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A Benefit Cost Analysis of Entire Male Pig Immuno-castration[1]

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Abstract

Consumers of fresh pork have long been aware of the risk of their pork purchases not meeting eating expectations due to unpleasant taste or smell or other unsatisfactory quality characteristics such as a lack of tenderness. Boar taint, or the risk of it, is one of the most important factors identified in surveys of consumers of pork as being responsible for having a poor eating experience. Immuno-castration (IC) of entire male pigs is one method of reducing boar taint in pork. Currently about 60 per cent of male pork produced in Australia is immune-castrated. The question asked here is whether it would be profitable for the industry if the remaining male slaughter pigs were immuno-castrated as well. The additional costs associated with IC include the costs of the vaccine, extra labour costs, and additional costs arising from abscesses at the injection site causing increased product downgrades and stoppages of the slaughter line for cleaning. A major benefit of IC for the pig industry is a reduction in consumers of pork enduring poor experiences from unpleasant taste or smell when they eat pork. Over time, reducing the occurrence, and the risk of occurrence, of having a less than satisfactory experience when consuming pork has the potential benefit of the industry avoiding losing customers, and even increasing demand for pork, above what it would be with the continuation of the current proportion of boar-tainted pork in the total national supply of pork. Over the next ten years, if national consumption of pork increases at the same trend of the past decade, the benefits from avoided annual losses of demand or from increases in demand by just 0.5 per cent of total annual national consumption of pork would cover the cost of the remainder of the industry adopting IC. This conclusion applies if IC was adopted fully and immediately and the cost was the lower of the range of possible cost estimates at $0.10/kg carcass weight. More realistically, if producers adopted IC more slowly and adoption of IC took five years, and the cost of using IC was $0.10/kg carcass weight, then avoiding or preventing a loss of 1.5 per cent in annual sales would mean the total benefits exceed the total costs of achieving this outcome. Such relatively small gains in sales or avoided losses of sales seem eminently achievable. The conclusion of the BCA is that an increased use of immuno-castration in Australia's pig production system that reduces the prevalence and the risk of boar taint would have a high likelihood of delivering a net benefit to participants in the industry.

Key words: pig industry, boar taint, immuno-castration, benefit cost analysis, scenario analysis

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Introduction

Decisions by consumers of pork to continue to buy pork are critically influenced by the eating experience they have enjoyed. The quality of the eating experience is determined in part by important sensory attributes, the taste of pork and the odour of pork. The taint of boar is an offensive odour and taste that is highly noticeable to many consumers when they prepare, cook and eat pork from entire male pigs that have reached puberty. Boar taint, or the risk of it, are the most important factors identified in surveys of consumers of pork as being responsible for 'Bad Eating Experience' and 'Pork Fail Rates'. This is the context in which a bad eating experience from boar-tainted pork, or just the risk of it, needs to be analysed.

Immuno-castration (IC) using the boar taint vaccine (Improvac®, Zoetis Australia Pty Ltd, Parkville, Australia) is an alternative method of castration to deal with off-odour and flavour issues in pork. Many studies show IC is effective at eliminating boar taint. In addition to the costs of the vaccine and the labour required to vaccinate the entire male pigs, IC affects some production parameters, which may have costs and benefits. For example, a meta-analysis has shown that adopting IC using the recommended regime (slaughter at greater than four weeks after second immunization) will increase feed intake (+429 g/day), will increase average daily (weight) gain (+119 g/d), and the final carcass weight is higher (+2.1 kg) but so is P2 back fat (+1.5 mm) (Dunshea et al., 2013). In addition, IC reduces lysine and other nutrient requirements (Moore et al., 2016), reduces injury and carcass damage from aggression (Dunshea et al., 2001) and increases survival rate (Morales, 2017). It improves eating quality (Channon et al., 2018) and increases muscle pH (Dunshea et al., 2013). However, it has some negative impacts on carcass trimming as a result of vaccination abscess (Dunshea et al., 2001).

These effects of IC on production and other parameters are well known, and about 60 per cent of male pork produced in Australia is immuno-castrated. Still, many producers are reluctant to use the technology. This reluctance stems in part from the cost of purchasing and applying the vaccine, as well as concerns about the potential for an increase in P2 backfat that can occur when using IC. The P2 backfat depth is a major determinant of price received by pork producers, so extra P2 backfat that puts the carcass into a lower price grid is a risk to be avoided.

Another major reason for (smaller) producers being reluctant to adopt IC is that, unless the pork is identified as coming from either entire males, IC males or females, price discounts for non-castrate pork will not be applied at retail, or premiums for castrate pork will not be received. Such price differentiation is not received at the farm-level unless the producer is in a position to negotiate with their buyer and pass-on some portion of the added cost of using IC. These and other factors are barriers to the adoption of IC for the remaining 40 per cent of the entire male pigs produced for pork[2].

To date, there has not been a benefit-cost analysis (BCA) of the size of industry net gains or avoided losses that would be necessary to achieve to justify increased IC use in pork production. That is the objective of the analysis reported in this paper.

The economic performance of the pork industry "With" and "Without" increased use of IC is the comparison. Standard benefit-cost methods are applied, using aggregate pig industry data about supply and demand for pork in the various markets, production costs, output, and price data from a representative pig production system. The BCA method involves identifying and quantifying all sources

[2] There are alternative approaches to using IC to mitigate some of its perceived negative effects. For example, slaughter of pigs two weeks after administration of the second dose of vaccine (Lealiifano et al., 2011) or feeding albus lupins to curb feed intake (Moore et al., 2021) can eliminate boar taint compounds without increasing P2. These strategies warrant closer examination too, though they are beyond the brief of this BCA.

of extra costs and extra benefits resulting from adopting and implementing IC technology in Australia's pig production systems and through value chains to the consumers.

Pork Consumption and Quality Attributes

In 2020 Australians consumed around 28 kg of pig meat per capita. In 2020 fresh pork consumption was 11.2 kg per capita (ABARES, 2021), with the remaining consumption in the form of processed pig meat such as bacon, ham and smallgoods.

Consumer preferences for pork are affected by a mix of attributes and the willingness of consumers to pay for this mix of attributes, from production to processing to preparation by the consumer, with the greater impacts on pork quality and consumer acceptance in processing and consumer preparation. Research indicates that the sex of the animal from which the pork is derived is a medium impact risk factor relative to factors further along the value chain through to consumer preparation.

The decision to purchase pork at retail comes with a risk that the purchase may turn out to be unsatisfactory because of a poor eating experience. If 10 per cent of consumers report that they experience a poor eating experience – which has happened each year over the five years to 2020, and is increasing (Thrive Insights, 2020) – then the probability of the purchase of pork turning out to be a poor decision is, at a minimum, around 10 per cent. One chance in 10 has to be weighed up by the consumer considering buying pork or an alternative source of protein with its odds of getting a bad eating experience.

A consumer with a choice of types of meat to buy, considers price, preferences, cooking method, type of cut and risk of the cut not meeting expectations. Risk of product failure is one part of the decision to purchase any type of meat. Suppose the risk of a purchase of a cut of pork turning out to be a poor buy is higher than the risk associated with purchasing an alternative meal of chicken, lamb, beef, or some other protein alternative such as fish or grains. In that case, the risk factor may be a dominant consideration among the factors that come into the decision.

The pork industry in Australia has strategic goals around the quality of pig meat and the quantity that is consumed. One goal is to increase the consumption of Australian pork. The industry's Strategic theme to 'Drive Consumer Demand' program aims to increase the per capita consumption of Australian pork above the 2020 level. To this end the industry conducts surveys and assembles empirical information about consumer responses to the quality of the pork they buy, cook and eat.

Research by Australian Pork Limited (APL) into eating quality and bad eating experiences includes surveys of pork consumers about the prevalence of less than satisfactory eating experiences since 2015 (Thrive Insights, 2020). This research has identified reasons for poor eating experiences, from attributes of the product (suppliers), the cuts of pork and its preparation (consumer), and by demographics, and tracked changes over the past seven years. The data show consistently, over five recent annual surveys, that around 10 per cent of consumers of pork have had a bad eating experience. A common cause of this bad experience with pork was boar taint. Other reasons included: 'too fatty', 'bad' meat quality, over-cooking or under-cooking the meat, inconsistent steak thickness, and incorrect cooking method. The 'poor eating experience' percentage for pork has increased consistently from 2015 to 2020 – and at a faster rate than for sheep meat, beef or chicken.

Consumer awareness of boar taint has been consistent at around 20 per cent in most years, increasing to 28 per cent in 2020. Of the people aware of boar taint, four out of five reported that the smell affected their perception of, and preference for, pork (Thrive Insights, 2020). Most people do not say they will stop consuming pork despite unsatisfactory experiences with it, for various reasons – but some do. Ten per cent of people say they will buy pork less frequently for a time, whilst others say they will buy it less often in the future (Thrive Insights, 2020).

The important point to note is that surveys of consumers of pork do not capture the views of people who do not consume pork, for whatever reason, some of whom may be considered as being potential consumers if they were more confident of a good eating experience. Less pork in the market that might give a bad eating experience will decrease the risk that current customers will experience a bad eating experience, and reduce or cease their pork consumption, while more positive experiences eating pork could increase community confidence about having a good eating experience which has the potential to increase the total number of pork customers. Non-consumers who have an association with pork consumers may also be swayed, one way or the other, by the changing experiences of the consumers of pork.

The pork industry uses some key performance indicators for eating quality based on measures about the number of regular consumers, such as the percentage of households consuming more than a given number of times per year. For instance, the Australian Pork Limited *Annual Report* for 2017-18 (APL, 2018) under 'Eating Quality Pathways Performance' had a category 'product fail rate percentage in best sales channel (bad taste)'. The target for 2017-18 was 2.15 per cent product fail rate. The realised rate of 'product fail' was 5.91 per cent. This meant that 5.91 per cent of sales in this selected channel came in with a response 'bad taste'.

In the 2018-19 *Annual Report* (APL, 2019) the Eating Quality Pathways Performance had a KPI with two criteria:

- Product Fail Rate Percentage in Best Sales Channel. The target was 5.11 per cent and the result was 5.65 per cent.
- Bad Taste/Smell/Dry/Chewy/Tough. The target was 8.63 per cent and the result was 9.87 per cent.

A large amount of research has been conducted to identify the specific attributes of fresh pork that adversely affect consumer acceptance of the product. Specifically, the eating quality of pork has been investigated by focussing separately and jointly on a group of the characteristics that play a role in determining the eating quality of fresh pork, to varying degrees and with varying degrees of interaction effects. These characteristics include: gender; ageing; initial Ph; handling; chilling; cut type and cooking method; end-point temperature; moisture infusion; hanging method; ultimate ph; and electrical stimulation. Sensory research has been used to identify the significance of these factors – defined as 'critical control points for eating quality' - to develop Pork Quality Scores (PQS). Eating quality scores are used to identify the extent to which consumers prefer or dislike pork from entire male pigs, IC pigs and females. Pig gender was found to be a statistically significant factor on consumers liking or disliking pork. Channon et al. (2016) found that 'overall liking' of pork was statistically higher for castrates than entire males.

In an 'overall liking' rating for a standardised treatment sample loin roast (70 ^{o}C, non-moisture infused, non-electrically stimulated, entire male carcase aged for one day with ultimate pH less than 5.5), the entire male pig scored an overall liking rating of 52.4 out of a possible 100. The industry has set a target of consumers giving an overall liking rating for pork of 65 in the future (McAlister, 2020). This research demonstrated the well-known consumer distaste for pork from male entire animals and preference for pork from female and castrated animals. Pork from female, physical castrate and IC male pigs scored 2.1 points, 3.5 points and 2.4 points respectively more than the entire male for overall liking. This represents a 4.6 per cent increase in PQS attributable to removing the boar taint only. A large database containing over 250 published and non-published datasets on effects of production, processing and cooking parameters on pork eating and technological quality indicated an overall liking of pork from entire males of PQS 48.37, while for IC pork the overall PQS was 57.60. This represents a 19 per cent improvement in eating quality score when all the factors affecting eating quality, including boar taint, are accounted for. The pork from the IC pigs also had higher intramuscular fat percentage, at 2.21 per cent, compared with the entire male pork at 1.82 per cent. At present, intramuscular fat is not included in the PQS system due to a lack of data on high and low intramuscular fat levels measured in commercial breeds of pork in Australia.

Thus, it appears that boar taint remains a major contributor to the 'product fail ratings' despite the availability of technology in Australia that has the potential to eliminate the major causes of boar taint: androsterone and skatole.

Method of Analysis

This study is about the benefits and costs of immuno-castration of the whole Australian pig herd. How would the Australian pork industry look without IC and with IC across the whole herd? The key questions are:

- Over the next decade, what would be the costs of immuno-castrating the balance of the uncastrated Australian entire male pigs produced each year?
- What are the likely benefits of immuno-castrating the Australian male pigs that are produced each year over the next decade?

To answer these questions, it is necessary to:

- Identify sources of benefits and costs of using immuno-castration.
- Quantify the sources of benefits and costs of using immuno-castration.
- Run the BCA model with generated inputs for plausible scenarios.
- Weigh up the probability of these scenarios being achieved in reality.

In the BCA, the additional costs to industry of using IC are related to vaccine and labour costs and carcass downgrades due to abscesses and stoppage time on the processing chain, and possibly measures needed to reduce negative effects on P2 backfat and dressing percentage from using IC (Table 1).

The benefits of IC come from the gains in the quantity and value of pork that is not boar-tainted in markets, and which replaces pork that is currently boar-tainted. This is pork sales that are not lost as a result of boar taint or the risk of it affecting consumers' purchasing of pork in the future; or, it could be any market growth attributable to the potential to supply increased pork that is free of boar-taint, along with a reduced risk of boar taint. A reduction in the supply of boar tainted pork could potentially slow the rate of increase in poor eating experience and thus increase pork sales.

Pork sales that have been lost due to a poor eating experience have not been measured, thus pork sales that may be regained through an improved eating experience cannot be known accurately. Some estimates are available. Using data from the annual Thrive Surveys, McAlister (2020) considered there was a 2.5 per cent potential increase in sales from reducing negative eating experiences (that is, through minimising dry tough pork and bad taste and smell). Lower estimates of 1 to 1.5 per cent increases in sales of pork from small increases in eating quality have been made by experienced industry participants (V. Gole, 2021, personal communication, 6 July). In this research four conservative estimates of potential increases in sales from the use of IC were evaluated (0.4 per cent, 0.5 per cent, 1.0 per cent and 1.5 per cent).

The implicit assumption is that, of the consumers who rated their pork purchase as being a 'failed product', at least some small percentage of these consumers would have given up on pork as a product they wish to consume for some time at least into the future.

The tests of the success of adoption of wider use of IC in producing pork are:

- Avoided loss of pork consumers (who previously identified boar taint occurring during cooking or eating); and
- Increased consumption of pork because there is no boar taint and more favourable perceptions, and fewer unfavourable impressions, of pork as a meat meal held throughout the general population by both consumers and non-consumers.

If the value of avoided lost sales exceeds the cost of avoiding these sales losses using IC, in present value terms, then the benefit cost ratio is positive, i.e., there is a net benefit. Expressed another way, if an increase in sales was attributable to less boar taint in pork and the value of the increase in sales outweighed the increase in cost of the industry to supply pork free of boar taint, then the cost of adopting IC throughout the industry would represent a sound investment.

Additional benefits at the production level come from positive effects on feed conversion efficiency, giving savings in feed costs per kilogram of liveweight turnoff, survival benefits, and processing efficiencies. Reduced aggression in immuno-castrated pigs also leads to improved animal welfare. It is difficult to quantify *all* the benefits of immuno-castration, such as improved animal welfare and sometimes improved growth rates. These types of benefits are very much case-by-case, specific to particular production systems. These benefits are not quantified in the benefit cost analysis; rather, they are simply identified and listed but, for completeness, they should be taken into account together with the quantitative results.

The adoption profile by producers of IC over the life of the technology determines the aggregate benefits and costs, which are discounted to present values to give net present values and B:C ratios using standard discount rates. The time horizon of the BCA is 10 years as this period of time allows for adoption of the IC technology to varying degrees and time for consumer experiences and perceptions to improve as more pork that is free of boar taint is purchased and the risk of poor eating experiences attributable to boar taint is reduced. Also, in a decade or more, alternative technology to reduce boar taint may become available and make the current IC technology redundant. Scenarios for different rates of adoption of IC and the different domestic consumption of pork that needs to be 'increased by not being lost' over the project life are analysed.

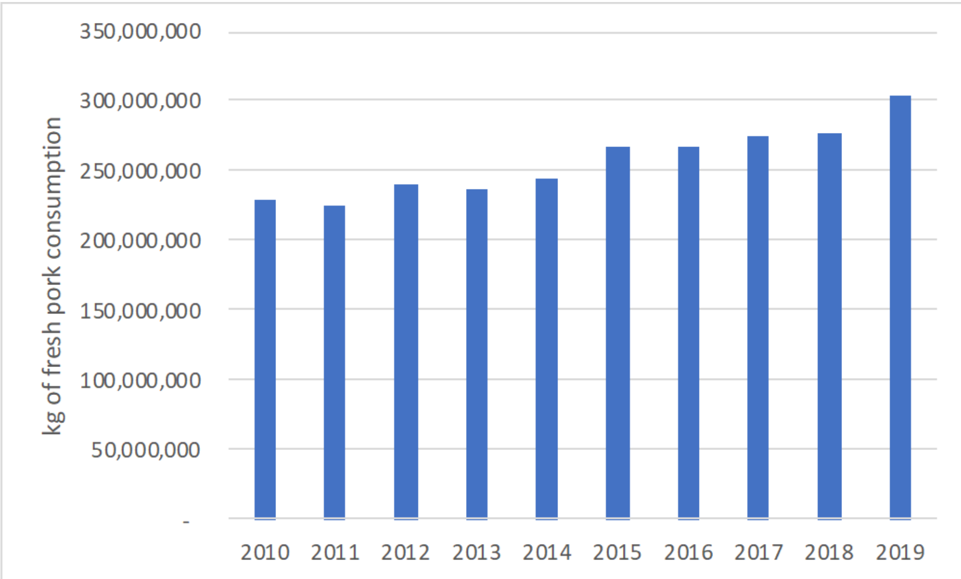
Data Requirements

Price and consumption data

The apparent annual consumption of fresh pork in Australia is the starting point of the analysis. The steadily increasing, albeit relatively slight, trend in apparent consumption of fresh pork from 2010 to 2019 is assumed to continue for the next decade. This growth has been the result of economy- and community-wide changes and is net of the annual losses of consumers of pork resulting from an adverse eating experience – the near 10 per cent 'product failure' as a result of bad smell and/or taste that shows up consistently in surveys. Consumers who give up purchasing pork each year because of poor eating experience of pork associated with boar taint, whether for a short or a long time, are included in the projected increases in pork consumption. If annual pork consumption increases at 1 per cent per year, this is the combined effects of changes in population, relative prices and preferences each year, and absorbs any losses that may also be occurring as a result of customer dissatisfaction for a range of reasons, including boar taint.

Apparent annual fresh pork consumption over the period 2010-2019 is shown in Figure 1. Consumption ranged from 225,000 tonnes to 300,000 tonnes with an average of 256,000 tonnes, but with a consistent upward trend from 2010 to 2019. In the analysis the average annual trend in consumption over the past 10 years has been applied to the next 10 years.

Figure 1. Apparent annual fresh pork consumption (kgs), Australia, 2010-2019



Source: (ABARES, 2021)

Annual total pork production and farm and consumer prices vary year-on-year and within a year because of increasing and decreasing grain prices, domestic production levels and net availability of pork to retailers, wholesalers and manufacturers after exports and imported pork is accounted for, and world pig meat production and prices. While the BCA could be done on the basis of likely average consumer prices over the period of the analysis – and this would give a reasonable approximation of the average net benefits – it can be more informative about the size of net benefits to account for the variations in the value of pork that will inevitably occur over the period of the benefit cost analysis.

The consumer price of pork is used to value the losses of pork sales that might be avoided by removing boar taint. Deriving a retail price of fresh pork consumed in Australia is complex, due to range of values for different forms and cuts of fresh pork sold through supermarkets, butchers, fresh produce markets and food service. The Australian Bureau of Statistics provide a retail price for a few cuts but these are only a small proportion of the carcass. A retail carcass equivalent value of fresh pork was estimated as $5/kg cold weight (the value across the major fresh pork cuts after allowing for the proportion of a carcass they represent, and the different additional value added to different cuts) (see Table 1).

The typical extra costs of using IC in pig production systems are the cost of the vaccine, additional casual labour and additional backfat (see Table 2). Although there is potential for additional benefits for a producer (Dunshea et al., 2013) there are also additional costs[3]. In summary, the extra cost of IC for a pork producer was set at $0.10/kg and $0.12/kg. Further work, beyond this desktop analysis, could look in greater detail at the costs and benefits for an individual producer of changing from producing entire males to IC.

[3] From industry experience, the differences between entire male and Improvac diets are minimal and the benefits from IC are weight gain but costs are reduced dressing percentage and greater backfat. Further, the increase in carcass weight is not enough to outweigh the costs of an increase in backfat.

Table 1. Farm level changes in costs for large and small pork producers moving from entire males to IC

Costs of IC	Net Change in costs for a producer ($/pig)
Large producer	
Vaccine	$4.50
Additional casual labour	$1.00
Additional backfat	$2.00
Total ($/pig) for a large producer	$7.50
Total ($/kg HSCW – assuming 75kg HSCW) for a large producer	$0.10
Smaller producer	
Vaccine	$6.00
Additional casual labour	$1.00
Additional backfat	$2.00
Total ($/pig)	$9.50
Total ($/kg HSCW – assuming 75kg HSCW)	$0.12

In addition to the costs for the producer from IC, there are expected to be additional costs associated with processing IC pork. The processor costs are associated with deep tissue abscesses from the vaccine. The cost for a representative processor was estimated to be $1,075,000 per year[4].

Adoption of immuno-castration in pork production

Forty per cent of male pigs produced in Australia in 2021 are not castrated. The BCA is done with an assumed rate of adoption of IC, and IC is assumed to result in nil boar taint. The adoption question is problematic in that 60 per cent of the male pigs are already immuno-castrated, predominantly done by the largest firms. This technology has been around for decades. Producers who do not castrate their pigs will no doubt have good reasons in the context of their operation. The adoption of IC technology is assumed to be on the mature part of the sigmoidal adoption curve and hence it will require more extension and market force incentives to bring the remaining late adopters and laggards to using IC.

Adoption of more IC across the industry could be anticipated to be slow, unless new incentives and information are brought to bear on the issue. Quantifying the potential future losses of markets with the current level of non-use of IC and the benefit of not losing market by using IC ought to be information that would have some positive effect on the incentive to adopt IC. Further, suppose the benefits of removing potential losses from boar taint are large compared to the costs of implementing IC across the entire industry. In that case, there are excess benefits available that could be used to encourage the adoption of IC that is required.

In the BCA a range of rates of adoption over the next 10 years to 2030 are investigated to identify the impacts of fast versus slow and small versus large rates of overall adoption of IC in the industry (Table 2).

[4] The costs associated with deep tissue abscess include downgrading of shoulder primal, boning room stoppage, cleaning of equipment, reduced throughput and increased labour. The extra annual cost to the processor was estimated to be $1,075,000 if IC was fully adopted.

Table 2. Summary of each scenario evaluated (see Appendix 2 for a more detailed description)

	Description
Scenario 1	100% adoption of IC from year 1
Scenario 2	It takes the first 5 years, of the 10-year planning horizon, to get to 100% adoption (assuming adoption and benefits and costs are incurred at a cumulative 20% each year– see the appendix scenario 2)
Scenario 3	It takes the first 5 years, of the 10-year planning horizon, to get to 100% adoption (assuming adoption and benefits and costs are incurred at different rates each year– see appendix scenario 3)
Scenario 4	It takes the first 5 years, of the 10-year planning horizon, to have only a proportion of those who have not adopted IC now adopting IC (assuming adoption and benefits and costs are incurred at the same rates each year – see the appendix scenario 4)
Scenario 5	It takes the first 5 years, of the 10-year planning horizon, to have only a proportion of those who have not adopted IC to now adopt IC (assuming adoption and benefits and costs are incurred at different rates each year – see the appendix scenario 5)
Scenario 6	It takes 10 years to have only a proportion of those who have not adopted IC to now adopt IC (assuming benefits and costs adoption and benefits and costs are incurred at the same rates each year – see the appendix scenario 6)
Scenario 7	It takes 10 years to have only a proportion of those who have not adopted IC to now adopt IC (assuming adoption and benefits and costs are incurred at different rates each year – see the appendix scenario 7)

Results

It is likely to be a good investment for the pork industry to increase the use of immuno-castration. These results are from looking at costs and benefits over the next 10 years to examine whether it is worth increasing the adoption of IC. As happens, the costs and benefits would continue in perpetuity.

The likely Net Present Values for the different scenarios outlined in Table 2 have been calculated and are shown in Figures 1 and 2. At a 6 per cent annual real opportunity cost rate, increasing the rate of immuno-castration from 60 per cent of the male production herd to 100 per cent immediately (from year 1) would be a good investment depending on the level of sales retained or grown and the costs of making this change at the farm level. If the adoption of IC takes time, or if it is never fully adopted, it could still be a good investment, but this depends on sales gained or avoided. Lastly, based on the analysis, a higher average cost of IC for a producer of pork (12c/kg pork produced) (Figure 2) compared to a slightly lower cost of IC (Figure 1) does not impact on the existence of a net benefit from IC, merely its size.

Given existing knowledge of the economic structure of the Australian pig meat industry (Mounter et al., 2005; Zhang et al., 2018), the distribution of the benefits across the various value chain participants was estimated. These shares are shown in Table 3. Pig producers receive 12 per cent of total benefits, value chain participants 9 per cent and consumers 79 per cent. These shares are consistent with other types of simulated industry changes reported in Zhang et al. (2018). However, the converse is also true - consumers eventually pay almost 80 per cent of the costs incurred at the farm level.

Figure 2. Net Present Value $ (at 6% p.a. real discount rate, 10 years, for each scenario) for four different levels of sales increases, assuming the cost of IC for a producer of pork is 0.10 $/kg pork produced

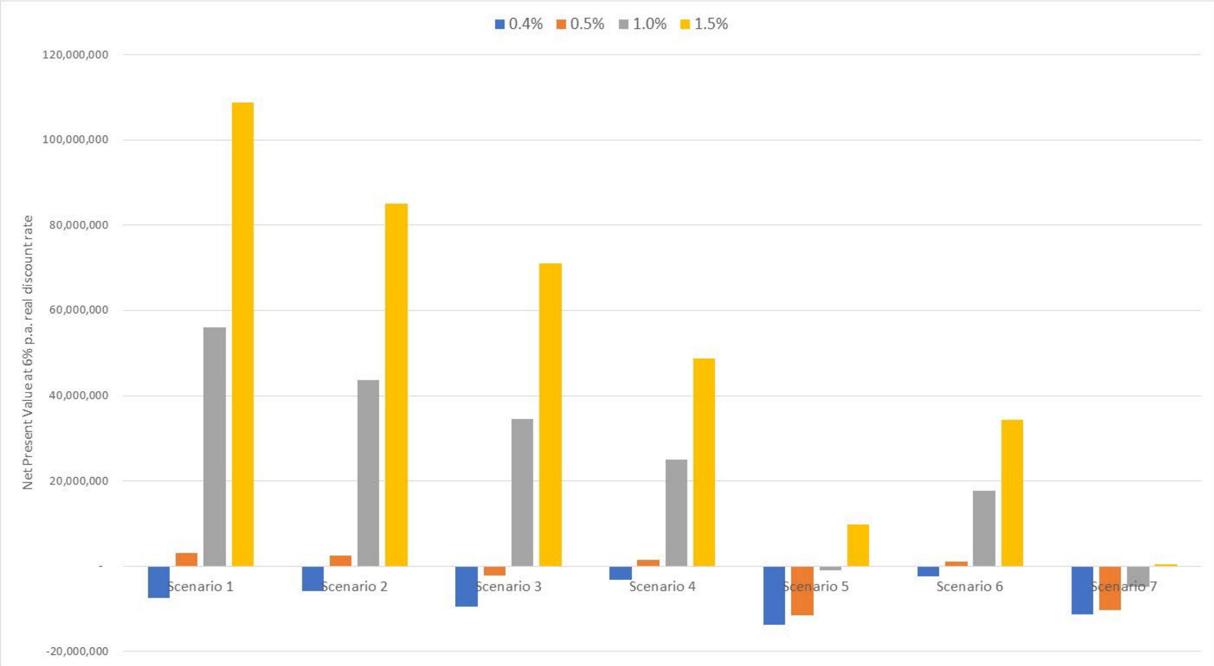


Figure 3. Net Present Value $ (at 6% p.a. real discount rate, 10 years, for each scenario) for four different levels of sales increases, assuming the cost of IC for a producer of pork is 0.12 $/kg pork produced

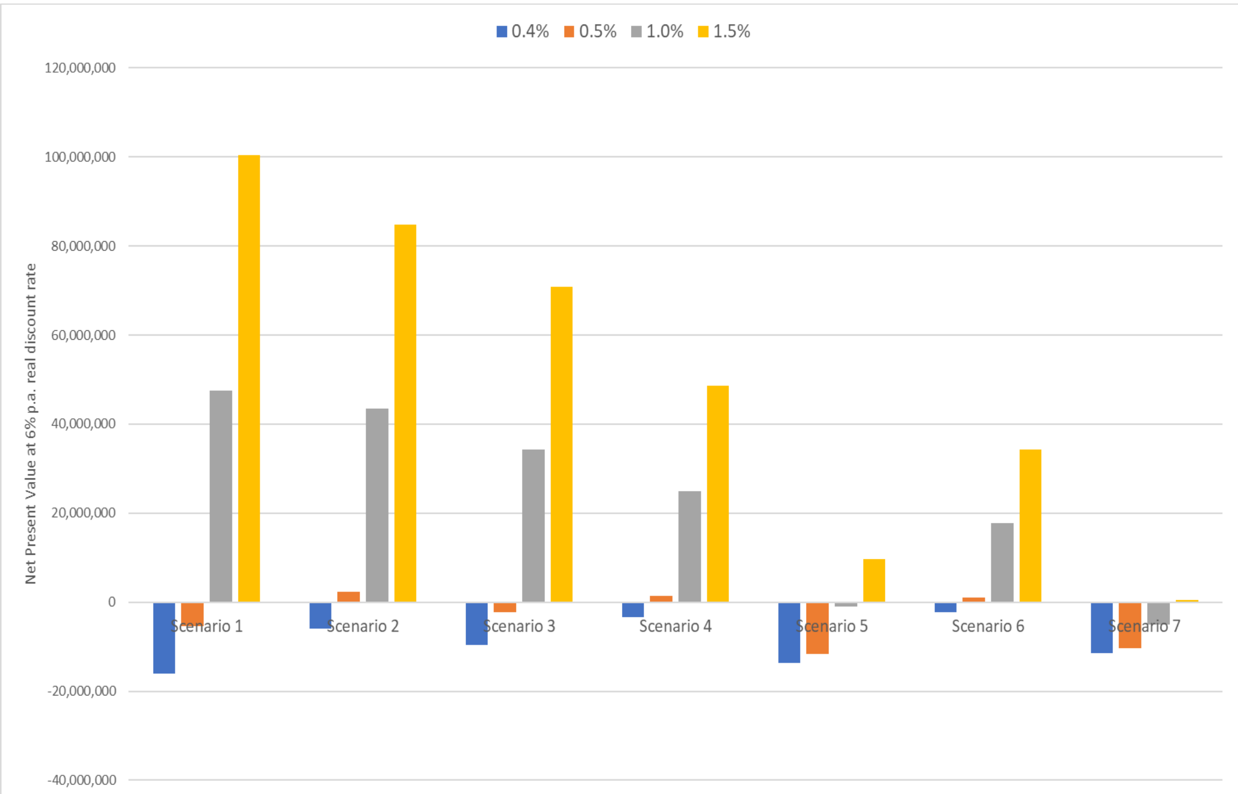


Table 3. Percentage shares of total surplus changes (%) to pig producers, value chain participants and domestic pig meat consumers from all scenarios, medium term

Change in economic surplus to	All Scenarios
	%
Pig producers	12
Abattoirs and boning rooms	1
Retailers/exporters/importers	8
Domestic pork consumers	78
Domestic bacon ham smallgoods (BHS) consumers	1
Total Surplus	100

Concluding Observations

The results of this benefit cost analysis show that, if increased use of immuno-castration in Australia's pig production systems reduced in a small way consumer experiences of product failure/boar taint, or the risk of it, and thus generated a small avoidance of otherwise lost consumption of pork or achieved a small increase in sales of pork, this would justify the cost of increased use of IC in the Australia pig industry. As noted above, well-informed judgement holds that there is high probability of achieving the reduced loss of sales and/or the increased sales of pork that is required to justify the cost of using IC to reduce or remove the incidence of boar taint from pork.

The greatest net benefit comes from a large proportion of the current non-castrating population of producers adopting IC rapidly. In this scenario, while costs are large and occur early in the 10-year planning horizon used in the analysis, so too are the benefits. Thus, the message for APL is the quicker IC is fully adopted by pig producers, the better the investment in IC is for the Australian pork industry. The best case is the cost to producers of IC is $0.10/kg pork produced. This requires only 0.5 per cent of pork consumption to be retained due to lower incidence of bad smell or taste due to the elimination of boar taint in 100 per cent of the national herd.

If adoption is slow, and low, and reached only 60 per cent of the producers of the remaining pork that was produced not using IC, and who represent the potential adopting population of producers, and the benefits and costs did not accrue linearly, then sales of pork would need to increase to (or a loss of sales be avoided to equate to an increase of) 1.5 per cent annually to make the industry investment in adopting extra IC worthwhile.

To form a view about the likelihood of the investment in IC delivering a net benefit, and thus earning the opportunity cost return on investment that is required, it is necessary to consider the required increase in sales or avoidance of lost sales in the context of the proportion of total pork consumed each year that is deemed a 'failed product' and the extent to which this failure is attributable to boar taint.

Ten per cent of pork each year falls into the category 'failed product' for the reason of bad smell or bad taste, which are likely, but not limited to boar taint. Boar taint contributes significantly to bad eating experiences and low eating quality score. Removing boar taint alone increases eating quality score by nearly 5 per cent. This means that, if between 5 per cent and 15 per cent of the total annual failed product due to bad smell/taste is transformed into an acceptable eating product due to not having boar taint by using IC, the investment is a good one.

The conclusion about the net benefit of IC rests on the likelihood that, without IC of the remaining non-castrated males, at least some of the dissatisfied consumers will cease to buy pork and would have continued to buy pork if not for the boar taint effect and, in the absence of boar taint, would be continuing customers of pork in future. Survey results from work by Thrive Insights (2020) indicated that despite a bad eating experience with pork, only 10 per cent of customers said they would buy less frequently in the future. Of these, half said they would eventually return to their usual frequency. The other half said they would purchase pork less often in the future. Thus, a bad eating experience results in losing customers for both a short and long time. Not counted are potential customers who have been 'turned off' pork forever, or never 'turned onto' pork, possibly by vicarious experience.

In the medium term, consumers would bear most of the additional costs incurred in the industry of immuno-castration – economic analyses show that around 80 per cent of the added cost is paid by consumers once the supply and demand effects have worked their way through the industry. Producers bear just over 10 per cent of the added cost and value chain participants around the same share of the additional cost. The benefits too are shared in the same proportions.

In summary, only a small positive effect on demand is needed to justify the cost of increased use of IC throughout the pig industry.

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Appendix 1. Raw Data and Assumptions

Table A1. Data used to estimate the trend in domestic fresh pork consumption

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Apparent consumption (tonnes) (ABARES 2020)	571,745	563,032	602,020	593,293	610,312	667,964	665,656	685,933	692,669	757,151
Processed consumption (tonnes) (assumed 60% of consumption)	343,047	337,819	361,212	355,976	366,187	400,778	399,394	411,560	415,601	454,291
Fresh pork consumption (tonnes) (assumed 40% of consumption)	228,698	225,213	240,808	237,317	244,125	267,186	266,262	274,373	277,068	302,860
Imports (tonnes) (ABARES 2020)	283,064	270,197	296,437	279,947	292,146	335,256	321,405	326,933	322,473	403,094
	59,983	67,622	64,775	76,029	74,041	65,522	77,989	84,627	93,128	51,197
Fresh pork consumption (tonnes)	228,698	225,213	240,808	237,317	244,125	267,186	266,262	274,373	277,068	302,860
Export fresh (ABARES 2020)	50,055	51,431	46,157	46,554	44,027	41,410	41,803	48,973	54,018	43,678
Domestic fresh pork consumption (tonnes)	178,643	173,782	194,651	190,763	200,098	225,776	224,459	225,400	223,050	259,182

Notes: To calculate the quantity of fresh pork consumption we followed the approach of Zhang *et al* (2018) then used excel function TREND along with the domestic fresh pork consumption data for the past 10 years to project forward the expected domestic fresh pork consumption.
Raw data sourced from: https://www.agriculture.gov.au/abares/research-topics/agricultural-outlook/data#2020

Table A2. Estimated domestic fresh pork consumption for 2020 to 2029

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Estimated domestic fresh pork consumption (tonnes)	254,588	262,772	270,955	279,138	287,322	295,505	303,688	311,871	320,055	328,238

Table A3. Estimated kg that will incur the cost of IC

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Total Kg of fresh pork	254,588,453	262,771,736	270,955,018	279,138,301	287,321,583	295,504,865	303,688,148	311,871,430	320,054,713	328,237,995
Of that 60% is from IC herd	152,753,072	157,663,041	162,573,011	167,482,980	172,392,950	177,302,919	182,212,889	187,122,858	192,032,828	196,942,797
Of that 40% is from herd without IC	101,835,381	105,108,694	108,382,007	111,655,320	114,928,633	118,201,946	121,475,259	124,748,572	128,021,885	131,295,198
Of that 40%, half the number of kg will incur the cost of IC -Males	50,917,691	52,554,347	54,191,004	55,827,660	57,464,317	59,100,973	60,737,630	62,374,286	64,010,943	65,647,599

Appendix 2. Adoption Scenarios

Scenario 1: 100% adoption in year 1, all benefits and costs incurred from year 1

Scenario 2: Assumed it would take 5 years to get to 100% adoption

	1	2	3	4	5	6	7	8	9	10
adoption: % of full adoption 100%	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%
proportion of benefit	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%

Scenario 3: Assumed it would take 5 years to get to 100% adoption and assumed benefits and costs accrue at different times

	1	2	3	4	5	6	7	8	9	10
adoption: % of full adoption 100%	20%	40%	60%	80%	100%	100%	100%	100%	100%	100%
proportion of benefit	0%	20%	40%	60%	100%	100%	100%	100%	100%	100%

Scenario 4: Assumed it would take 5 years to get a proportion of those who have not adopted IC now adopting this technology (that is 60% of the 40% of producers who have not adopted IC now adopt IC)

	1	2	3	4	5	6	7	8	9	10
adoption: % of full adoption 100%	10%	20%	30%	40%	60%	60%	60%	60%	60%	60%
proportion of benefit	10%	20%	30%	40%	60%	60%	60%	60%	60%	60%

Scenario 5: Assumed it would take 5 years to get a proportion of those who have not adopted IC now adopting this technology (that is 60% of the 40% of producers who have not adopted IC now adopt IC) and assumed benefits and costs accrue at different times

	1	2	3	4	5	6	7	8	9	10
adoption: % of full adoption 100%	10%	20%	30%	40%	60%	60%	60%	60%	60%	60%
proportion of benefit	0%	0%	10%	20%	30%	30%	30%	30%	30%	30%

Scenario 6: Assumed it would take 10 years to get a proportion of those who have not adopted IC now adopting this technology (that is 60% of the 40% of producers who have not adopted IC now adopt IC)

	1	2	3	4	5	6	7	8	9	10
adoption: % of full adoption 100%	6%	12%	18%	24%	30%	36%	42%	48%	54%	60%
proportion of benefit	6%	12%	18%	24%	30%	36%	42%	48%	54%	60%

Scenario 7: Assumed it would take 10 years to get a proportion of those who have not adopted IC now adopting this technology (that is 60% of the 40% of producers who have not adopted IC now adopt IC) and assumed benefits and costs accrue at different times

	1	2	3	4	5	6	7	8	9	10
adoption: % of full adoption 100%	6%	12%	18%	24%	30%	36%	42%	48%	54%	60%
proportion of benefit	0%	0%	10%	20%	30%	30%	30%	30%	30%	30%