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

Published in:
Animal

DOI:
10.1017/S1751731115002098

Print publication: 01/04/2016

Document Version
Peer reviewed version

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

R. B. D'Eath[1], J.K. Niemi[2], B. Vosough Ahmadi[1], K.M.D. Rutherford[1], S.H. Ison[1], S.P. Turner[1], H.T. Anker[3], T. Jensen[4], M.E. Busch[4], K.K. Jensen[3], A.B. Lawrence[1], P. Sandøe[3,5]

[1] *SRUC, West Mains Road, Edinburgh, EH9 3JG, UK*

[2] *Natural Resources Institute Finland (Luke), Economics and Society, Kampusranta 9, FI-60320 Seinäjoki, Finland*

[3] *Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 25, 1958 Frederiksberg C, Copenhagen, Denmark*

[4] *Danish Pig Research Centre, SEGES, Axeltorv 3, 1609 Copenhagen V, Denmark*

[5] *Department of Large Animal Sciences, University of Copenhagen, Grønnegårdsvej 8, 1870 Frederiksberg C, Copenhagen, Denmark*

* Corresponding author: Rick D'Eath.

Email: rick.death@sruc.ac.uk. Tel +44 (0)131 651 9356

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

Abstract

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

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

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

Implications

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

Introduction

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

The EU Directive (2001/93/EC amending Directive 91/630/EEC, now codified in Council Directive 2008/120/EC) which came into force in January 2003 states that tail docking must not “be carried out *routinely* but only where there is evidence that injuries … to other pigs' ears or tails have occurred. Before carrying out these procedures, other measures shall be taken to prevent tail biting and other vices taking into account environment and stocking densities. For this reason, inadequate environmental conditions or management systems must be changed" (italics added). It goes on to state that "…pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals."

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

In this article we aim to understand the barriers standing in the way of the goal of the EU Council Directive 2008/120/EC: to stop or severely limit the use of tail docking in such a way that it will benefit the welfare of the affected pigs. To achieve this we develop an economic model of four management and housing scenarios, three without tail-docking and one with tail docking. In our analysis and discussion of these scenarios we focus on legal frameworks, financial incentives, consequences for animal welfare and finally on ethical considerations.

Materials and methods

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

Financial analysis of four pig production scenarios

The four scenarios are:

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

Standard Docked resembles current Danish production where 0.7 m^2/pig is recommended, even though the legal requirement is only 0.65 m^2/pig; Standard

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

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

Financial inputs

Production and price data for the four scenarios were gathered, and gross and net margins (€/pig) were estimated in the absence of any costs associated with tail biting (Table 2). The net margin for Standard Docked was based on Udesen (2013). The net margins for the three Undocked scenarios were calculated by differentiating the costs by the characteristics of production. The main differences between the scenarios are labour costs associated with docking tails (used only in Standard Docked), the material and labour costs of providing straw and enrichment materials (straw is provided only in Efficient and Enhanced Undocked) and fixed costs of buildings (cost of additional space per pig in Efficient and Enhanced Undocked).In Finland, a new Decree requires that at least two thirds of the pen floor area must be either solid or drained (i.e. perforations <10% of the area, in effect from 2013, except already existing pig houses for which it will become in effect 2028; Finnish Government, 2012), whereas in Denmark one third of the floor must be solid or drained from July 2015 (Danish Government, 2000). Hence, we have assumed that the two Standard scenarios have two thirds slatted and the Efficient and Enhanced Undocked have one third slatted floor. Solid or drained floor is less expensive to build than slatted floor but is more labour intensive to keep clean. Differences in fixed costs, labour costs and materials needed are reflected in our calculations (Table 3).

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

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

A pen size of 11 was chosen because tail biting data used in a key study originated from a farm where there were on average 11 pigs per pen. Although pig farms often have larger pens than this (e.g. 16 pigs per pen is the most common in Denmark), extending the results to larger pens could have biased our parameters. However, there is no strong evidence suggesting large group size as a major risk factor for tail biting.

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

Size of tail biting outbreaks

In all four scenarios, outbreaks of tail biting can occur. In Standard Docked, the outbreaks are expected to be less likely to occur and to affect fewer pigs than in the three Undocked scenarios. This was based on evidence from experimental studies showing that tail docking is partially effective in reducing the incidence and impact of tail biting (e.g. Sutherland *et al*., 2009; reviewed by Sutherland & Tucker 2011). Industry figures from abattoirs can be difficult to interpret because scoring systems are not standardised across studies or locations (EFSA, 2007; Keeling *et al*., 2012), but some studies compare pigs from different production systems delivering to the same abattoir. In a farmer system survey combined with abattoir data, docked pigs had 2-3% bitten tails, while undocked pigs had 6-8%, regardless of deep, light or no straw being provided (Hunter *et al*., 2001). Data from a single Danish abattoir in which conventional (tail docked; 0.5-1.5% bitten), ecological and free-range pigs (tail intact; 1-5% bitten) were slaughtered showed higher average and more variable levels of tail biting over a 19 month period (Forkman *et al*., 2010). These studies indicate that levels of tail injury are lower in docked pigs from standard environments than in intact-tailed pigs from enriched environments.

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

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

Probability of tail biting outbreaks

The probability of small, medium-sized and large outbreak was estimated based on data by Sinisalo *et al*. (2012) on the condition that the probability of no outbreak (“P_{no}”) is given. These data cover daily animal-level health records on 6,812 fattening pigs raised in 2007-2008 in an experimental farm similar to Enhanced Undocked. Thus for Enhanced Undocked (and for Efficient Undocked which was assumed to have the same tail biting risk), the relationship between the probability of no outbreak and small or medium outbreak was estimated using monthly statistics about the frequencies of tail biting outbreaks (Table 4). Because the use of docking and the housing environment affect tail biting, the probability of outbreak varies by scenario. The probability of no outbreak or of small, medium or large outbreaks in a pen for the two Standard scenarios was determined by extrapolation after consulting and synthesising data from various studies which give the total incidence (rather than individual pen data) in similar scenarios (Table 4). For Standard Docked, abattoir data suggest a prevalence of 0.5 to 3% (Hunter *et al*., 1999; EFSA, 2007; Forkman *et al*., 2010), but these are thought to underestimate the on-farm incidence (Busch et al., 2004). For Standard Undocked, only small experimental studies are available (Van de Weerd *et al*., 2005 and 2006; Zonderland *et al*., 2008). In addition to the detailed data of Sinisalo *et al*. (2012), two further studies were available as a check of our estimated incidence for Enhanced Undocked and Efficient Undocked (Partanen *et al*., 2012; Munsterhjelm, 2013). Incidence as used here and throughout this paper is meant in the sense of the % of pigs that will be affected by tail biting injury at some point during their time on the farm, rather than prevalence which would be a snapshot of affected pigs at a given instant.

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

Decision tree model

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

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

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

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

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

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

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

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

Results

Expected monetary values (EMV) of the considered costs in the four housing scenarios were simulated at –€14.2/pig for Standard Docked, –€16.8/pig for Standard Undocked, –€20.6 /pig for Enhanced Undocked and -€15.8/pig for Efficient Undocked. These average payoffs were determined by our initial assumptions and calculations and would also have been found if we had used a deterministic model. Based on these results and given the input data and assumptions used, Standard Docked resulted in the largest EMV. Although Standard Docked had slightly higher costs than Standard Undocked when excluding the costs of tail biting, the losses due to tail biting are expected to be approximately five times higher in Standard Undocked than in Standard Docked (17.3% rather than 3.1% incidence; Table 4). In contrast to this, Enhanced Undocked incurs larger fixed costs and higher labour costs caused by the increased use of straw and space than the Standard housing scenarios. Efficient Undocked, in which we simulated a well managed farm, able to control tail biting with less space and straw than Enhanced Undocked, performed second only to Standard docked. Enhanced Undocked and Efficient Undocked resulted in losses due to tail biting which are 63% lower than those in Standard Undocked.

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

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

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

Discussion

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

How to interpret the results of the economic modelling

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

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

Our results suggest that producers do not currently have an economic incentive to stop tail docking. To change this, the profitability of the Enhanced Undocked scenario would need to increase through reduced costs or increased income, and more producers would need to approach or exceed the success of our Efficient Undocked model scenario. Production costs per pig in enhanced housing (and efficient housing) were estimated to be higher (due to increased space, labour and enrichment) even without the costs of tail biting than in the two standard scenarios (which were similar in cost). Costs could be reduced for the enhanced or efficient housing: for example automated delivery of enrichments to pigs would reduce labour costs of allocating straw. If the level of tail biting assumed for Enhanced and Efficient Undocked could be achieved in an even smaller space than that of Efficient Undocked (between 0.7 and 0.9m^2 per pig), there is a potential for cost reduction. Thus we calculate that each 0.1 m^2 reduction in pen space would decrease fixed costs by €1.07 per pig.

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

Finally, we have assumed that all scenarios have a similar level of productivity, but increased space allowance can improve both average daily gain (Gonyou and Stricklin, 1998) and feed conversion ratio (Turner *et al*., 2000). Meta-analysis suggests a linear relationship between space and weight gain, but only up to a threshold after which further increases in space have no further effect (Gonyou *et al*., 2006). Pigs in pens of 1.0 m^2/pig (Enhanced) do not reach this threshold before slaughter, while at 0.7m^2/pig (Standard), pigs reach this threshold at around k=0.0317 - 0.0348 (where area (m^2) = k × $weight^{2/3}$), which equates to between 90.2kg and 103kg. After this threshold daily gain is reduced by 0.98% for each 0.001 of k (Gonyou et al., 2006). If we take the upper estimate of 0.0348 and assume that daily gain is reduced by the amount suggested by Gonyou *et al*. (2006) after a threshold of 90.2kg, then this would result in a 0.94kg lower live weight at 90 days, which equates to 1.06 €/pig. This would reduce the difference between the scenarios, but not by enough to affect the conclusions of our model.

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

The legal status of tail docking in the EU

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

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

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

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

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

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

Besides economics and legislation, other factors can contribute to pig producers' decisions on how to manage their herd. A study of pig producers' attitudes towards tail docking in the Netherlands, where docking is widespread (Bracke *et al*., 2013) showed that conventional pig producers frequently agreed with the following statements: "docking is necessary to prevent tail biting" (mean 4.9 on a scale from 1 to 6), and "it is better to dock all tails than to run the risk of tail biting even if it concerns just one bitten pig" (mean 5.0). There was lower agreement with the statement "I know how to effectively treat tail biting when it arises" (mean 4.1). Thus, most producers who currently use tail docking perceive the risk of tail biting as very serious, and most know some actions they could take in case of an outbreak but do not feel they can handle an outbreak of biting entirely effectively. These findings indicate that producers dislike tail biting not just because of the expected economic losses but perhaps also because they fear losing control over the situation. However, there is an absence of studies into producer attitudes to tail docking in countries where it has never been allowed or has been banned, and anecdotal reports suggest that farmers can learn to manage undocked pigs. It is also worth considering that factors other than production economics affect producer decision making. Farmers are conscious of potential conflict between production and animal welfare (Jääskeläinen et al 2014), thus farmers working with a system which they feel better meets the needs of pigs may enjoy greater job satisfaction, pride and a sense that they are promoting good animal husbandry.

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

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

Welfare consequences of tail biting and tail docking

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

Tail bitten pigs probably experience pain as evidenced by their vocalisations (Blackshaw 1981), avoidance of biting pigs and changes in tail posture (Zonderland et al 2009) although this has never been systematically quantified. As well as causing pain, inflammation and blood loss, tail wounds can get infected, and infection can spread to the spine (sometimes resulting in paralysis of the hind limbs) and to other organs including the lungs (Munsterhjelm et al 2013). Repeated tail bites resulting in a messy wound and partial or total tail loss must presumably be a more painful way for a pig to lose its tail than by tail docking in a quick single event. Furthermore, suffering due to secondary infections (which are rare following tail docking) adds further to the negative welfare consequences of being tail bitten.

The ethical balance concerning tail docking and tail biting

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

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

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

Standard Undocked: 17.3U(B)

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

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

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

It could be argued, based on these calculations and plausible assumptions, that Enhanced (or Efficient) Undocked is better from the point of view of the pigs than Standard Docked, which in turn is better than Standard Undocked. Thus, it seems plausible that comparing Standard Docked and Enhanced (or Efficient) Undocked, a doubling of the risk of tail biting, where the tail biting is still at a relatively low level, is a price worth paying for avoiding tail docking, whereas it does also seem plausible that comparing Standard Docked and Standard Undocked, an almost six fold increase in tail biting to a level of more than one out of six pigs being bitten is a too high price to pay for avoiding tail docking. However, this relies on the assumption that the pain of tail biting is not as much as 31 times greater than the pain of docking, and this judgement will depend on the degree of pain suffered by docked pigs compared to bitten pigs. If pain during docking were reduced by the use of refined methods or effective analgesia (Sutherland *et al.,* 2011), or pain resulting from being bitten were reduced for example by earlier detection and intervention (D'Eath *et al*., 2014), the balance would be altered.

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

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

So far the discussion has focussed on consequences for pig welfare. From a human perspective, costs and benefits apply to different parties: The financial costs of implementing the four scenarios are borne by farmers (to some extent passed on to consumers) while the financial benefits are the availability of affordable pig meat products (a market good for consumers). Finally the benefits of improved welfare are a 'non-market good' benefiting farmers and other citizens concerned for the pigs' welfare. An important aspect of weighing up good and bad features of the different scenarios is to ask whether there is the right balance between costs and benefits for humans and welfare consequences for the pigs. The question is whether Enhanced or Efficient Undocked systems represent an improvement in animal welfare to match the higher cost of production (compared to Standard housing), and whether society at large or a subset of consumers are willing to pay farmers to reflect this, or whether a lower financial cost of producing pig meat is a higher priority. Meta-analysis has shown that a higher income is the strongest predictor of increased willingness to pay for high animal welfare products (Lagerkvist & Hess 2011). Thus the perception of the proper ethical balance between the pig and human perspectives is likely to be different for wealthy or poorer countries or individuals.

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

Finally, there is reason to mention that, for some, this sort of weighing of ethical costs and benefits is not considered acceptable. From a deontological ethical perspective, avoiding a larger evil cannot normally justify a lesser evil (Nozick, 1974). Tail docking does not address the underlying welfare problem which is an important contributor to tail biting in the first place: that pigs bite due to an unmet motivational need to forage, root, investigate and explore (Taylor *et al*., 2010). Hence, from a deontological perspective, tail docking can be considered wrong. It should also be considered wrong to have a form of production which makes tail docking necessary. Neither situation is ethically acceptable. This deontological argument demands changes to housing and management to reduce tail biting to an acceptably low level without the need for docking (D'Eath *et al*., 2014; Spoolder *et al*., 2011).

Conclusion

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

Acknowledgements

Funding from SEGES, Danish Pig Research Centre supported this review. This funding is mainly from pig industry sources, and two of the authors of the paper also work for this organisation, resulting in a potential or perceived conflict of interest. However, the contract for this research with two of the independent academic partners (SRUC and University of Copenhagen) explicitly endorses that the work is at 'arm’s length' from commercial interests, and the first and senior author have led the process, and are satisfied that the result is independent. MTT Agrifood did not receive funding from SEGES. SRUC also receives funding from the Rural and Environment Science and Analytical Services (RESAS) Division of the Scottish Government. Emma Baxter and Helle Lahrmann contributed to valuable discussions and provided comments on earlier drafts.

References

Arnoult MH, Ahmadi BV, Stott AW, Cain PJ, Guy JH, Seddon Y and Edwards SA 2011. Economics of higher welfare pig production. An independent scientific report commissioned by the RSPCA, Newcastle University and SAC, Edinburgh, UK.

Blackshaw JK 1981. Some behavioural deviations in weaned domestic pigs: persistent inguinal nose thrusting, and tail and ear biting. Animal Production 33, 325-332.

Bracke M, De Lauwere CC, Wind SM and Zonderland JJ 2013. Attitudes of Dutch Pig Farmers Towards Tail Biting and Tail Docking. Journal of Agricultural and Environmental Ethics 26, 847-868.

Broome J 1991. Weighing Goods: Equality, Uncertainty and Time. Blackwell, Oxford, UK.

Busch ME, Wachmann H, Nielsen EO and Petersen HH 2004. Tail biting - can slaughter data be used to identify herds with a high prevalence? (In Danish: Halebid - Kan slagtedata anvendes til at identificere besætninger med høj forekomst?). Report: Meddelelse 643.

Danish Pig Research Centre (PRC), Copenhagen, Denmark. Retrieved on 22 August 2014 from http://vsp.lf.dk/Publikationer/Kilder/lu_medd/2004/643.aspx?full=1.

Cicia G and Colantuoni F 2010. Willingness to Pay for Traceable Meat Attributes: A Meta-analysis. International Journal of Food System Dynamics 3, 252-263.

D'Eath RB, Arnott G, Turner SP, Jensen T, Lahrmann HP, Busch ME, Niemi JK, Lawrence AB and Sandøe P 2014. Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? Animal 8, 1479-1497

EFSA 2007. The risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems (Question No EFSA-Q-2006-013). Annex to the EFSA Journal 611, 1-13.

FAWC 2011. Opinion on mutilations and environmental enrichment in piglets and growing pigs. Farm Animal Welfare Council, London, UK.

Finnish Government 2012. Valtioneuvoston asetus sikojen suojelusta (Finnish Government decree on the protection of pigs).VNa 15.11.2012/629.

Forkman B, Olsen P, Nørgaard N, Laursen PB, Pedersen LJ, Holm L, Viekilde K and Søndergaard JT 2010. Working group report on the keeping of pigs (In Danish: Arbejdsgrupperapport om hold af svin). Justitsministeriet (Ministry of Justice), Copenhagen, Denmark.

Gonyou HW and Stricklin WR 1998. Effects of floor area allowance and group size on the productivity of growing/finishing pigs. Journal of Animal Science 76, 1326-1330.

Gonyou HW, Brumm MC, Bush E, Deen J, Edwards SA, Fangman T, McGlone JJ, Meunier-Salaun M, Morrison RB, Spoolder H, Sundberg PL and Johnson AK 2006. Application of broken-line analysis to assess floor space requirements of nursery and grower-finisher pigs expressed on an allometric basis. Journal of Animal Science 84, 229-235.

Harley S, More S, O'Connell N, Hanlon A, Teixeira D and Boyle L 2012. Evaluating the prevalence of tail biting and carcase condemnations in slaughter pigs in the Republic and Northern Ireland, and the potential of abattoir meat inspection as a welfare surveillance tool. Veterinary Record 171, 621.

Herskin MS, Thodberg K and Jensen HE 2014. Effects of tail docking and docking length on neuroanatomical changes in healed tail tips of pigs. Animal FirstView, 1-5 http://dx.doi.org/10.1017/S1751731114002857

Huirne RBM and Dijkhuizen AA 1997. Basic methods of economic analysis. In Animal health economics: principles and applications (eds. AA Dijkhuizen and RS Morris), pp. 32-39. University of Sydney, Sydney, Australia.

Hunter EJ, Jones TA, Guise HJ, Penny RHC and Hoste S 1999. Tail biting in pigs 1: the prevalence at six UK abattoirs and the relationship of tail biting with docking, sex and other carcass damage. The Pig Journal 43, 18-32.

Hunter E J, Jones TA, Guise HJ, Penny, RHC, and Hoste S 2001. The relationship between tail biting in pigs, docking procedure and other management practices. Veterinary Journal 161(1), 72-79.

Jääskeläinen T, Kauppinen T, Vesala KM and Valros A 2014. Relationships between pig welfare, productivity and farmer disposition. Animal Welfare 23, 435-443.

Keeling LJ, Wallenbeck A, Larsen A and Holmgren N 2012. Scoring tail damage in pigs: an evaluation based on recordings at Swedish slaughterhouses. Acta Veterinaria Scandinavica A 54, 32.

Kiley-Worthington M 1976. Tail Movements of Ungulates, Canids and Felids with Particular Reference to Their Causation and Function As Displays. Behaviour 56, 69-115.

Kritas SK and Morrison RB 2007. Relationships between tail biting in pigs and disease lesions and condemnations at slaughter. Veterinary Record 160, 149-152.

Lagerkvist CJ and Hess S 2011. A meta-analysis of consumer willingness to pay for farm animal welfare. Europpean Review of Agricultural Economics 38, 55-78.

Lassen J and Sandøe P 2009. GM Plants, Farmers and the Public - A Harmonious Relation? Sociologia Ruralis 49, 258-272

Lusk JL, Nilsson T and Foster K 2007. Public Preferences and Private Choices: Effect of Altruism and Free Riding on Demand for Environmentally Certified Pork. Environmental Resource Economics 36, 499-521.

MAFF 2000. Cost guidelines of construction in accordance with the law on agricultural industry, MMM-RMO E 2 building costs. (In Finnish: Maaseutuelinkeinolain mukaiset rakentamisen ohjekustannukset, MMM-RMO E 2 Rakennuskustannukset). Maa- ja metsätalousministeriön yleiskirje 18.2.2000. Ministry of Agriculture and Forestry, Helsinki, Finland.

Mäki-Mattila M 1998. Production costs of pork under intensive and animal friendly extensive production systems. (Sikojen hyvinvointia edistävien tuotantotapojen kustannusvaikutukset). Agricultural Economics Research Institute working papers 4/98. Agricultural Economics Research Institute, Helsinki, Finland.

Marchant-Forde J, Lay D, McMunn K, Cheng H, Pajor E and Marchant-Forde R 2009. Postnatal piglet husbandry practices and well-being: The effects of alternative techniques delivered separately. Journal of Animal Science 87, 1479-1492.

Mattson B, Susic Z, Lundeheim N, Persson E 2004. Arbetstidsåtgång i svensk grisproduktion. Praktiskt Inriktade Grisförsök Nr 31. 12 p. (in Swedish).

Munsterhjelm C 2013. Piloting of the Welfare Quality®-assessment system on Finnish pig farms 2010-2013. Retrieved on 22 August 2014 from http://finnishpigwq.edublogs.org/briefly-in-english/.

Munsterhjelm C, Simola O, Keeling L, Valros A and Heinonen M 2013. Health parameters in tail biters and bitten pigs in a case-control study. Animal 7, 814-821.

Niemi JK 2006. Dynamic programming model for optimising feeding and slaughter decisions regarding fattening pigs. Agricultural and Food Science 15, 1-121.

Niemi JK and Karhula T 2011. Costs of compliance to alternative housing standards in the Finnish pig sector. In: Hulgren J, Persson P, Nadeau E and Fogelberg F (eds) 24th NJF Congress "Food, Feed, Fuel and Fun - Nordic Light on Future Land Use and Rural Development".Book of Abstract. NJF Report 7

Nozick R 1974. Anarchy, State and Utopia. Basil Blackwell, Oxford, UK.

Partanen K, Niemi J, Voutila L and Jukola E 2012. Responsible pig meat production (In Finnish: Vastuullisen tuotannon vaatimusten täyttäminen näkyy lihasikalan tuloksessa).

In Maataloustieteen Päivät 2012 (eds. N Schulman and H Kauppinen). Publications of Scientific Agricultural Society of Finland 28. Retrieved on 22 August 2014 from www.smts.fi.

Parviainen H 2001. The research of working time and working methods in a rationalized piggery (In Finnish with an English abstract). Work Efficiency Institute Agricultural Bulletin 534. Work Efficiency Institute, Rajamäki, Finland.

Schrøder-Petersen DL and Simonsen HB 2001. Tail biting in pigs. Veterinary Journal 162, 196-210.

Sinisalo A, Niemi JK, Heinonen M and Valros A 2012. Tail biting and production performance in fattening pigs. Livestock Science 143, 220-225.

Spoolder H, Bracke M, Mueller-Graf C and Edwards S 2011. Preparatory work for the future development of animal based measures for assessing the welfare of pig - Report 2: Preparatory work for the future development of animal based measures for assessing the welfare of weaned, growing and fattening pigs including aspects related to space allowance, floor types, tail biting and need for tail docking. In Technical report submitted to EFSA. http://www.efsa.europa.eu/en/supporting/pub/181e.htm

Studnitz M, Jensen MB and Pedersen LJ 2007. Why do pigs root and in what will they root? A review on the exploratory behaviour of pigs in relation to environmental enrichment. Applied Animal Behaviour Science 107, 183-197.

Sutherland M, Davis B and McGlone J 2011. The effect of local or general anesthesia on the physiology and behavior of tail docked pigs. Animal 5, 1237-1246.

Sutherland MA, Bryer PJ, Krebs N and McGlone JJ 2008. Tail docking in pigs: acute physiological and behavioural responses. Animal 2, 292-297.

Sutherland MA, Bryer PJ, Krebs N and McGlone JJ 2009. The effect of method of tail docking on tail-biting behaviour and welfare of pigs. Animal Welfare 18, 561-570.

Sutherland MA and Tucker CB 2011. The long and short of it: A review of tail docking in farm animals. Applied Animal Behaviour Science 135, 179-191.

Taylor NR, Main DCJ, Mendl M and Edwards SA 2010. Tail-biting: A new perspective. The Veterinary Journal 186, 137-147.

The Council of The European Union 2001. Council Directive 2001/88/EC of 23rd October 2001 amending Directive 91/630/EEC laying down minimum standards for the protection of pigs. Official Journal L 316, 1-4.

The Council of The European Union 2008. Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs. The Official Journal L47. 5-13.

Thodberg K, Jensen KH and Jørgensen E 2010. The risk of tail-biting in relation to level of tail-docking. 91. Proceedings of the 44th Congress of the International Society for Applied Ethology, Uppsala, 91.

Torrey S, Devillers N, Lessard M, Farmer C and Widowski T 2009. Effect of age on the behavioral and physiological responses of piglets to tail docking and ear notching. Journal of Animal Science 87, 1778-1786.

Turner SP 2011. Breeding against harmful social behaviours in pigs and chickens: State of the art and the way forward. Applied Animal Behaviour Science 134, 1-9.

Turner SP, Ewen M, Rooke JA and Edwards SA 2000. The effect of space allowance on performance, aggression and immune competence of growing pigs housed on straw deep-litter at different group sizes. Livestock Production Science 66, 47-55.

Udesen F 2013. Basis of the estimated weaner price (In Danish: Grundlag for den beregnede smågrisenotering) Juni 2013, Notat nr. 1326. 2013. Pig Research Centre, Copenhagen, Denmark. Retrieved on 22 August 2014 from http://www.vsp.lf.dk/Publikationer/Kilder/Notater/2013/1326.aspx.

Valros A and Heinonen M 2015 Save the pig tail. Porcine Health Management 1, 2.

Van de Weerd HA and Day JEL 2009. A review of environmental enrichment for pigs housed in intensive housing systems. Applied Animal Behaviour Science 116, 1-20.

Van de Weerd HA, Docking CM, Day JEL, Breuer K and Edwards SA 2006. Effects of species-relevant environmental enrichment on the behaviour and productivity of finishing pigs. Applied Animal Behaviour Science 99, 230-247.

Van de Weerd HA, Docking CM, Day JEL and Edwards SA 2005. The development of harmful social behaviour in pigs with intact tails and different enrichment backgrounds in two housing systems. Animal Science 80, 289-298.

Zonderland JJ, van Riel JW, Bracke MBM, Kemp B, den Hartog LA and Spoolder HAM 2009. Tail posture predicts tail damage among weaned piglets. Applied Animal Behaviour Science 121, 165-170.

Zonderland JJ, Wolthuis-Fillerup M, Van Reenen CG, Bracke MBM, Kemp, B den Hartog LA and Spoolder HAM 2008. Prevention and treatment of tail biting in weaned piglets. Applied Animal Behaviour Science 110, 269-281.

Zupan M, Janczak AM, Framstad T and Zanella AJ 2012. The effect of biting tails and having tails bitten in pigs. Physiology and Behaviour 106, 638-644.

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

Table 2. *Summary of costs and revenues (€/pig produced) for the four finishing pig production scenarios in 2012 used in the model 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 (€/pig)	Standard Undocked (€/pig)	Enhanced Undocked (€/pig)	Efficient Undocked (€/pig)
Total revenue	123.93	123.93	123.93	123.93
Total variable costs[1,3]	124.86	124.86	128.87	126.36
Total fixed costs[2,3]	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

[1] Variable cost include: weaner cost, feed, vet and medicine, transport and marketing, straw and enrichment materials, water and electricity, carcass condemnation, interest on capital in animals and interest on capital in variable inputs.

[2]Fixed cost include: interest and depreciation of fixed capital, insurance and maintenance and labour (including tail docking labour).

[3]Detailed figures of variable and fixed costs are presented in Table 3.

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)
Variable costs				
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[1]	0.50[2]
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
Total Variable costs	124.86	124.86	125.69	125.19
Fixed costs				
Interest and depreciation	8.82	8.82	10.71[3]	9.64[3]
Labour costs	3.88	3.75[4]	6.92[1,3]	4.92[2]
Total Fixed costs	12.71	12.57	17.43	14.56

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

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

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

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

[4] Cost savings compared to Standard Docked represent estimated cost of labour used in tail docking procedure at the given wage rate (Parviainen, 2001).

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

Scenario	Probability (P_i) for size of outbreak category *i* to occur[2]				Incidence[3] (%)
	No outbreak (i=no)[1]	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

[1]The probability of no outbreak in the pen is P_{no}. Hence, the probability of either small, medium-sized or large outbreak to occur is $1-P_{no}$. Values for P_{no} were determined after a synthesis based on estimated incidence for the different scenarios. Standard Docked: Hunter *et al*. (1999), EFSA (2007), Forkman *et al*. (2010); Standard Undocked: Van de Weerd *et al*. (2006), Van de Weerd *et al*. (2005), Zonderland *et al*. (2008); Enhanced Undocked: Partanen *et al*. (2012), Sinisalo *et al*. (2012) and Munsterhjelm (2013).

[2] Probability P_i, i = (S,M,L), refers to the probability of small (S), medium-size (M) or large (L) outbreak to occur. When probability of no outbreak P_{no} is given, other probability parameters can be determined as 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, P_M and P_L are adjusted accordingly when a value for P_{no} is drawn from a distribution during the simulations. P_i was estimated with a time-series model and data provided by Sinisalo *et al*. (2012) for Enhanced Undocked, and then this was extrapolated to other scenarios based on the total expected incidence. The values in table represent average parameter values.

[3] Incidence is the % of pigs that will be affected by tail biting injury at some point during their time on the farm.

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

Simulation	Distribution: Normal (Mean μ, St. Dev. σ)			
	Standard Docked	Standard Undocked	Enhanced Undocked	Efficient Undocked
RS1[1]	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

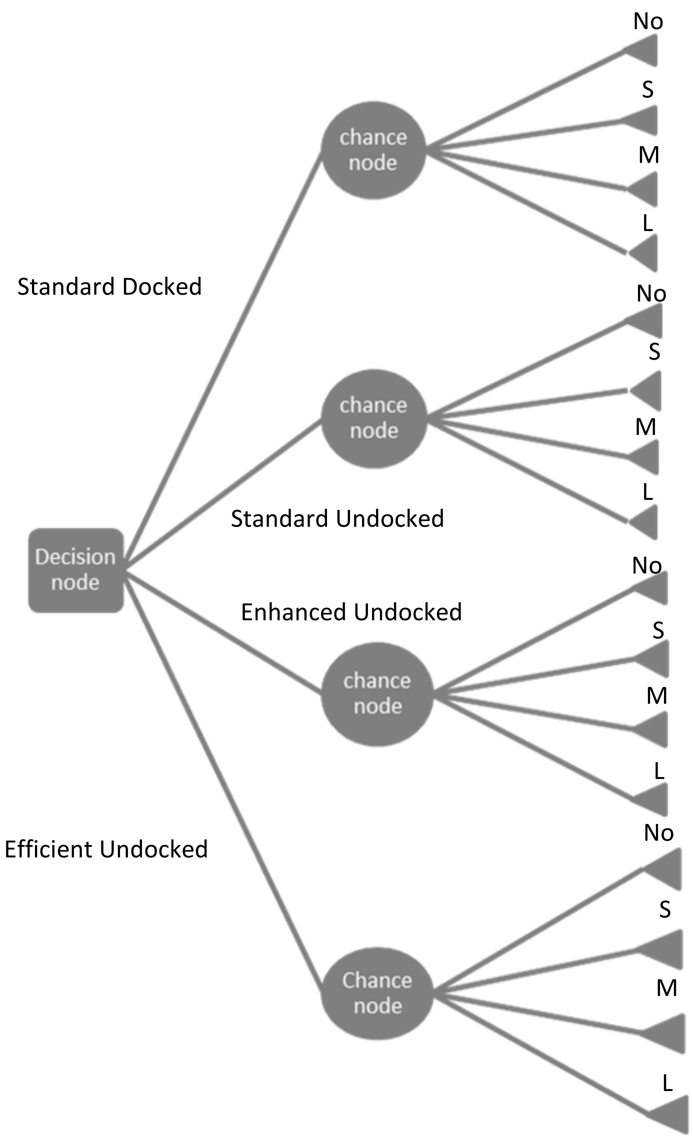
[1] Standard deviations for the three Undocked scenarios were determined according to the standard deviation of probability of no outbreak observed in the data of Sinisalo *et al*. (2012).

Figure Legends

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

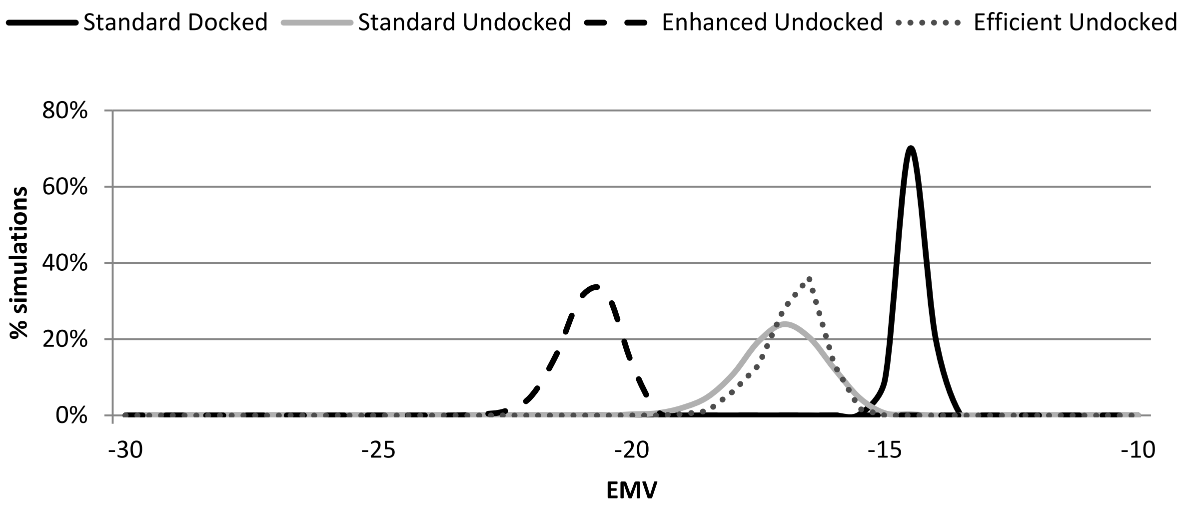
Figure 2 a) Result of risk simulation RS1 when normally distributed uncertainty was added to the probability of no outbreak in each of the scenarios. The following values were used: Mean (μ), St. Dev. (σ) Standard Docked: (0.846, 0.05); Standard Undocked: (0.43, 0.1); Enhanced Undocked and Efficient Undocked: (0.73, 0.1). b) Result of risk simulation RS2 when normally distributed uncertainty was added to the probability of no outbreak in each of the scenarios. Following values used: Mean (μ), St. Dev. (σ) Standard Docked: (0.846, 0.05); Standard Undocked: (0.43, 0.2) and Enhanced Undocked and Efficient Undocked (0.73, 0.2). The percentage values represent the share of simulated batches which fall within each €0.5 interval when grouped according to EMV and when tail biting occurs systematically in the pens of a compartment.

Figure 1



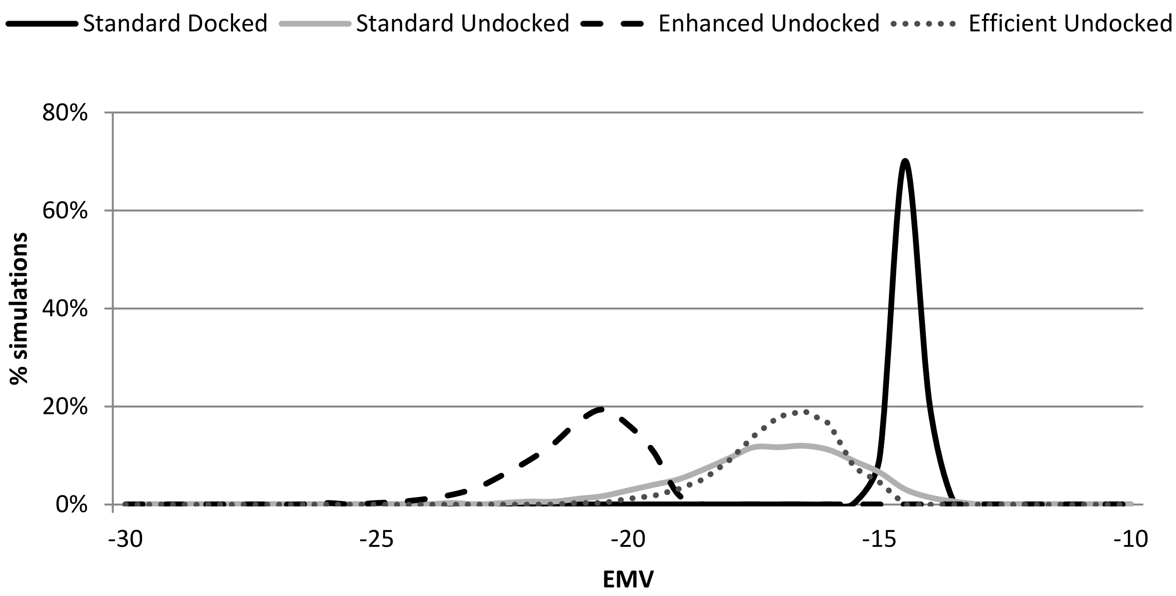
Decision node
Standard Docked
Standard Undocked
Enhanced Undocked
Efficient Undocked
chance node
chance node
chance node
Chance node
No
S
M
L
No
S
M
L
No
S
M
L
No
S
M
L

Figure 2



Standard Docked
Standard Undocked
Enhanced Undocked
Efficient Undocked
80%
60%
40%
20%
0%
% simulations
-30
-25
-20
-15
-10
EMV

a)



Standard Docked
Standard Undocked
Enhanced Undocked
Efficient Undocked
80%
60%
40%
20%
0%
% simulations
-30
-25
-20
-15
-10
EMV

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

R. B. D'Eath, J.K. Niemi, B. Vosough Ahmadi, K.M.D. Rutherford, S.H. Ison, S.P. Turner, H.T. Anker, T. Jensen, M.E. Busch, K.K. Jensen, A.B. Lawrence, P. Sandøe

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.

References

Ashworth CJ, Hogg CO, Hoeks CW, Donald RD, Duncan W, Lawrence AB and Rutherford KM 2011. Pre-natal social stress and post-natal pain affect the developing pig reproductive axis. Reproduction 142, 907-914.

Blackshaw JK 1981. Some behavioural deviations in weaned domestic pigs: persistent inguinal nose thrusting, and tail and ear biting. Animal Production 33, 325-332.

Done SH, Guise J and Chennells DJ 2003. Tail biting and tail docking in pigs. The Pig Journal 51, 136-154.

EFSA 2007. The risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems (Question No EFSA-Q-2006-013). Annex to the EFSA Journal 611, 1-13.

FAWC 2011. Opinion on mutilations and environmental enrichment in piglets and growing pigs. Farm Animal Welfare Council, London, UK.

Guatteo R, Levionnois O, Fournier D, Guémené D, Latouche K, Leterrier C, Mormède P, Prunier A, Servière J, Terlouw C and Le Neindre P 2012. Minimising pain in farm animals: the 3S approach - 'Suppress, Substitute, Soothe'. Animal 6, 1261-1274.

Heinonen M, Orro T, Kokkonen T, Munsterhjelm C, Peltoniemi O and Valros A 2010. Tail biting induces a strong acute phase response and tail-end inflammation in finishing pigs. Veterinary Journal 184, 303-307.

Herskin MS, Thodberg K, and Jensen HE 2014 Effects of tail docking and docking length on neuroanatomical changes in healed tail tips of pigs. Animal FirstView, 1-5. http://dx.doi.org/10.1017/S1751731114002857

Huey RJ 1996. Incidence, location and interrelationships between the sites of abscesses recorded in pigs at a bacon factory in Northern Ireland. Veterinary Record 138, 511-514.

Kluivers M, Reimert H and Lambooij E 2010. Infrared thermography of the skin to assess pain in piglets. In Book of abstracts of the 61st annual meeting of the European association for animal production. Book of abstracts No. 16, 23rd-27th August 2010, Heraklion, Greece, 279.

Kritas SK and Morrison RB 2007. Relationships between tail biting in pigs and disease lesions and condemnations at slaughter. Veterinary Record 160, 149-152.

Manteuffel G, Puppe B and Schon PC 2004. Vocalization of farm animals as a measure of welfare. Applied Animal Behaviour Science 88, 163-182.

Marchant-Forde J, Lay D, McMunn K, Cheng H, Pajor E and Marchant-Forde R 2009. Postnatal piglet husbandry practices and well-being: The effects of alternative techniques delivered separately. Journal of Animal Science 87, 1479-1492.

Millman S 2007. Sickness behaviour and its relevance to animal welfare assessment at the group level. Animal Welfare 16, 123-125.

Munsterhjelm C, Simola O, Keeling L, Valros A and Heinonen M 2013. Health parameters in tail biters and bitten pigs in a case-control study. Animal 7, 814-821.

Noonan GJ, Rand JS, Priest J, Ainscow J and Blackshaw JK 1994. Behavioural observations of piglets undergoing tail docking, teeth clipping and ear notching. Applied Animal Behaviour Science 39, 203-213.

Prunier A, Mounier AM and Hay M 2005. Effects of castration, tooth resection, or tail docking on plasma metabolites and stress hormones in young pigs. Journal of Animal Science 83, 216-222.

Rutherford KMD, Piastowska A, Donald RD, Robson SK, Ison SH, Brunton PJ, Russell JA and Lawrence AB 2014. Prenatal stress produces anxiety prone female offspring and impaired maternal behaviour in the domestic pig. Physiology and Behaviour 129, 255-264.

Rutherford KMD, Robson SK, Donald RD, Jarvis S, Sandercock DA, Scott EM, Nolan AM and Lawrence AB 2009. Pre-natal stress amplifies the immediate behavioural responses to acute pain in piglets. Biology Letters 5, 452-454.

Sandercock DA, Gibson IF, Rutherford KM, Donald RD, Lawrence AB, Brash HM, Scott EM and Nolan AM 2011. The impact of prenatal stress on basal nociception and evoked responses to tail-docking and inflammatory challenge in juvenile pigs. Physiology and Behaviour 104, 728-737.

Simonsen HB, Klinken L and Bindseil E 1991. Histopathology of Intact and Docked Pig tails. British Veterinary Journal 147, 407-412.

Statham P, Green L, Bichard M and Mendl M 2009. Predicting tail-biting from behaviour of pigs prior to outbreaks. Applied Animal Behaviour Science 121, 157-164.
Sutherland M, Davis B and McGlone J 2011. The effect of local or general anesthesia on the physiology and behavior of tail docked pigs. Animal 5, 1237-1246.
Sutherland MA, Bryer PJ, Krebs N and McGlone JJ 2008. Tail docking in pigs: acute physiological and behavioural responses. Animal 2, 292-297.
Sutherland MA and Tucker CB 2011. The long and short of it: A review of tail docking in farm animals. Applied Animal Behaviour Science 135, 179-191.
Torrey S, Devillers N, Lessard M, Farmer C and Widowski T 2009. Effect of age on the behavioral and physiological responses of piglets to tail docking and ear notching. Journal of Animal Science 87, 1778-1786.
Valros A, Ahlstrom S, Rintala H, Hakkinen T and Saloniemi H 2004. The prevalence of tail damage in slaughter pigs in Finland and associations to carcass condemnations. Acta Agriculturae Scandinavica, A 54, 213-219.
Van Putten G 1969. An investigation into tail-biting among fattening pigs. British Veterinary Journal 125, 511-517.
Zonderland JJ, van Riel JW, Bracke MBM, Kemp B, den Hartog LA and Spoolder HAM 2009. Tail posture predicts tail damage among weaned piglets. Applied Animal Behaviour Science 121, 165-170.
Zupan M Janczak AM Framstad T and Zanella AJ 2012. The effect of biting tails and having tails bitten in pigs. Physiology and Behaviour 106, 638-644.

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

R. B. D’Eath, J.K. Niemi, B. Vosough Ahmadi, K.M.D. Rutherford, S.H. Ison, S.P. Turner, H.T. Anker, T. Jensen, M.E. Busch, K.K. Jensen, A.B. Lawrence, P. Sandøe

Supplementary Table: *Details of the costs included to estimate the total costs of the victims of tail biting* [1]*.*

Cost item	Value (€/victim pig)	Assumptions
Vet and medicine	6.00	Pig treated for 5 days[3]: (0.4 €/day medicine + 0.35 €/day vet work[2])× 1.6
Extra labour effort by farm workers	6.85	Extra time/victim: 27 minutes [4], Duration of treatment 5 days, time spent in hospital 14 days, and proportion of victims moved to hospital pen 14.8% based on Niemi *et al*. (2012a). Price of labour 15€/hour[5].
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 *et al*. (2011).
Loss of condemned meat	1.22	0.8 kg condemned/victim based on Niemi *et al*. (2012a), price €1.52/kg pigmeat.
Reduced daily gain and consequent increased feed use to finishing[6]	1.80	Simulated based on Niemi *et al*. (2012b) and Sinisalo *et al*. (2012)

[1] 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.

[2] Estimated after consultation with Professor Mari Heinonen, University of Helsinki and University Pharmacy.

[3] 1.6 is a multiplier for secondary infections for each victim based on Niemi *et al*., 2012a.

[4] 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).

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

[6] 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.

References

Mäki-Mattila M 1998. Production costs of pork under intensive and animal friendly extensive production systems. (Sikojen hyvinvointia edistävien tuotantotapojen kustannusvaikutukset). Agricultural Economics Research Institute working papers 4/98. Agricultural Economics Research Institute, Helsinki, Finland.

Niemi JK, Sinisalo A, Valros A and Heinonen M 2012a. Tail biting – a cause or a consequence? (In Finnish: Hännänpurenta –syy vai seuraus?). In Maataloustieteen Päivät 2012 (eds. N Schulman and H Kauppinen). Publications of Scientific Agricultural Society of Finland 28. Retrieved on 22 August 2014 from www.smts.fi.

Niemi JK, Sinisalo A, Valros A and Heinonen M 2012b. Market and policy-oriented incentives to provide animal welfare: The case of tail biting. Paper presented at the 126th EAAE seminar “New challenges for EU agricultural sector and rural areas. Which role for public policy?”, June

27-29, 2012, Capri, Italy. Retrieved on 22 August 2014 from http://ageconsearch.umn.edu/handle/125957.

Parviainen H 2001. The research of working time and working methods in a rationalized piggery (In Finnish with an English abstract). Work Efficiency Institute Agricultural Bulletin 534. Work Efficiency Institute, Rajamäki, Finland.

Sinisalo A, Niemi JK, Heinonen M and Valros A. 2012. Tail biting and production performance in fattening pigs. Livestock Science 143, 220-225.

Zonderland JJ, Bosma B and Hoste R. 2011. Report on the financial consequences of tail damage due to tail biting among pigs in conventional pig farms in the Netherlands. 2011. Livestock Research Wageningen UR report 543. ISSN 1570-8616.