard Undocked	Enhanced Undocked	Efficient Undocked
	Standard housing with tail docking	Standard housing with no tail docking	Enhanced housing with extra space and straw, no tail docking	More space and straw than Standard, less than Enhanced, no tail docking
Labour cost of tail docking	Yes	No	No	No
Losses due to victims of tail biting outbreaks	Small	Large	Intermediate	Intermediate
Extra variable and fixed costs of reducing tail biting (straw, space)	No	No	Yes	Yes, between standard and enhanced

913

914 **Table 2.** Summary of costs and revenues (€/pig produced) for the four finishing pig production scenarios in 2012 used in the model  
 915 when not taking into account potential differences in tail biting and not taking into account potential costs associated with tail biting.

Monetary values	Standard Docked	Standard Undocked	Enhanced Undocked	Efficient Undocked
	(€/pig)	(€/pig)	(€/pig)	(€/pig)
Total revenue	123.93	123.93	123.93	123.93
Total variable costs <sup>1,3</sup>	124.86	124.86	128.87	126.36
Total fixed costs <sup>2,3</sup>	12.71	12.57	14.46	13.39
Gross margin	-0.93	-0.93	-4.94	-2.43
Net margin	-13.64	-13.50	-19.40	-15.82

916 <sup>1</sup> Variable cost include: weaner cost, feed, vet and medicine, transport and marketing, straw and enrichment materials, water and electricity, carcass  
 917 condemnation, interest on capital in animals and interest on capital in variable inputs.

918 <sup>2</sup>Fixed cost include: interest and depreciation of fixed capital, insurance and maintenance and labour (including tail docking labour).

919 <sup>3</sup>Detailed figures of variable and fixed costs are presented in Table 3.

920



921 **Table 3** Details of variable and fixed costs included in margin calculations when not  
 922 taking into account potential differences in tail biting and not taking into account  
 923 potential costs associated with tail biting.

Description	Standard Docked (€/pig)	Standard Undocked (€/pig)	Enhanced Undocked (€/pig)	Efficient Undocked (€/pig)
<i>Variable costs</i>				
Weaner cost	58.41	58.41	58.41	58.41
Feed	57.36	57.36	57.36	57.36
Vet & medicine	0.74	0.74	0.74	0.74
Transportation & marketing	1.70	1.70	1.70	1.70
Straw & enrichment materials	0.17	0.17	1.00 <sup>1</sup>	0.50 <sup>2</sup>
Electricity	1.50	1.50	1.50	1.50
Water	0.37	0.37	0.37	0.37
Carcass condemnation	0.27	0.27	0.27	0.27
Other variable costs	3.46	3.46	3.46	3.46
Interest on capital in animals	0.29	0.29	0.29	0.29
Interest on capital in variables	0.59	0.59	0.59	0.59
<b>Total Variable costs</b>	<b>124.86</b>	<b>124.86</b>	<b>125.69</b>	<b>125.19</b>
<i>Fixed costs</i>				
Interest and depreciation	8.82	8.82	10.71 <sup>3</sup>	9.64 <sup>3</sup>
Labour costs	3.88	3.75 <sup>4</sup>	6.92 <sup>1,3</sup>	4.92 <sup>2</sup>
<b>Total Fixed costs</b>	<b>12.71</b>	<b>12.57</b>	<b>17.43</b>	<b>14.56</b>

924 Data are based on Sinisalo *et al.* (2012) and Udesen (2013) except items marked by superscripted  
925 numbers:

926 <sup>1</sup> Assuming straw costs 6 cents per kg (providing 200 g/d/pig of chopped straw) and a labour use  
927 scenario for part-slatted systems based on information provided by Mäki-Mattila (1998). Labour costs  
928 include the distribution of clean straw and removal of dirty straw.

929 <sup>2</sup> Compared to Enhanced Undocked, these figures are lower because only 100g/d/pig of chopped straw  
930 is provided and no labour for extra cleaning of dirty straw out of pens is assumed. Labour use for straw  
931 allocation is based on information provided by Mattson *et al.* (2004).

932 <sup>3</sup> The cost differences between Enhanced Undocked and the two standard scenarios are because of the  
933 greater size of pens, with Efficient Undocked pen sizes (and thus costs) being intermediate. Cost per m<sup>2</sup>  
934 of pen area is based on MAFF (2000).

935 <sup>4</sup> Cost savings compared to Standard Docked represent estimated cost of labour used in tail docking  
936 procedure at the given wage rate (Parviainen, 2001).

937

938

939 **Table 4** Average probabilities of tail biting outbreaks derived from datasets as used in  
 940 the model.

Scenario	Probability ( $P_i$ ) for size of outbreak category $i$ to occur <sup>2</sup>				Incidence <sup>3</sup> (%)
	No outbreak ( $i=no$ ) <sup>1</sup>	Small ( $i=S$ )	Medium ( $i=M$ )	Large ( $i=L$ )	
Standard Docked	0.846	0.10	0.03	0.02	3.1
Standard Undocked	0.43	0.19	0.24	0.14	17.3
Enhanced Undocked	0.73	0.15	0.07	0.04	6.3
Efficient Undocked	0.73	0.15	0.07	0.04	6.3

941  
 942 <sup>1</sup>The probability of no outbreak in the pen is  $P_{no}$ . Hence, the probability of either small, medium-sized or  
 943 large outbreak to occur is  $1-P_{no}$ . Values for  $P_{no}$  were determined after a synthesis based on estimated  
 944 incidence for the different scenarios. Standard Docked: Hunter *et al.* (1999), EFSA (2007), Forkman *et*  
 945 *al.* (2010); Standard Undocked: Van de Weerd *et al.* (2006), Van de Weerd *et al.* (2005), Zonderland *et*  
 946 *al.* (2008); Enhanced Undocked: Partanen *et al.* (2012), Sinisalo *et al.* (2012) and Munsterhjelm (2013).  
 947 <sup>2</sup>Probability  $P_i$ ,  $i = (S,M,L)$ , refers to the probability of small (S), medium-size (M) or large (L) outbreak to  
 948 occur. When probability of no outbreak  $P_{no}$  is given, other probability parameters can be determined as  
 949 follows:  $P_S = (0.783-0.783(1-P_{no})) (1-P_{no})$ ;  $P_L = (0.094+0.259(1-P_{no}))(1-P_{no})$ ;  $P_M = 1 - P_S - P_L - P_{no}$ .  $P_S$ ,  
 950  $P_M$  and  $P_L$  are adjusted accordingly when a value for  $P_{no}$  is drawn from a distribution during the  
 951 simulations.  $P_i$  was estimated with a time-series model and data provided by Sinisalo *et al.* (2012) for  
 952 Enhanced Undocked, and then this was extrapolated to other scenarios based on the total expected  
 953 incidence. The values in table represent average parameter values.

954 <sup>3</sup> Incidence is the % of pigs that will be affected by tail biting injury at some point during their time on the  
 955 farm.

956

957 **Table 5** Values for mean and standard deviation of probability of no outbreak ( $P_{no}$ ) for  
 958 each scenario used in risk simulations RS1 and RS2

Simul- ation	Distribution: Normal (Mean $\mu$ , St. Dev. $\sigma$ )			
	Standard Docked	Standard Undocked	Enhanced Undocked	Efficient Undocked
RS1 <sup>1</sup>	0.846, 0.05	0.43, 0.1	0.73, 0.1	0.73, 0.1
RS2	0.846, 0.05	0.43, 0.2	0.73, 0.2	0.73, 0.2

959  
 960 <sup>1</sup> Standard deviations for the three Undocked scenarios were determined according to the standard  
 961 deviation of probability of no outbreak observed in the data of Sinisalo *et al.* (2012).

962

963

964 **Figure Legends**

965

966 **Figure 1** Decision Tree structure representing choices (four housing/management  
967 scenarios), four states of nature or chance nodes, four conditional probabilities  
968 including size (No, S, M, and L) and probability of tail biting outbreaks for each chance  
969 node and the monetary values of outcome.

970

971 **Figure 2** a) Result of risk simulation RS1 when normally distributed uncertainty was  
972 added to the probability of no outbreak in each of the scenarios. The following values  
973 were used: Mean ( $\mu$ ), St. Dev. ( $\sigma$ ) Standard Docked: (0.846, 0.05); Standard  
974 Undocked: (0.43, 0.1); Enhanced Undocked and Efficient Undocked: (0.73, 0.1). b)  
975 Result of risk simulation RS2 when normally distributed uncertainty was added to the  
976 probability of no outbreak in each of the scenarios. Following values used: Mean ( $\mu$ ),  
977 St. Dev. ( $\sigma$ ) Standard Docked: (0.846, 0.05); Standard Undocked: (0.43, 0.2) and  
978 Enhanced Undocked and Efficient Undocked (0.73, 0.2). The percentage values  
979 represent the share of simulated batches which fall within each €0.5 interval when  
980 grouped according to EMV and when tail biting occurs systematically in the pens of a  
981 compartment.

982

Figure 1

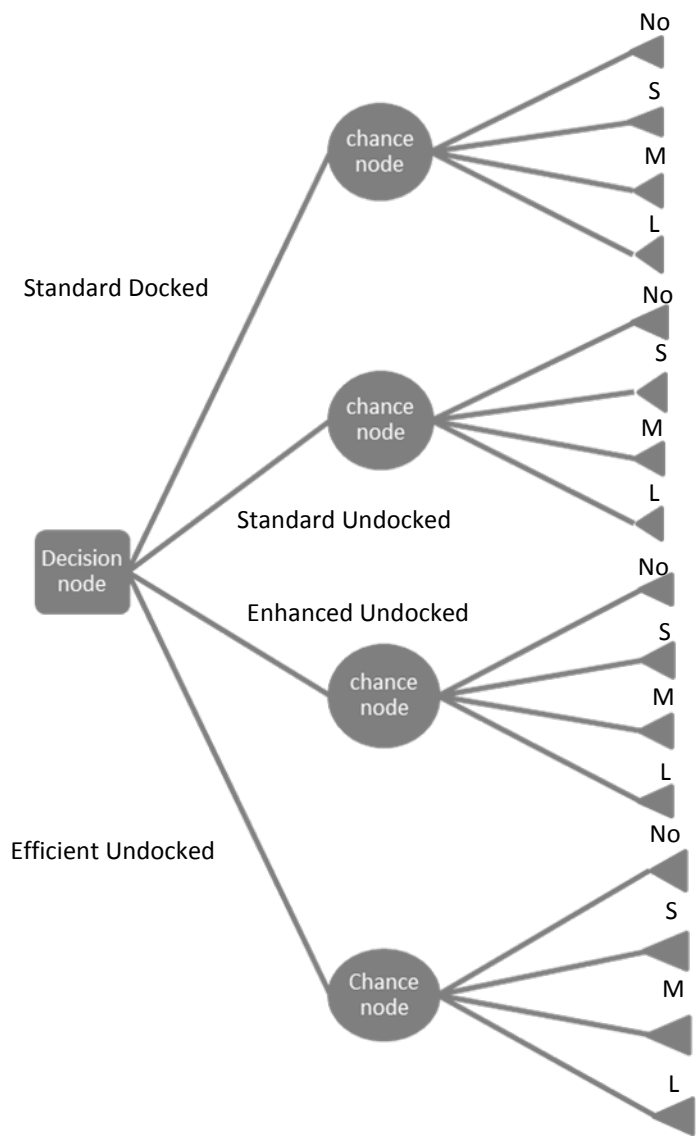
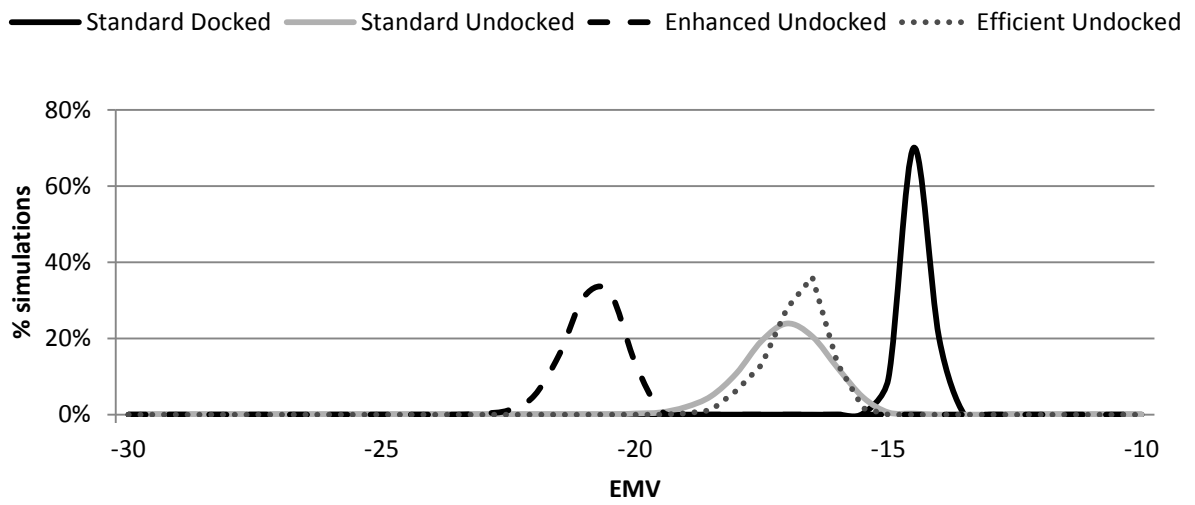
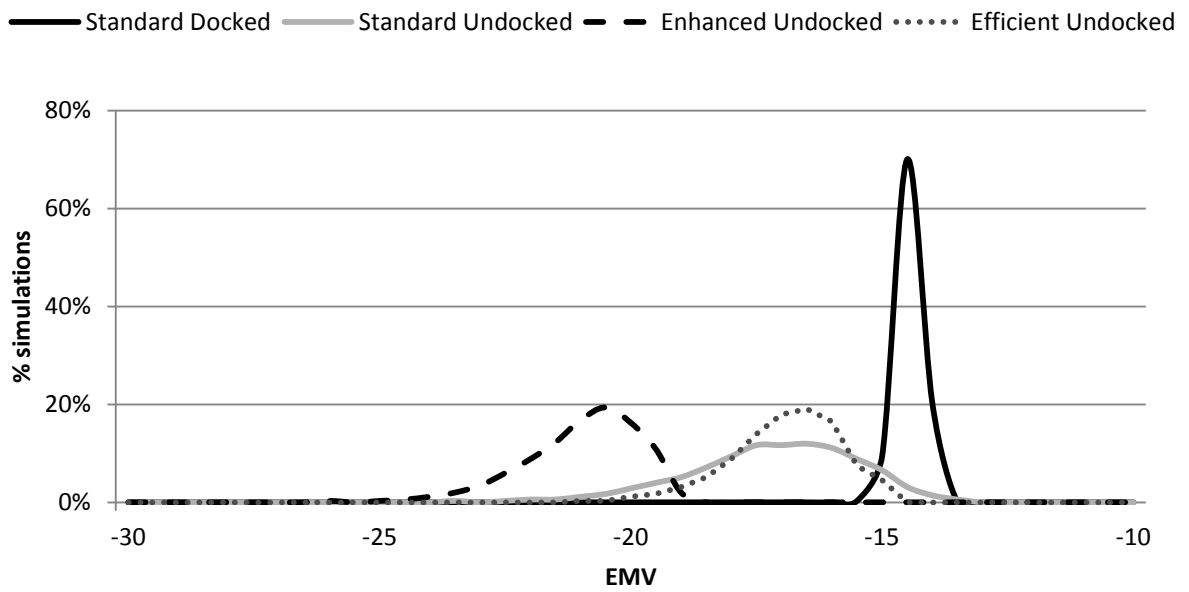


Figure 2



a)



b)

# **Why are most EU pigs tail docked? Economic and ethical analysis of four housing and management scenarios in the light of EU legislation and animal welfare outcomes**

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## **Supplementary material**

### **Welfare consequences of tail biting and tail docking**

#### *Welfare effects of tail biting*

Being the recipient of tail biting is undoubtedly very negative for a pig's welfare. The immediate effect is injuries to the tail which are presumably painful (Van Putten, 1969), although this has not been systematically studied. However, it seems highly likely that a series of bites over time resulting in a messy wound and loss of part or all of the tail is rather painful. In response to being bitten, pigs show changes in behaviour including avoidance of biting pigs and changes in tail position ('tucked under' Statham *et al.*, 2009; Zonderland *et al.*, 2009), which are likely to be defensive reactions, and vocalisations (Blackshaw, 1981) which indicate pain and distress (Manteuffel *et al.*, 2004). Tail bitten pigs show changes to their heart-rate patterns which could indicate psychological disturbance (Zupan *et al.*, 2012). Even tail chewing that does not result in obvious wounds may cause an inflammatory response (Munsterhjelm *et al.*, 2013; Simonsen *et al.*, 1991).

Further challenges to pig welfare occur subsequent to biting. As well as the direct trauma and blood loss, there is an increased risk of bacterial infection in the tail (Heinonen *et al.*, 2010; Munsterhjelm *et al.*, 2013). The infection can spread locally leading to osteomyelitis in the coccygeal vertebrae and abscesses in the surrounding tissue (Huey, 1996). In addition, haematogenous spread of bacteria through the body of the pig can lead to septicaemia and pyaemia. The pyaemic processes resulting from tail lesions



include osteomyelitis, especially in the vertebrae, and abscesses in the lungs and other organs (Huey, 1996; Kritas and Morrison, 2007; Valros *et al.*, 2004). Lesions in the vertebrae may in some cases lead to paralysis of the hind limbs (EFSA, 2007). The pig's experience of infections, the formation of abscesses and paralysis must represent a considerable challenge to its welfare (Millman, 2007).

#### *Short-term effects of tail docking on welfare*

Tail docking is acutely painful for piglets (Guatteo *et al.*, 2012; Sutherland and Tucker, 2011). This is indicated by behavioural changes including disrupted suckling, increased activity, lying separately from other piglets, tail wagging, jamming, sitting and bottom scooting (sitting, dragging bottom along the floor (Noonan *et al.*, 1994; Rutherford *et al.*, 2009; Sutherland *et al.*, 2008; Torrey *et al.*, 2009). Tail docking can also result in physiological stress, indicated by elevated cortisol and/or ACTH in some studies (Sutherland *et al.*, 2011) but not others (Prunier *et al.*, 2005) or only for certain docking methods (Sutherland *et al.*, 2008). The stress of docking is also indicated by a short-term decrease in skin temperature (Kluivers *et al.*, 2010) and in white blood cell counts (Sutherland *et al.*, 2008).

The exact period after the procedure during which piglets experience pain and discomfort is unknown, as few studies have attempted to track piglets in the days after docking. Studies generally only investigate behavioural responses in the immediate minutes after the procedure (Noonan *et al.*, 1994; Rutherford *et al.*, 2009), or for a small number of hours afterwards (Sutherland *et al.*, 2008 and 2011; Marchant-Forde *et al.*, 2009). Some studies have extended behavioural analysis for longer, and behavioural effects have been seen in the days following docking (tail docked piglets showed more tail jamming on day 3: Torrey *et al.*, 2009). Physiological assessment, for instance of stress physiology, is also generally conducted for only one to three hours after the procedure, and in any event, findings are variable: some studies (Marchant-Forde *et al.*, 2009; Prunier *et al.*, 2005) found no effect of docking on cortisol levels, whereas increased cortisol in tail docked piglets relative to handled controls has been seen at 30 (Sutherland *et al.*, 2011) and 60 (Sutherland *et*

*al.*, 2008) minutes after the procedure, but not later. A full account of the welfare significance of tail docking would require further studies to examine behavioural and physiological effects beyond the first few hours after docking.

Although there are no direct statistical comparisons between tail docking and other painful procedures performed on piglets, a comparison of the degree of biological alteration seen following the procedures can be made. For instance, compared to cold tail docking, there were around five to eight times as many squeals in response to castration by cutting or tearing respectively, and there were three to four times as many escape attempts following castration compared to docking (Marchant-Forde *et al.*, 2009). Peak vocal frequency (in Hz) was also between 60 and 80% higher during castration than during tail docking (Marchant-Forde *et al.*, 2009). Prunier *et al.* (2005) found a significant increase in ACTH (up to 60 minutes) and cortisol (up to 90 minutes) following castration but no response to tail docking, or teeth resection. Comparison to other procedures is more equivocal: Noonan *et al.* (1994) found that the immediate vocalisation reaction to tail docking was greater than that seen in response to teeth resection or ear notching. However, in a different study, teeth grinding or clipping was associated with similar levels of grunting to tail docking, and the number of escape attempts seen following docking was lower than after teeth resection (Marchant-Forde *et al.*, 2009). On the basis of these studies, tail docking could be considered to be less painful than piglet castration (Marchant-Forde *et al.*, 2009; Prunier *et al.*, 2005), and roughly similar in painfulness, or slightly more painful than teeth resection (teeth clipping or grinding), ear notching or ear tagging (Marchant-Forde *et al.*, 2009; Noonan *et al.*, 1994).

A limited amount of research has been carried out to investigate ways to reduce tail docking pain either by comparing different methods of docking, or by using analgesia (Kluivers *et al.*, 2010; Marchant-Forde *et al.*, 2009; Sutherland *et al.*, 2011). Refinements in the methods used have the potential to considerably reduce the welfare challenge of tail docking.

### *Long-term effects of tail docking on welfare*

The suggestion that tail docking alters sensory function in tails, and possibly causes chronic pain (continuing after the tail has healed) is based on identification of neuromas in docked tails (Done *et al.*, 2003; Herskin *et al.* 2014; Simonsen *et al.*, 1991). However, no research has yet attempted to establish whether pigs experience chronic pain as a consequence of tail docking (FAWC, 2011). Sandercock *et al.* (2011) found no difference at 5-8 weeks of age in nociceptive function (altered sensitivity to mechanical or cold stimuli) in tail-docked pigs.

Other (non-pain) effects of tail docking have been found: reproductive development was altered (at day 40), with docked pigs showing lower oestradiol, and males having reduced testis weight and females having reduced proliferation of Leydig cells (Ashworth *et al.*, 2011). Central physiological stress pathways are also altered: tail-docked female pigs show increased expression of mRNA for CRH receptor 1 in the amygdala, while both sexes show increases in CRH receptor 2 mRNA expression (Rutherford *et al.*, 2014). The significance of these changes for welfare is not known.

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**Why are most EU pigs tail docked? Economic and ethical analysis of four housing and management scenarios in the light of EU legislation and animal welfare outcomes**

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**Supplementary Table:** Details of the costs included to estimate the total costs of the victims of tail biting <sup>1</sup>.

Cost item	Value (€/victim pig)	Assumptions
Vet and medicine	6.00	Pig treated for 5 days <sup>3</sup> : (0.4 €/day medicine + 0.35 €/day vet work <sup>2</sup> )× 1.6
Extra labour effort by farm workers	6.85	Extra time/victim: 27 minutes <sup>4</sup> , Duration of treatment 5 days, time spent in hospital 14 days, and proportion of victims moved to hospital pen 14.8% based on Niemi <i>et al.</i> (2012a). Price of labour 15€/hour <sup>5</sup> .
Materials	0.30	An extra enrichment of 0.5 kg/day/victim is provided in the original pen for 5 days and for two weeks in the hospital pen.
Disposal	2.80	The same percentage of victims (2.12%) to be destroyed as reported by Zonderland <i>et al.</i> (2011).
Loss of condemned meat	1.22	0.8 kg condemned/victim based on Niemi <i>et al.</i> (2012a), price €1.52/kg pigmeat.
Reduced daily gain and consequent increased feed use to finishing <sup>6</sup>	1.80	Simulated based on Niemi <i>et al.</i> (2012b) and Sinisalo <i>et al.</i> (2012)

<sup>1</sup> Numbers based on authors' calculations, literature and data from an experimental farm. The fixed costs of hospital pens are not included as the farm is assumed to have a fixed hospital pen capacity and the costs are included in the fixed costs.

<sup>2</sup> Estimated after consultation with Professor Mari Heinonen, University of Helsinki and University Pharmacy.

<sup>3</sup> 1.6 is a multiplier for secondary infections for each victim based on Niemi *et al.*, 2012a.

<sup>4</sup> Including: 2 minutes/day/victim for medication (including secondary infections) for five days for 1/3 of victims + 2.55 minutes/victim for moving the animal to hospital pen for 14.8% of victims + 1 minute/day/victim for providing extra enrichments and extra cleaning for two weeks after tail biting (except 2.9 minutes in a hospital pen).

<sup>5</sup> Assumptions concerning the amount and cost of labour based on authors' calculations and Mäki-Mattila (1998), Parviainen (2001) and Niemi *et al.* (2012a).

<sup>6</sup> In our model, average daily weight gain in bitten pigs was reduced by 1-3% compared with unaffected pigs, which results in a longer finishing period and a greater use of feed, meaning that feed efficiency is also affected due to longer fattening time requiring more feed for body maintenance (Sinisalo *et al.*, 2012). We have assumed that there are no separate direct effects on feed conversion efficiency itself. Of the €1.80 reported here, the effect of increased feed consumption due to the decreased average weight gain accounts for €1.39 per pig in extra costs whereas the direct impact of reduced weight gain in terms of reduced throughput of pigs per unit of time was €0.41 per pig.

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