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Ex ante evaluation of selected RD&E technologies for the Australian Lamb Industry using whole farm and industry models

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Abstract

The objective of this work is to estimate the value to the Australian lamb industry of some new technologies which alter the cost of producing lamb on farms. The analysis has two key parts: First is farm modelling to identify the effect of some new technologies on the cost of producing lamb. This part of the analysis will be performed using a whole-farm bio-economic model. The second part of the analysis consists of industry modelling to estimate the value to the entire Australian lamb industry of the changes in the cost of producing lamb which are derived from the farm modelling.

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Introduction

The objective of this work is to estimate the value to the Australian lamb industry of some new technologies which alter the cost of producing lamb on farms. The analysis has two key parts: First is farm modelling to identify the effect of some new technologies on the cost of producing lamb. This part of the analysis will be performed using a whole-farm bio-economic model. The second part of the analysis consists of industry modelling to estimate the value to the entire Australian lamb industry of the changes in the cost of producing lamb which are derived from the farm modelling. This part of the analysis will be performed using an equilibrium displacement model.

An important overall aspect of this analysis is representing, despite uncertainty, the limited extent to which some of the determinants of the value of new technologies are known. This has been done using stochastic simulation of both the farm and industry models. For example, estimating the change in the cost of producing lamb brought about by a particular technology requires estimates of the costs incurred in implementing that technology. Currently, the precise technologies to be used are unknown and hence so are the associated costs. Uncertainty about the value of the costs associated with developing and implementing specific technologies has been captured in this analysis by using probability distributions to represent a range of possible on-farm costs which could be associated with each of the technologies considered.

Other uncertain variables that have been represented in this analysis include parameters in the industry model used to estimate the net value of these technologies to the lamb industry as a whole. For example, the price elasticities of supply and demand in the lamb market are crucial determinants of the distribution of economic surplus between consumers and producers. However, the precise values to be taken by these parameters in the coming years cannot be currently known and hence these variables have also been represented using probability distributions. This representation of uncertainty in the farm and industry models means that the ultimate output of this work are probability distributions of possible values associated with each technology.

In addition to the uncertainty about the value to attach to variables because the information is not known well, there is also uncertainty about the levels that key parameters in farm systems, such as yields, feed deficiencies and output prices will take, as seasons unfold and economic conditions emerge. These stochastic, unknowable variables are also relevant to this analysis, and have been represented by incorporating probability distributions of the future values they may take. In the farm model, stochastic variables include the prices and quantities of inputs used and outputs produced by the farm. For the industry, stochastic variables include the aggregate prices paid and received for lamb by producers and consumers, and the overall quantities of lamb produced and sold in the Australian lamb industry.

Representing uncertain and stochastic variables with probability distributions means the ultimate outputs of this work are distributions of possible net values to the Australian lamb industry of the technologies which have been analysed. These distributions are considered to be a better representation of the true state of knowledge about the net value of new technologies than deterministic (single-point) estimates or sets of possible net values produced by a sensitivity analysis, in which case the probabilities of the various possible estimates occurring are unknown. Furthermore, the distributions of net present values generated in this work can be used to better understand the risk associated with research and development investments.

For the purpose of making decisions to invest in research and development, risk is not always a relevant consideration. In particular, when such investments are made entirely using public funds only the weighted-average, or expected value of benefits generated is relevant, because society as a whole is hedged against the risk associated with individual investments, and as such is indifferent to this risk. However, research and development organisations in Australian agriculture typically use a mixed funding model, whereby private and public funds are invested in RD&E. For these institutions, the risk associated with potential RD&E investments is a relevant consideration. In this report, risk analysis is restricted to defining the probability that research costs may exceed the net present value of the technologies to the Australian lamb industry.

Part 1: Whole-farm modelling

A whole-farm model is the tool used in this analysis to estimate the magnitude of the effect on the cost of producing lamb which is brought about by the adoption of a new technology. The model contains a complete representation of the physical and biological characteristics of the farm, and of prevailing commodity prices. These characteristics are defined for the farm system prior to the new technology being adopted (the base case), and once each of the new technologies have been adopted (the scenarios).

The whole-farm model represents a real case-study farm in south-west Victoria. The farm system employed on this farm is large scale specialist lamb production. The biophysical characteristics of the farm are described below. Before presenting this information, it is important to be clear about what the choice of case study farm implies for this analysis.

Specifically, the case study farm represents a highly productive and profitable lamb farm system which is already using, at high standard of operation and to good effect, all relevant currently-available technology for lamb production. To reduce the cost per unit of production on this farm, *new* technologies are needed to push the production possibilities outwards to *new* production possibilities frontiers. This is different to the case of less efficient lamb producers; these farmers can reduce the cost of production by adopting or more effectively using technologies which are already available. That is, innovating and adopting and moving closer to the *existing* production possibilities frontier.

The analysis is based on a highly productive lamb farm system using current technology at a high standard so that any improvements to the lamb farm system that are considered in this analysis represent new technologies created by research and development. The objective is to evaluate the merit of new technologies, not the net gains from better use of existing technologies which can be brought about by extension and adoption. The focus on as yet undiscovered technology is because the objective of this analysis is to help research organisations identify the most beneficial research and development (R&D) opportunities from the suite of potential R&D projects, not to identify the best extension opportunities.

Stochastic simulation of the farm system

As noted above, a particularly important aspect of this modelling is representing uncertainty in the different types and quantities of inputs used (the technical change) and the outputs produced by the farm, as well as the stochastic nature of the commodity prices. These uncertainties and variability have been represented using stochastic simulation. Specifically, probability distributions are used to represent possible prices and quantities. In each iteration of the farm model individual values are drawn from the distributions of these variables, and used to estimate farm profit in the base case and in each of the scenarios. Accordingly, the outputs of the farm model are distributions of farm profit with and without each of the technologies considered. The effect of the new technologies on farm profit is estimated by comparing the value of farm profit generated in each scenario relative to that generated in the base case.

In performing stochastic simulation of the farm model, care has been taken to represent the correlations which have existed, and are expected to exist in the future, within and between quantities and prices. For example, in each iteration of the model, the same commodity prices must apply in all scenarios unless the new technology has the effect of altering the price paid for an input or received for an output. This is because each of the scenarios represents the operation of the farm in an alternative ’future’. If a new technology alters only the quantities of inputs used or outputs produced by the farm, the effect of that technology on farm profit can only be estimated sensibly when the same commodity prices apply in the base and when the new technology is used.

In addition, correlations between prices which are expected to exist within individual years have also been represented in the farm level model. In particular, reflecting close relationships in consumption and production, the prices of lamb, mutton and replacement ewes at each point in time are strongly positively correlated. These correlations between commodity prices have been represented in the simulation model using a correlation matrix. The quantities of inputs used and outputs produced by the farm are also positively correlated within individual years, reflecting the shared effect of prevailing seasonal conditions on these quantities. The correlations have been directly represented in the farm-level simulation model by ensuring that in each iteration of the model, all the quantities of inputs used and outputs produced reflect the same set of climatic conditions.

Specifically, the biophysical model GrassGro has been used to estimate all the input and output quantities used in this analysis. Given a description of the physical and biological characteristics of a farm system, GrassGro estimates farm input and output quantities using individual years of weather data. The case study farm represented in this analysis is located in Minjah, south west Victoria. GrassGro has been run using weather data for this location for the period 1970-71 to 2010-11.

Within each year of the GrassGro simulation, correlations exist between the input and output quantities, reflecting the shared effect of prevailing seasonal conditions on these quantities. These correlations have been directly represented in each iteration of the model by drawing input and output quantities from the same year of GrassGro data. This means that whatever correlations exist between these quantities (even if they change depending on seasonal conditions) have been directly captured in the analysis.

Finally, correlations between input and output quantities which exist over time have also been represented in the analysis. These correlations reflect the impact of prevailing seasonal conditions in a particular year on the quantities of inputs used and outputs produced by the farm in subsequent years. For example, the prevailing seasonal conditions at the time ewes are joined in one year have implications for the number of lambs available for sale in the following year.

Where relevant, these correlations have been represented in the analysis by directly linking the quantities represented in each year of the simulation period. Specifically, the correlations which exist between years are captured by ensuring that the quantities which apply in each of the years of a multi-year simulation period are sequential. For example, if the quantities used in the first of the simulation period are those estimated for 1985-86, then the quantities used in the second year will be those estimated for 1986-87, and so on through to the final year of the simulation period.

Before discussing the new technologies which have been represented in this work, the biophysical characteristics of the case study farm are described. The biophysical characteristics of the farm system determine the kind of new technologies which can be considered, and the magnitude of the benefits which are generated by these technologies.

The model farm system

The model represents a 1,000 hectare lamb farm in south-west Victoria. The soils are 80% red loam clay over basalt, and 20% cracking black clay. The feedbase of the farm comprises 800 hectares of a high-performance ryegrass and clover pasture, and 200 hectares of a lucerne and plantain mix sown on the red soil. The entire farm is fenced into ten hectare paddocks and a rotational grazing system is used. The livestock system of the farm consists of 10,000 first-cross ewes joined to Dorset rams to produce approximately 13,000 prime lambs for sale per year. Ewes weigh 70-75kg each and are purchased at 10 months of age, joined at 12 months and retained for 5 years. The farm operator estimates the annual stocking rate per hectare averaged across the whole farm is 25 DSE, with a DSE being the annual metabolisable energy required to maintain a livestock unit defined as a 48kg wether for one year.

All ewes are joined in a six-week period from mid-February until the end of March. Lambing occurs in early August and weaning occurs in mid-December. At weaning the composition of lambs by weight is typically 30% at 50kg, 50% at 40kg and 20% at 30kg. Lambs are aimed to be turned off at 50kg liveweight, thus lambs that reach this weight by weaning time are sold. Lambs that have not reached 50kg by weaning are retained on the lucerne and plantain pasture over summer. Light lambs are sold in mid-March, by which time, typically, 70% have reached 50kg liveweight and the remaining 30% have reached 40kg.

The total energy balance submodel of the farm model, representing animal demand and pasture supply plus supplementary feed of the farm, has been calibrated from discussions with the operator of the case-study farm. Specifically, in the feed demand and supply model, supplementary feed is provided to all breeding stock to ensure that the condition score of the leanest animals does not fall below 2.0. In the majority of years (62 per cent) this condition-score rule is not triggered, and hence no supplementary feed is required. Over the whole simulation period, the average quantity of supplementary feed used per year by the whole farm is 99 tonnes.

This average annual quantity of supplementary feed used is increased by the relatively rare occurrence of particularly unfavourable seasonal conditions, which occasionally cause a large quantity of supplementary feed to be used. For example, it is estimated in the model that 735 tonnes of supplementary feed was used in 1982-83. In reality, other strategies such as reducing stock numbers or sourcing agistment would be employed by the farm owner in times of severe feed shortage.

However, the strategy used in a particular year will depend on a range of factors, including the relative prices of livestock, supplementary feed and agistment. These factors are not included in the model, hence only the strategy of purchasing supplementary feed has been represented. This simplifying assumption can be justified on the basis that the cost associated with this strategy in any given year will be similar to the cost of any other strategy, given relatively efficient markets and rational behaviour.

Overall, aside from the situations discussed above, the relatively low level of supplementary feed used in the model is consistent with the experience and observations of the farm owner. Given the relatively high stocking rate of this farm, the low supplementary feeding reflects the maintenance of a high-quality feedbase and the use of a system of intensive rotational grazing. A comprehensive annual program of fertilizer and pasture maintenance is accounted for in the profit budget, with annual maintenance fertiliser applied in proportion to the stocking rate. Specifically, soil phosphorus is maintained in the model by applying 0.95 kilograms of phosphorous annually for every dry sheep equivalent on the farm. This corresponds to an average annual application of single superphosphate of around 265 kilograms per hectare.

The following table summarises the inputs and outputs of this farm system:

Case study farm system: average annual data	
System	
Farm size (ha)	1,000
Ewes joined (No.)	10,000
Stocking rate (DSE/ha)	24.5
Outputs	
Wether lambs sold (No.)	6,349
Ewe lambs sold (No.)	6,333
Weight of wether lambs sold (kg)	48.6
Weight of ewe lambs sold (kg)	46.6
Culled ewes sold (No.)	1,786
Weight of culled ewes sold (kg)	72
Quantity of wool sold (kg)	53,288
Inputs	
Quantity of supp. feed purchased (tonnes)	99
Replacement ewes purchased (No.)	2,171
Replacement rams purchased (No.)	27
Quantity of super purchased (tonnes)	265

The next table contains the profit budget for the base case farm system, in a year in which these average annual input and output quantities are realised, and average commodity prices prevail. Figures have been rounded to aid interpretation. It is recognised that such an outcome is no more likely to occur than any other combination of possible prices and quantities; this information is presented only to help the reader understand the characteristics of the case study farm system.

Whole-farm profit budget: Base Case	
Revenue	
Lambs	1,324,000
Culls	90,000
Wool	189,000
Total	1,603,000
Variable Costs	
Replacement ewes	282,000
Replacement rams	21,000
Supplementary feed	24,000
Annual maintenance fertiliser	102,000
Livestock sale costs	91,000
Animal husbandry	159,000
Total	680,000
Total gross margin	923,000
Overhead costs	195,000
Annual operating profit	728,000

Reproductive performance scenarios: description

The two technologies analysed in this report involve improving the reproductive performance of the case study farm. To explain how these technologies have been represented, it is first necessary to discuss the representation of reproductive performance of the farm in the base case. In reality, the owner of the case study farm measures reproductive performance as number of lambs marked, divided by the number of ewes joined. On average, this ratio is approximately 1.30 or 130 per cent on this farm.

In GrassGro, reproductive performance is defined by choosing the proportion of ewes joined which conceive one, two or three lambs, given a condition score of 3 at the time of joining. In the base case, reproductive performance has been defined by setting the proportion of ewes that have one and two lambs as 44 per cent and 56 per cent, respectively. This corresponds to a weighted-average conception rate of (0.44 x 1) + (0.56 x 2) = 1.56, or 156 per cent.

However, this conception rate only applies at a condition score of 3, and given the energy balance of the farm, ewes in the base case model have an average condition score of 3.5 at the time of joining. Hence, the modelled average conception rate of the case study flock is somewhat higher than 156 per cent, namely 161 per cent. Once the average rate of lamb mortality is taken into account, this conception rate corresponds to the average reproduction rate which is observed by the owner of the case study farm, namely 1.3 lambs marked for each ewe joined.

Lamb mortality is the other major determinant of reproductive performance in the model. The main time of lamb deaths in GrassGro is at birth. The proportion of lambs that die at birth primarily depends on the prevailing seasonal conditions at this time, and in particular the "chill index" to which newborn lambs are exposed. Other variables which alter the proportion of lambs which die at birth include the age and condition score of ewes, and the size of lambs. In the GrassGro modelling of the base case farm system, an average of 19.9 per cent of lambs die at birth.

The other main source of lamb mortality in the model is through the death of pregnant adults. In particular, the annual rate of adult mortality is 3 per cent, hence over the 5 month gestation period, 1.25 per cent of joined ewes die. At the conception rate defined above, each of the ewes that dies during pregnancy is carrying an average of 1.61 lambs; hence an additional (1.25 x 1.61) = 2.0 per cent of lambs also die during the gestation period. In GrassGro, it is assumed that no pregnancies end prematurely.

In summary, on the case study farm 10,022 ewes are joined each year, on average. At an average conception rate of 161 per cent, this corresponds to 16,117 lambs conceived. Of these, an average of 12,894 lambs survive birth. Hence the average number of lambs lost between conception and birth each year is 3,223. As described above, 19.9 per cent of these lambs die at birth and the remainder are lost as a result of ewe mortality during pregnancy. Once these deaths are taken into account, the ratio of lambs born to ewes joined is (12,894 / 10,022) = 1.3. A small number of lambs also die between birth and marking (as a result of adult mortality during the month which separates these two events); however the ratio of lambs marked to ewes joined remains equal to the observed ratio of 1.3.

Given this definition of reproductive performance in GrassGro, there are several ways in which improved reproductive performance can be represented. One is to increase the average conception rate across the whole flock. Such an increase is the first scenario considered in this report. Another way of improving reproductive performance is to reduce the mortality rate of lambs. This change is represented in scenario 2. Both these scenarios are described in more detail below.

Scenario 1: increasing the conception rate

According to the *Making More from Sheep* guidelines, ewes should have a minimum condition score of 3 at the time of joining to achieve the optimum conception rate. Furthermore, these guidelines suggest that maiden ewes should be within 75 to 80 per cent of their mature body weight at the time of joining. If either of these conditions were not being satisfied in the base case farm system, reproductive performance could presumably be improved by making whatever changes were required to meet these conditions.

However, in the base case farm system both of these determinants of the conception rate are already within the suggested range. Specifically, mature ewes weigh an average of 67.9 kg at the time of joining and are in condition score of 3.6. At lambing, mature ewes weigh 65.1 kg on average, and are in condition score 3.1. Maiden replacement ewes are purchased each year in January at 10 months of age, at 50 kg per head and in condition score 3. They are joined at 12 months of age, by which time they have an average liveweight of 53.6 kilograms (77 per cent of mature body weight), and a condition score of 3.0. At lambing, these ewes have an average liveweight of 60.3 kg and a condition score of 3.0.

In some years of the simulation period, the average condition score of maiden ewes is greater than 3 and in others it is less than 3. Providing supplementary feed to these ewes to avoid their condition score falling below 3.0 at any point during pregnancy was found to have little effect on the conception rate or on the mortality rate of lambs at birth, and hence had little effect on the number of lambs produced. Furthermore, the average amount of supplementary feed required to maintain this condition score was relatively large, and the cost of this feed more than outweighed the small value of benefits generated.

In any event, as noted above, the purpose of this analysis is to investigate new technologies, rather than those which already exist. Accordingly, in this scenario the new technology used to increase the conception rate is assumed to be a different kind of intervention, such as increasing the genetic merit of ewes and rams, or the use of a chemical treatment such as a hormone injection. An increase in the conception rate which is brought about through such an intervention can be represented in GrassGro by simply increasing the proportion of ewes which are assumed to conceive more than one lamb.

In this scenario, the proportion of ewes which conceive two lambs has been increased from 56 to 60 per cent, and the proportion of ewes which conceive one lamb is decreased from 44 to 40 per cent. Hence, the weighted-average conception rate of ewes at condition score 3 increases from 156 per cent to 160 per cent. Considering the actual average condition score of ewes at the time of joining, this increase in conception rate is consistent with an increase in the weighted average conception rate of 2.7 percentage points (from 160.6 per cent to 163.4 per cent). The distribution of benefits generated by this scenario are presented and discussed in the results section below.

Scenario 2: Reducing lamb mortality

As noted above, 19.9 per cent of lambs die at birth in the base case farm system. Given the liveweight and condition scores of ewes at the time of joining and at birth, altering ewe nutrition before, during or after pregnancy in GrassGro modelling has little effect on this proportion. Similarly, reducing the mature body weight of rams does not generate a significant reduction in lamb weight at birth, and hence does not reduce the lamb mortality rate. In any event, interventions such as these are already well-known and widely used, hence are unsuitable for the present analysis.

An alternative method for reducing lamb mortality is to increase the genetic merit of ewes and rams for this trait, such that fewer lambs die at birth. In GrassGro, this technology has been somewhat artificially represented by reducing the wind speed of the paddock in which lambing occurs. To avoid this scenario altering the energy demand of sheep during the rest of the year, in all scenarios a lambing paddock has been added to the model farm in addition to the 1,000 hectares of the case study farm. This paddock is only occupied for six days each year – the three days either side of the lambing date. This paddock is 50 hectares in size and is assumed to produce sufficient pasture that supplementary feeding is rarely required while ewes are in this paddock.

In the reduced lamb deaths scenario, the wind speed in this paddock is reduced to 1 per cent of the level which prevails in the base case. This reduces the chill index in this paddock when lambs are born, and hence reduces lamb deaths. Specifically, the mortality rate of lambs declines by 2.8 percentage points, from 19.9 per cent to 17.1 per cent. While ewes also benefit from the reduction in wind speed (in the sense that their energy requirements are lower than they would otherwise be), as ewes are only in the lambing paddock for six days each year, this phenomenon is expected to have little effect on farm profit through the energy budget. Similarly, the effect of including this lambing paddock on the amount of pasture produced by the other paddocks on the farm is also expected to be small, given that it is only occupied for six days per year.

It is important to note that the use of this method to reduce lamb deaths in GrassGro does not mean that the data generated by this scenario can only be used to analyse technologies which reduce wind speed, such as installing shelter. This is simply the device by which the reduction in lamb mortality has been brought about in GrassGro. It is recognised this is a simplification, but it has been done because it is one of the only ways in which the mortality rate of lambs can be significantly reduced in GrassGro without concomitantly altering many other aspects of the farm system.

This representation of the technology in the biophysical model allows the benefits of a reduction in lamb deaths to be estimated (including important biological effects such as increased energy requirements of ewes) while interfering minimally with other aspects of the farm system. The distribution of benefits generated by this scenario are presented and discussed in the results section below.

Before discussing these results, the magnitude of the changes in reproductive performance which have been represented in these two scenarios warrants consideration. Specifically, the increase in the conception rate which has been represented in the model is 2.7 percentage points, and the reduction in the lamb mortality rate is 2.8 percentage points. These changes are of a similar absolute magnitude, but in relative terms they are very different. The increased conception rate scenario represents a 2.7 / 160.6 = 1.7 per cent increase from the base case, while the reduction in the mortality rate represents a 2.8 / 19.9 = 14.1 per cent decrease from the base case.

Reducing the mortality rate is commonly considered to be more valuable than increasing the conception rate to the same extent. As shown below and in other studies, in absolute terms this is true, but because the conception rate is much greater than the mortality rate, equal-sized absolute changes in these two rates represent different-sized relative changes.

Thus, it is incorrect to state that an x per cent reduction in the mortality rate is worth more than an x per cent increase in the conception rate – the correct expression is that a reduction in the mortality rate of x *percentage points* is worth more than an increase in the conception rate of x *percentage points*. This is different to the way in which scenarios such as these are typically constructed and expressed, i.e. in relative terms. This is an important distinction because as shown above, the relative change in the mortality rate represented in this analysis is much larger than the relative change in the conception rate which has been represented.

Finally, it should be noted that the absolute magnitude of the changes in the conception and mortality rates that have been represented in this analysis (approximately 3 percentage points) are arbitrary. Changes of this magnitude have been chosen on the basis that they are sufficiently large to have a systematic effect on the stochastic returns generated by the case-study farm without being unrealistically and unattainably large.

Reproductive performance scenarios: benefits

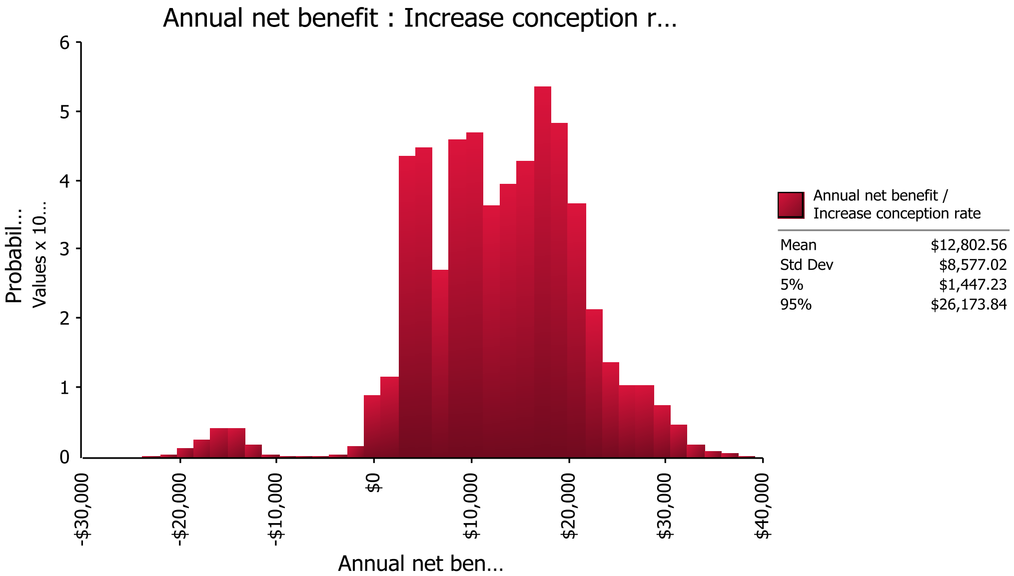
The distributions net benefits associated with each of the technologies described above are presented in this section.

Scenario 1: increasing the conception rate

In this scenario benefits are primarily generated by an increase in the number of lambs sold each year. Specifically, an average of 12,865 lambs are sold each year in this scenario, an increase of 183 from the 12,682 sold in the base case. This is an average increase of 1.4 per cent. Average lamb sale weights decline by 0.2 per cent. The overall average increase in annual lamb sale revenue is $16,659. The relative increase in the number of lambs sold is smaller than the relative increase in the conception rate (1.7 per cent) because the average mortality rate of lambs across the whole flock increases when the proportion of ewes bearing more than one lamb increases.

Other benefits in this scenario include a small increase in wool sales, reflecting the greater number of lambs shorn. The most significant extra cost associated with this scenario is a 4.4 per cent increase in supplementary feed costs, from an average of $24,452 in the base case to $25,517 in this scenario. Other extra costs include a 1.1 per cent increase in livestock sale costs and 0.5 to 0.6 per cent increases in labour, fertiliser and animal husbandry costs.

Overall, with the increase in conception rate the average annual farm operating profit increases from $728,310 in the base case to $741,113 in this scenario. The average annual increase in farm profit is $12,803. This increase in profit is the average annual net benefit generated by this technology. Stochastic simulation of the farm model generates a distribution of possible annual net benefits. This distribution is shown in the graph below:



The 5th and 95th percentiles of this distribution are $1,447 and $26,174 respectively. While the majority of values (96.3 per cent) are positive, this change to the farm system also has the potential to cause some losses. Although they are rare, it is valuable to understand the reasons for these losses, of which there are two:

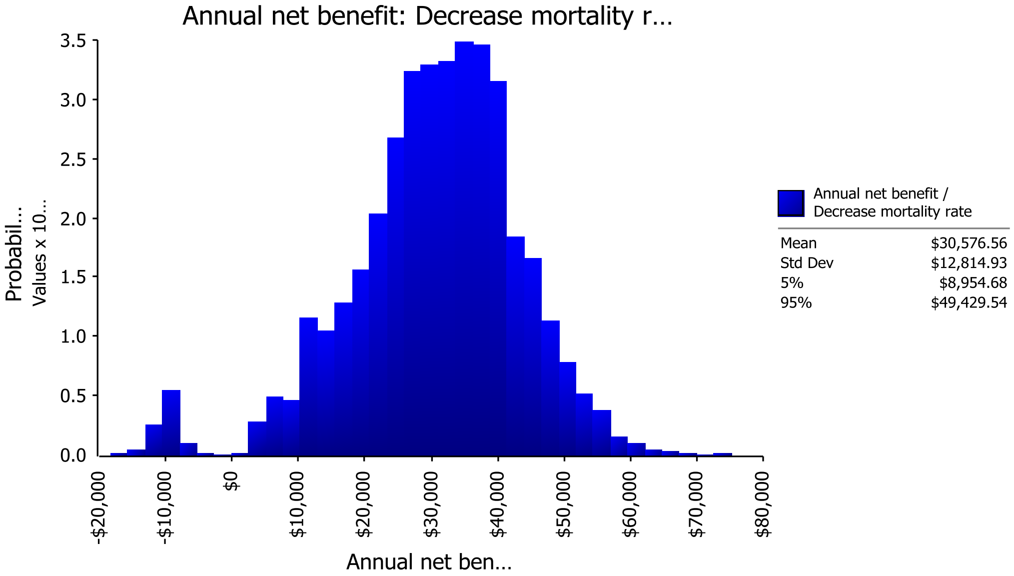
One reason is when feed is scarce relative to energy demand during the period in which ewes are pregnant (March to July), such that their condition scores are below 3 at the time of lambing. In these years, the average condition score of ewes in this scenario is generally lower than it is in the base case because total ewe energy requirements increase with the conception rate. In these years, the relatively high mortality rate more than offsets the increase in the conception rate, such that fewer lambs are sold in total, which causes profit to be lower in this scenario than in the base case.

The other cause of losses in this scenario with increased conception is low supply of energy relative to demand while lambs are being grown for sale (August to January or February). In these years, the greater energy demand of the larger number of lambs in this scenario means that the average weight of lambs at the time of sale is lower than it is in the base case. In some of these years, the decrease in the per-head weight of lambs sold more than offsets the increase in the number of lambs sold, such that revenue from lamb sales is lower in this scenario than it is in the base case.

Scenario 2: decreasing the mortality rate

This reduced mortality scenario results in an average 3.1 per cent increase in the number of lambs sold. Specifically, the average number of lambs sold in this scenario is 13,075 – an increase of 393 from the average of 12,682 lambs sold per year in the base case. This is more than double the 1.4 per cent increase in lamb sales which is brought about by the increase conception rate scenario. On average, with this change, lamb sale weights decrease by an average of 0.4 per cent. The average increase in lamb sale revenue relative to the base case is $36,546. The other main benefit is a 0.6 per cent increase in the value of wool sold, produced by the additional lambs.

The average supplementary feed cost increases by 3.9 per cent to $25,418 in this scenario, from $24,452 in the base case. Livestock sale costs increase by 2.4 per cent and animal husbandry costs increase by 1.2 per cent. Annual maintenance fertiliser and labour costs increase by 1.1 and 0.9 per cent respectively, reflecting the higher effective stocking rate in this scenario. The graph below contains the distribution of annual net benefits generated by reducing lamb mortality rate:



The average value of annual net benefits generated by this scenario is significantly greater at $30,577 compared to $12,803 in the increased conception rate scenario. The 5th and 95th percentiles of the distribution are $8,955 and $49,430 respectively. The distribution of annual net benefits from reducing lamb mortality is similar to the distribution of net benefits generated by the increase conception rate scenario, in that the majority (97.6 per cent) of annual net benefits generated are also positive.

The larger annual net benefit associated with reducing lamb mortality primarily reflects the fact that this scenario causes a larger increase in the number of lambs sold. Consistent with previous studies, the greater value of net benefits indicates that, all else being equal, reducing the mortality rate of lambs is a more profitable change for this farm system. However, once all the costs of achieving these changes to the farm system are taken into account this may or may not remain the case.

The simulation results show that this technology also has the potential to generate negative annual net benefits. Again, these losses are primarily caused by two events. First, if the supply of feed is scarce relative to demand while lambs are growing, the weight per head of lambs sold in this scenario can be lower than in the base case, to the extent that this decrease more than offsets the increase in the number of lambs sold, meaning that the value of revenue from lamb sales is lower than it is in the base case.

The second cause of losses is when feed is scarce relative to demand while ewes are pregnant, such that the average condition score of ewes at the time of lambing is below 3. In these years lamb deaths reflect the relatively low condition score of ewes as well as the chill index. Accordingly, in these years the reduction in the lamb mortality rate which is achieved in this scenario is relatively small. This means the net benefits generated are also relatively small. In such years, if feed is also relatively scarce between birth and weaning, the increase in the cost of supplementary feed can outweigh the increase in lamb sale revenue, causing the realised net benefit to be negative.

Development Costs

In this analysis, consideration of the development costs incurred at the farm level to adopt and implement these technologies is kept separate from the measurement of the benefits they are expected to generate. This is because the industry model used to estimate the value of these technologies to the Australian lamb industry requires estimates of the change to the cost of producing lamb in in the case study system the steady state – once the technology has been installed and is fully operational. Development costs are incurred prior to this time and need to be counted separately in the discounted cash flow analysis that is used to estimate the overall value of the technologies to the lamb industry.

In both of the scenarios considered here, the benefits generated by the new technologies are clear – increasing the conception rate results in more lambs being sold and higher livestock trading revenue and farm profit. Furthermore, extra costs associated with the change to the farm system can be identified and included in the estimation of net benefits. For example, when the conception rate is increased the number of lambs on the farm increases and hence whole-farm annual energy demand increases. All else being equal, this means the average supplementary feed cost also increases. As well, with more lambs weaned and sold, costs such as labour, animal husbandry and fertiliser increase. All of these changes in costs which are caused by the use of the new technologies have been included in the distributions of net benefits above.

However, the investment of capital and annual costs required to bring about the change in the farm system represented in each scenario are not included in the model. Estimates of the investment and annual costs must be provided by the analyst. These expenditures may be in the form of an initial capital investment such as purchasing rams or ewes with particular genetic values, the purchase of a new piece of machinery to handle stock, or attendance at a training course to learn how to perform a particular task. In addition to initial capital costs, extra annual costs may be incurred to maintain the improvement in reproductive performance. These annual costs may be the extra annual amount depreciation on the extra capital investment in rams and ewes with particular genetic traits, extra labour required to implement the new technology, or the annual cost of purchasing the chemical or other treatment applied to stock to improve reproductive performance.

These expenditures are unlikely to be zero (otherwise the new technology would be the hard to find free lunch). To establish whether or not the total benefits of a given change to the farm system exceed the total costs, all extra costs need to be identified and, where possible, quantified. The difficulty with doing this is that the new technologies represented in this analysis do not currently exist in a commercial form. This means the costs likely to be associated with adopting them are also not known. Uncertainty about the true value of costs is represented in this analysis by using probability distributions to represent the range of possible costs which may be associated with each technology.

In both of the scenarios considered here, the same method has been used to construct the distributions of initial capital cost which have been represented for each of the technologies. Specifically, a version of the surplus approach has been used. This method involves estimating the largest value that costs *could* be, if the change is to be worthwhile, given the estimated magnitude of benefits generated by the technology. This is called the threshold approach. This calculation is assisted by making some assumptions about the likely adoption decisions of farmers, and the length of time benefits will be received after incurring the initial costs to make the change.

Specifically, at the time of making the adoption decision farmers are assumed only to know the expected value (the average) of the annual distribution of benefits which will be generated by the technology. This assumption is based on the proposition that farmers know that for an investment in a new technology which generates a particular improvement in reproductive performance, the value of benefits generated will depend on the seasonal conditions and commodity prices which are realised over the life of the investment. The values to be taken by these variables over the relevant (future) years cannot be predicted perfectly, hence the investment decision will be made on the basis of expectations about these variables. Here these expectations are assumed to be the average of the values that occurred in the past.

Assuming the decision to invest in a particular new technology is made on the basis of the average value of benefits generated, the maximum value of costs that will be paid is the value which generates an expected rate of return on the capital invested which is equal to the minimum rate of rate of return the farmer will accept, or the opportunity cost of capital. Here, this is assumed to be 7 per cent per annum real. In other words, the maximum value of costs that can be paid is the value which generates a net present value of the project of zero, when the discount rate is 7 per cent per annum real, i.e. the costs that are consistent with the investment having an IRR of 7 per cent real.

The assumption is that both of the technological changes described above will generate benefits on farms for a period of 15 years. Accordingly, to estimate the maximum costs that farmers would be willing to incur to make the change, it is first necessary to calculate the present value of average benefits received over the 15-year life of the project. This has been done using a discounted cash flow analysis. The net present value of benefits generated by the increase in conception rate and decrease in lamb mortality rate scenarios are $116,609 and $278,493 respectively. These present values are the maximum amounts that could be paid to obtain the benefits generated by each of these scenarios while earning a rate of return of 7 per cent on capital invested.

The minimum value that initial capital costs could have depends on the individual characteristics of the technologies, which are not known. However, these costs are likely to be substantially greater than zero; for it to be otherwise farmers would already need to have all the skills, experience, knowledge and tools required to implement the technologies, in which case they would presumably have already implemented it. Here, this minimum value is assumed to be 30 per cent of the average present value of cumulative net benefits received. Accordingly, the minimum possible costs of investing in the increase conception rate and decrease lamb mortality rate scenarios are $34,983 and $83,548 respectively.

Given this definition of the maximum and minimum values of the initial capital costs associated with the technologies, the remaining question is to select a functional form of the probability distribution used to represent these costs in the discounted cash flow analysis. In the absence of information to suggest that any one particular cost is any more likely than another, the uniform functional form has been chosen. In uniform distributions, every possible value has the same probability of occurring hence the probability density function is completely square (in contrast to the bell-shaped curve of the normal distribution). The distributions of possible development costs which may be incurred by the case-study farm to adopt these two technologies are summarised in the table below:

	Development costs incurred by case-study farm		
	Minimum	Mean (also median)	Maximum
Increase conception rate	$34,983	$75,796	$116,609
Decrease mortality rate	$83,548	$181,020	$278,493

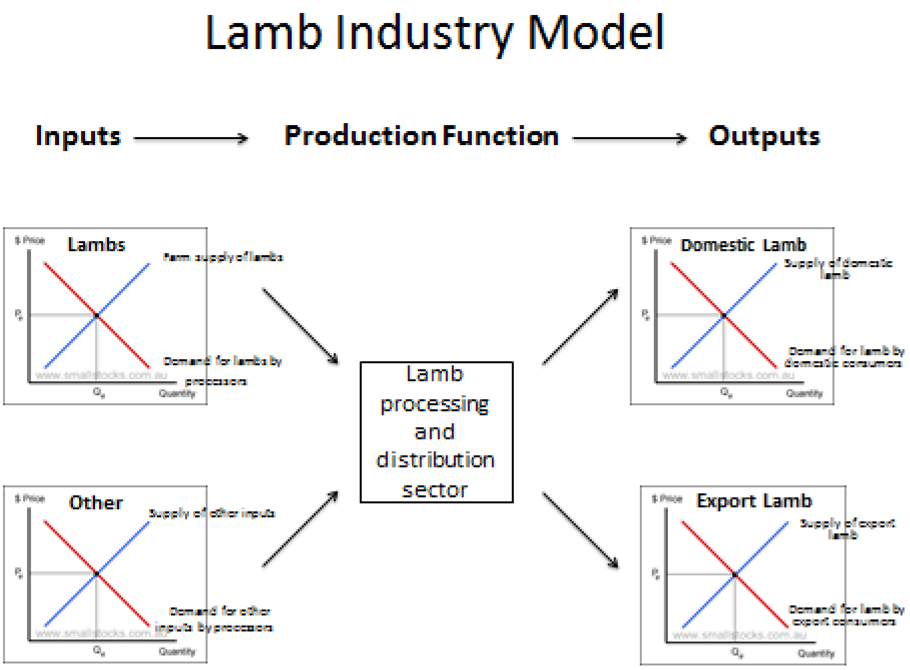
It must be recognised that defining the distributions of costs in this way does not mean that the investments will always earn a real annual rate of return of 7 per cent. This will only be the case if the average value of benefits is received in every year of the life of the project, and the maximum possible value of costs is paid. This particular combination of events is extremely unlikely to occur. In reality, annual benefits will be drawn from the distribution shown above and will be greater or less than the average in most years. Furthermore, the value of costs paid will not always be the maximum, instead it will be some value between the minimum and the maximum values. Accordingly, the estimated rate of return on capital invested in each iteration of the model will be greater or less than 7 per cent per annum real.

It should also be noted that it has been assumed that no extra annual costs specific to the new technology are incurred in order to continue using the new technologies, beyond those which have already been included in the model. Including extra annual operating costs would reduce the present value of cumulative net benefits generated by each technology, and, given the method used above, reduce the maximum possible value of initial capital costs. Accordingly, nothing would be gained by separately representing extra annual technology-specific costs in addition to initial capital costs. In the absence of information suggesting that these particular technologies have specific extra continuing costs, only initial capital costs have been represented. Finally, to include these development costs in the estimation of the value of these technologies to the Australian lamb industry, they must be aggregated from the farm to industry level. As explained in more detail below, this has been done using the industry model.

Part 2: Industry-level benefits

The successful adoption of new technologies in an industry generates economic surplus which is shared between the participants in that industry. Estimates of the magnitude and distribution of this surplus can be obtained from an equilibrium displacement model (EDM). Here, such a model has been used to estimate the value to the Australian lamb industry as a whole (farmers, other input suppliers, and consumers) of the changes in the cost of producing lamb generated by the technologies described above.

The EDM of the lamb industry used in this research has been adapted from an EDM of the pig industry (Mounter *et al.*, 2005). The lamb model is a relatively simple EDM with one central processing sector, two input markets and two output markets. Specifically, the model contains a lamb processing and distribution sector which combines lambs from farms and other inputs (such as labour and capital) to produce lamb meat which is sold to domestic and export consumers. The structure of the model is illustrated in the following diagram:



The data required to calibrate this model are estimates of prices and quantities which represent equilibrium in each of the four markets, own-price elasticities of demand for each of the outputs, own-price elasticities of supply for each of the inputs, and some characteristics of the production function in the processing and distribution sector, namely the elasticity of input substitution and the elasticity of product transformation. This data is described in the following section.

The "Farm supply of lambs" curve in the "Lambs" market of the model represents the Australian farm sector. Hence, any technology which is to be adopted on farms to alter the cost of producing lamb will be represented by applying a displacement (known as a "K-shift") to the supply function for lambs. Similarly, any technology or policy change which altered the cost of the other inputs used in the production and distribution of lamb would be represented by applying a K-shift to the supply function for the "other" input. Furthermore, the effects of efforts to increase the demand for lamb (such as a marketing campaign) in the domestic or export markets would be represented by applying a K-shift to the demand function for lamb in either of these markets.

A much larger model of the Australian sheep industry was constructed by Mounter *et al.* (2008). This model contains a detailed representation of the joint products of lamb in both production and consumption. As explained by these authors, representing joint products improves the accuracy with which the magnitude and distribution of research benefits is estimated. In contrast, the lamb industry model used in this work does not include markets for the joint products of lamb in production, namely wool and mutton. Similarly, the joint products of lamb are not represented in consumption. This means that the possibility of substituting lamb for mutton and vice versa by consumers is not represented in the model.

The model used in this research has been kept simple for two reasons. First, the amount of data required to run the larger model is large, and calibrating the model is a time-consuming and expensive task. Second, the impact of not including joint products on the estimated magnitude of research benefits is relatively small, and is already known from the work of Mounter *et al.,* (2008). The relatively small increase in accuracy that would result from a more comprehensive model of the lamb industry is not worth the extra time and cost associated with running the larger model.

An important aspect of this industry model used in this analysis is that it has been constructed to allow stochastic simulation to be performed. Specifically, the change in the cost of producing lamb which is achieved on a particular farm when using a given technology varies because of the stochastic nature of farm prices and quantities. Accordingly, probability distributions will be used to represent the K-shifts generated by each technology. Further, in estimating the value to the industry as a whole of the new technology, uncertainty about market parameters and the variability associated with future prices and quantities is represented using stochastic simulation.[1]

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[1] Note that the stochastic representation of prices and quantities in the farm and industry models does not mean the stochastic element of these variables has been double-counted. Specifically, although the prices and quantities which define equilibrium in the lamb supply market of the industry-level model are logically the aggregation of farm-level prices and quantities, this does not mean that lamb prices and quantities can only be stochastic in one of the models.

In the farm model, the distribution of possible changes in operating profit associated with each technology is estimated as of the set of relative differences (one for each iteration of the model) between operating profit in the scenario with the new technology and in base case. In each iteration of this model, the same commodity prices apply in the scenario with a new technology and in the base case. Accordingly, the stochastic representation of lamb prices does not contribute at all to the variation of possible changes in operating profit which is then represented in the industry model. This means there is no possibility of double-counting the effect of variation in lamb prices on the value of a particular new technology to the Australian lamb industry. Representing the price of lamb as a stochastic variable in the farm-level model is useful because it increases the realism of the model and allows more sensible distributions of annual net benefits associated with particular technologies to be estimated. However, for the narrow objective of estimating the distribution of changes in operating profit values, a non-stochastic representation of all commodity prices would generate the same results.

Farm-level quantities also enter the industry model through the changes in operating profit generated by each technology. In fact, given that the same prices apply in each scenario within each iteration of the model, these changes in operating profit effectively represent the additional quantities of outputs produced and inputs used with the new technologies. These quantities are not necessarily related to the quantity of lamb produced by the entire Australian lamb industry in any given year. In the farm model, the magnitude of the *change* in the quantity of lamb produced when using a particular

In each iteration of the industry model, a particular value of the change in the cost of producing lamb generated by each technology (the K-shift) is drawn from the distribution of possible changes associated with that technology. This is done because the new technology will not cause the same change in the cost of production in all years. Furthermore, in each iteration of the model, a set of market parameters are drawn from the relevant distributions and used to estimate the value of that particular K-shift to the industry as a whole. This reflects the fact that the values of relevant market parameters in the industry model are not perfectly known. The values which have been used to represent these parameters are discussed in the following section.

Data: Market parameters

The market parameters in the model above are the price elasticities of the supply and demand functions, and the elasticities with which inputs and outputs can be substituted for one another in production. There is uncertainty about the true value of most of these parameters because they are seldom estimated. Accordingly, all market parameters in the model have been represented using PERT (program evaluation and review technique) distributions.

The PERT distribution is a special form of the beta distribution, scaled so that any range of values can be represented (rather than only 0 – 1). An advantage of this distribution is that it is defined by only three parameters: the minimum, most likely and maximum values. This means that extreme values (beyond the bounds of theory or common sense) can be excluded. Furthermore, because the entire distribution is defined only by these values, the distribution does not need to be symmetrical (unlike the normal distribution).

Other advantages of the PERT distribution are that it is easily understood and transparent, and can be calibrated using readily available subjective estimates of the minimum, most likely and maximum values a variable can take, while retaining important characteristics of probability distributions such as a curved shape. This is in contrast to alternative distributions such as the triangular, which arguably places too much probability weight on values in the tails of the distribution.

The minimum, most likely and maximum values used to calibrate the PERT distributions in this analysis are based on the literature reviewed in Mounter *et al.,* (2008) plus some economic theory and subjective judgements. The values used to represent the market parameters in the model are presented in the table below. While their model is not identical, the values used by Mounter *et al.,* (2008) are also provided for reference.

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technology varies from year to year depending on realised seasonal conditions, and so this is a stochastic variable. Quite separately, the stochastic quantity variable in the industry-level model reflects the fact that the total quantity of lamb produced by all farms in Australia varies from year to year depending on realised seasonal conditions.

Name	Mounter *et al.* (2008)	PERT distribution parameters		
		Minimum	Most Likely	Maximum
Own-price elasticity of supply of lamb from farms	1.3	1.0	1.3	2.0
Own-price elasticity of supply of 'other' processing inputs	2.0	1.0	2.0	3.0
Elasticity of input substitution between lamb and other inputs	0.1	0.05	0.1	0.8
Elasticity of product transformation between domestic and export lamb	-0.5	-1.0	-0.75	-0.5
Elasticity of product transformation between export and domestic lamb	-0.5	-1.0	-0.75	-0.5
Own-price elasticity of retail demand for lamb (domestic)	-1.5	-1.5	-1.0	-0.75
Own-price elasticity of retail demand for lamb (export)	-2.5	-2.25	-2.0	-1.5

Data: Prices and quantities

The equilibrium prices and quantities in each of the four markets in the model define the overall value of the Australian lamb industry. Accordingly, these prices and quantities are important determinants of the value of any technology which alters the cost of production in the lamb industry. Because these variables are not constant over time and cannot be predicted with certainty, it is realistic to represent these prices and quantities as stochastic variables rather than using single (deterministic) values.

Like the market parameters, PERT distributions can also be used to represent stochastic prices and quantities. However, doing so probably causes the variability in these variables to be understated. This is because using the lowest and highest values which have occurred over the past four years to define the minimum and maximum of the PERT distribution would mean these values almost never occur (they are the extreme tail values), rather than occurring 25% of the time which logically should happen.

A solution to this problem is to widen the range of the PERT distribution by choosing lower and higher values to represent the maximum and minimum values; however this involves making some fairly arbitrary decisions about which numbers to choose. An alternative solution is to choose a distribution which is defined by parameters which can be calculated from the historical data, namely the mean and standard deviation.

One common distribution which is completely characterised by such data is the normal distribution. The main drawback associated with using this functional form is that it is always symmetrical; using this distribution to represent particular variables requires the assumption that the values which can be taken by these variables are also symmetrical around the most likely value. While it is not clear that this assumption holds for all prices and quantities, it is also not clear that any other distribution would provide a more accurate representation of these variables in the medium term. Accordingly, the equilibrium prices and quantities used in the model have been represented by normal distributions which have been calibrated using the mean and standard deviation of the past four years of historical data. The table below contains this data.

	Actual data Quantity units: kt CWE, Price units: real$/t CWE					
Year	Supply of lambs	Price of lambs	Quantity of domestic demand	Price of domestic lamb	Quantity of export demand	Price of export lamb
2006-07	413	3,600	233	9,408	179	4,777
2007-08	435	3,613	242	9,284	194	4,520
2008-09	423	4,750	238	9,585	184	5,316
2009-10	420	4,717	230	9,883	190	4,933
Mean	**423**	**4,170**	**236**	**9,540**	**187**	**4,886**
Standard deviation	**10**	**651**	**5**	**260**	**6**	**333**
Coefficient of variation	**2%**	**16%**	**2%**	**3%**	**3%**	**7%**

The supply of the "other" inputs to production is not included in the table because it is calculated as a residual. Specifically, the equilibrium conditions of the model state that the quantity and value of inputs used is equal to that of the outputs produced. Hence, rather than attempting to construct estimates of the prices and quantities of all the other inputs used in the processing and distribution sector of the lamb industry, the cost share of this industry is calculated as the residual of the cost share of the lamb input. The following table contains the weighted-average revenue and cost shares of the two outputs and two inputs which are implied by the equilibrium prices and quantities in each of the markets in the model:

Input	**Cost Share**		**Output**	**Revenue Share**
Lambs	56%		Domestic	71%
Other	44%		Export	29%

Data: Correlations

In using probability distributions to represent the market parameters and the equilibrium prices and quantities in the model, care is needed avoid impossible combinations of uncertain variables being simultaneously drawn in individual iterations of the model. For example, the equilibrium price and quantity of lamb produced by the farm sector is likely to be negatively correlated (i.e. the price is most likely to be relatively low when the quantity is relatively high and vice versa).[2] The same applies for market parameters – if the elasticity of substitution in inputs is high, then the elasticity of product transformation must also be high.

[2] Including these correlations in the lamb industry equilibrium displacement model does not represent double-counting the market parameters, in particular the elasticities of the supply and demand functions. The correlations mean that particular price and quantity combinations are more likely to occur than others in defining the equilibrium in each market. The market parameters define the magnitude of flow-on effects in related markets following the displacement of this equilibrium caused by a shock to a supply or demand function.

This is because the production system is either flexible or inflexible, and if it is flexible then it must be so in both inputs and outputs.

Some empirical data is available to define these correlations; however economic theory and common sense have also been used where necessary. The table below contains the correlations between the uncertain equilibrium price and quantity variables which have been included in the industry model.

Variable	Farm supply of lamb	Farm price of lamb	Export lamb demand	Export lamb price	Domestic lamb demand	Domestic lamb price
Farm supply of lamb	1					
Farm price of lamb	-0.7	1				
Export lamb demand	0.7	-0.5	1			
Export lamb price	-0.5	0.7	-0.7	1		
Domestic lamb demand	0.7	-0.5	0.7	-0.5	1	
Domestic lamb price	-0.5	0.7	-0.5	0.7	-0.7	1

The following table contains the correlations between the uncertain market parameters which have been applied in the model:

Variable	Input substitution elasticity	Elasticity of product transformation: domestic to export	Elasticity of product transformation: export to domestic
Input substitution elasticity	1		
Elasticity of product transformation: domestic to export	0.7	1	
Elasticity of product transformation: export to domestic	0.7	1	1

Data: K-shifts

The first step towards estimating the value of the new technologies considered in this work to the Australian lamb industry is to convert the expected effects of the technologies on annual operating profit into “K-shifts”, which represent the effect of the new technologies in the industry model. To estimate the distribution of possible K-shifts for each technology, the change in annual, steady-state operating profit earned with the new technologies relative to that earned in the base case is calculated for each iteration of the farm-level model. This produces a distribution of 5,000 possible percentage changes in operating profit. These changes are equivalent to the percentage changes in the cost of producing lamb (K-shifts) which are the required by the industry model. The distributions of possible K-shifts associated with each technology are presented in appendix 1.

Industry level benefits

The annual, steady-state value of benefits generated by each technology to the Australian lamb industry have been estimated using the equilibrium displacement model described above. The distributions of these annual values are shown in appendix 2. However, the technologies considered in this work are expected to generate benefits for some time into the future, not just for one year. Accordingly, the total value of benefits generated by these technologies to the industry as a whole is calculated using a discounted cash flow analysis. Performing such an analysis requires assumptions about the period of time for which the technology is expected to generate benefits, and the proportion of producers in the industry which can be expected to adopt it. Each of these considerations is discussed below.

Effective life of technology

The period of time for which these technologies can be expected to generate benefits is not indefinite, because they will become redundant as other new technologies are developed and adopted. One way to think about this is that even if these new technologies are adopted, the value of extra profit generated will gradually decline over time because the base case farm system will improve as other new technologies become available.

Here, it is has been assumed that the new technologies considered in this work will generate benefits to the Australian lamb industry for a period of 30 years. At the end of this period, the technologies are expected to be obsolete. An alternative view, with similar implications, is that if the technology was not discovered and developed and used in the 30 years as a result of this particular investment in RD&E, it would by that time have been discovered and developed by some other investment in RD&E services.

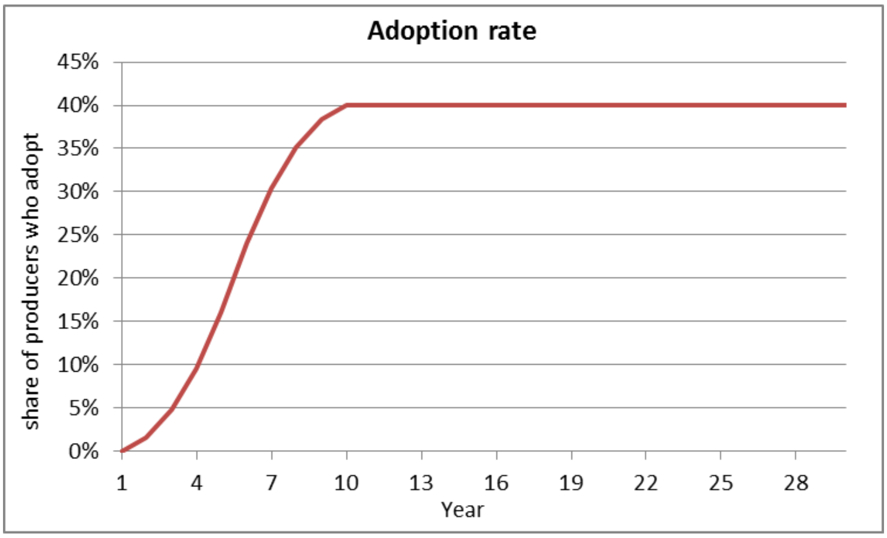
Adoption

The value of industry-level benefits generated by a particular technology is estimated in the equilibrium displacement model assuming that the K-shift generated by that technology applies uniformly across all producers in the industry. That is, all lamb producers are assumed to immediately achieve whatever K-shift is drawn from the distribution of possible values. In reality, there will be a period of delay before any producers adopt the new technology, and another period of delay until all producers who will ever adopt the new technology actually do so. Typically, the ultimate proportion of producers who adopt will be less than 100 per cent.

Accordingly, to estimate the realised value of the new technology to the industry as a whole, an adoption profile must be specified. As discussed by Kuehne *et al.* (2011) the rate and eventual extent of adoption depends on a range of factors, including the profitability and risk associated with adoption, the complexity or simplicity of the change, and the relative ease with which potential adopters can learn about the new technology. In the absence of specific information about the nature of the new technologies considered here, simple adoption profiles will be assumed to apply in both cases.

Specifically, it is assumed that the proportion of lamb producers who adopt each technology can be described by a logarithmic curve which increases from 0 per cent in the first year, to a peak level of adoption after 10 years. This adoption profile defines the proportion of total output from the Australian lamb industry which is produced using the new technology. The shape of this adoption profile is based on the adoption of moderately profitable, low risk agricultural innovations in the past. To allow for uncertainty which exists about the proportion of lamb producers who will ultimately adopt this technology, a uniform probability distribution has been used to represent a range of possible peak adoption levels which are reached after 10 years. This distribution ranges from a minimum of 30 per cent to a maximum of 50 per cent, with an average value of 40 per cent.

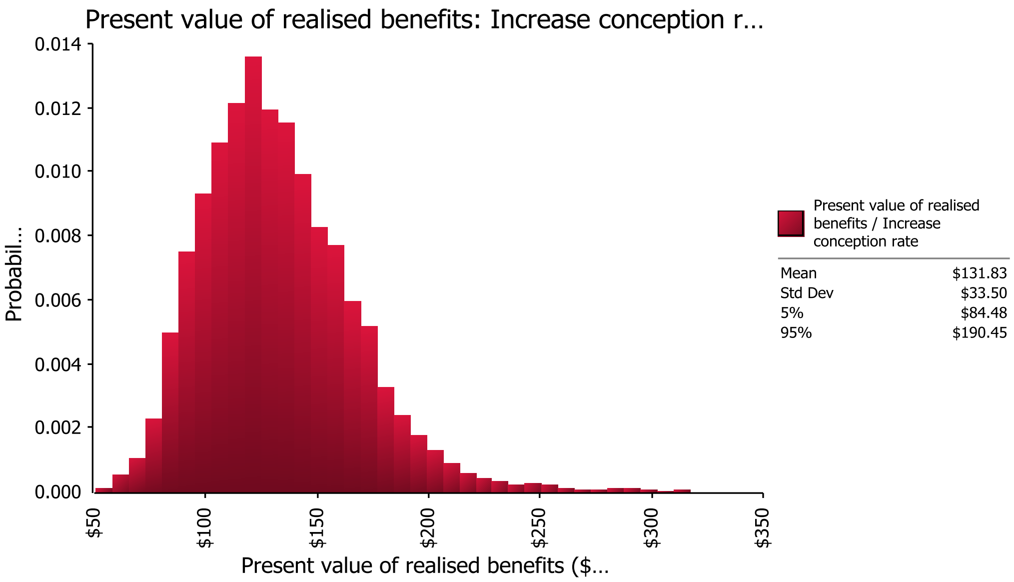
Although the decrease lamb mortality rate technology generates an average increase in annual operating profit which greater than that generated by the increase conception rate technology, the increase in the variability of whole-farm profit (a measure of risk) is also larger. These two effects have offsetting effects on the ultimate proportion of producers who will adopt the technologies; hence the same adoption profile has been applied to both. Without more information about the precise nature of the technologies considered in this work it is not possible to specify more precise adoption functions. The following graph illustrates the average adoption profile of the new technologies over time:



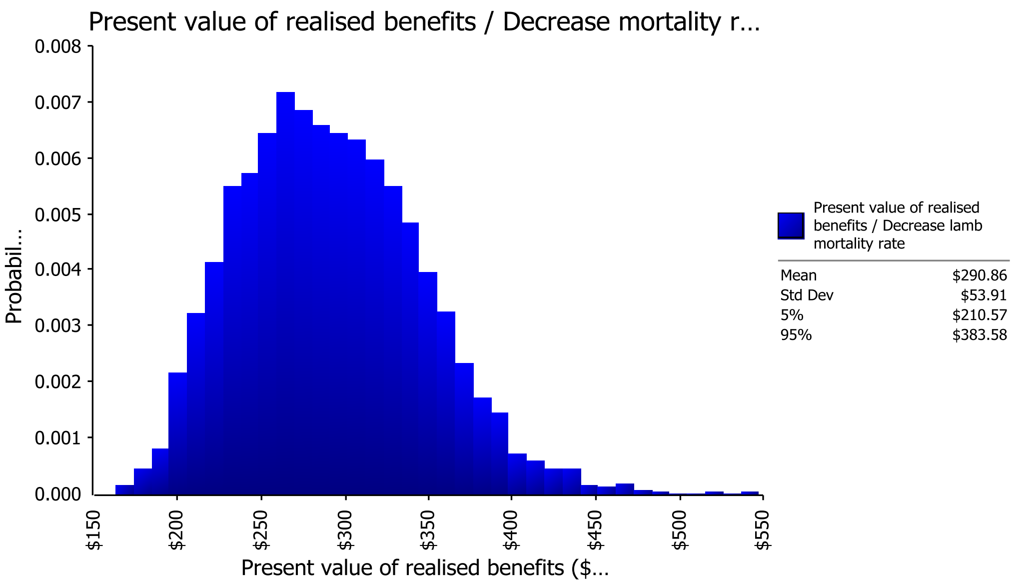
Present value of realised benefits

Given the assumptions outlined above and the estimates of annual benefits generated by the new technologies, discounted cash flow analysis is used to estimate the present value to the Australian lamb industry of the new technologies considered in this work. This involves multiplying the annual benefit generated by each technology by the proportion of producers who are expected to have adopted the technology in each year. This generates the set of realised annual benefits in each year of the effective life of the technologies. This set of 30 values is then converted to a present value using a discount rate of 7 per cent per annum real.

In each year for which the project is expected to run, the benefit obtained from the EDM is a stochastic variable (reflecting variation in the K-shift, the value of the lamb industry, and the market parameters of the industry model). Accordingly, the output of the discounted cash flow analysis is a distribution of 5,000 possible present values of benefits for the Australian lamb industry as a whole generated by each technology. The graph below contains the distribution of the present value of benefits generated by an increased conception rate:



The average present value of total realised benefits associated with this scenario is $131.8 million; 90 per cent of all values fall in the range $84.5 million to $190.5 million. The graph below contains the distribution of net present values generated by the decreased lamb mortality rate scenario:



The average net present value of benefits generated by this scenario is $290.9 million; 90 per cent of values fall in the range $210.6 to $383.6 million.

Industry-level costs

The farm costs described in the first section of this report have been aggregated to the industry level using the same procedure as that used to obtain the industry-level value of benefits. Specifically, the value of development costs associated with each technology were expressed as K-shifts by dividing the stochastic value of development costs by the value of farm operating profit in the base case in that iteration of the model. The industry-level value of these costs was then estimated using the equilibrium displacement model. The logic behind this approach is that in the year in which development costs are incurred, they represent an increase in the cost of producing lambs. Hence, the value of these costs can be estimated by representing them as a negative K-shock in the EDM.

The K-shift used to represent the value of costs in the industry model is stochastic for two reasons. First, given that the technologies are yet to be developed, the costs incurred by farms to adopt them are currently uncertain. This is why uniform distributions are used to represent these costs in the farm-level analysis. Second, because the K-shift represents the change in operating profit brought about by incurring development costs, variation in the level of operating profit in the base case (reflecting stochastic prices and quantities) means the K-shift would be stochastic even if the value of development costs was known and constant. The distributions of development cost K-shifts associated with each technology are shown in appendix 3.

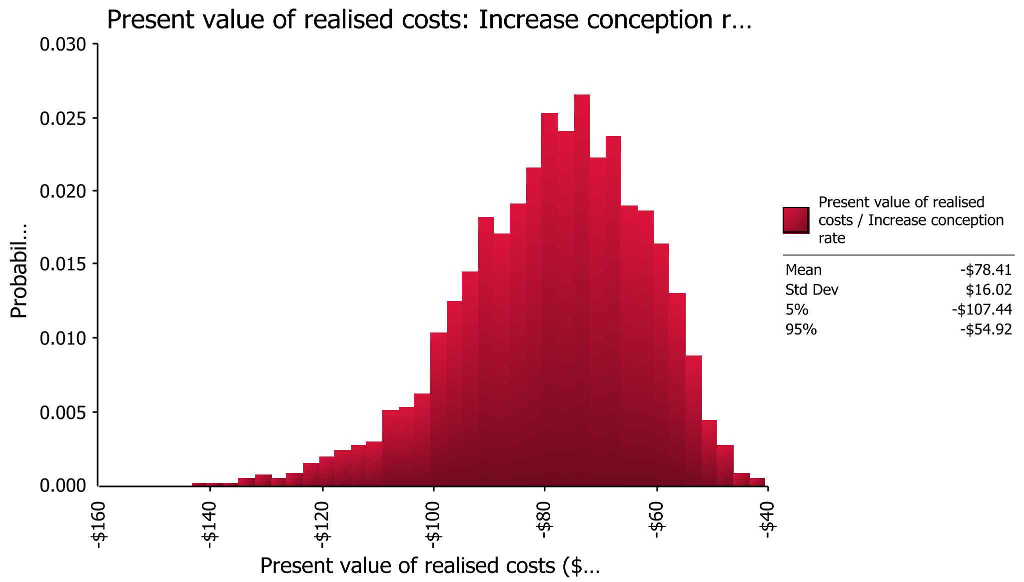
The annual value of the development costs associated with each technology to the Australian lamb industry has been estimated using the equilibrium displacement model. These distributions are shown in appendix 4. However, these distributions represent the value of the development costs associated with these technologies to the lamb industry assuming that all producers adopt the technologies, and that they adopt them at the same time. To include correctly the value of development costs when estimating the net present value of these technologies to the Australian lamb industry, the adoption profile and productive life of the technologies must also be taken into account.

Specifically, these costs will only be incurred by those farmers who do adopt the technologies, and they will only be incurred when these farmers choose to adopt. Accordingly, similar to the valuation of realised net benefits, in each year of the discounted cash flow calculation the annual industry-level development costs have been multiplied by the proportion of farmers who have adopted the technology by that year, to calculate the realised value of development costs in each year.

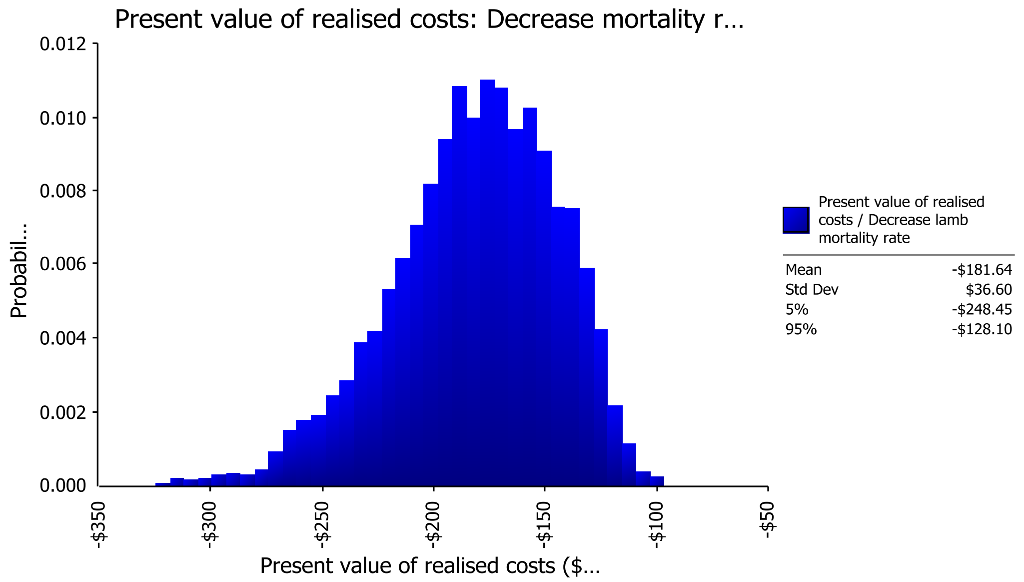
Furthermore, as noted above the technologies are not expected to become obsolete for 30 years, hence in the discounted cash flow analysis it is assumed these technologies will create benefits to the Australian lamb industry for 30 years. However, 30 years is a long time for a single on-farm investment to generate benefits. Indeed, it has been assumed here that the technologies will actually only generate benefits for a period of 15 years following the initial payment of development costs.

To ensure that costs are correctly accounted for at the industry level, it is assumed that after the first 15 year period, those farmers who have adopted the new technology will pay the development cost again in order to continue using it. Specifically, in years 16 to 24 of the discounted cash flow analysis, development costs are incurred again by the proportion of producers who need to do so to continue accessing the new technology. For producers who re-incur the development costs in year 24 this means that only 6 of the 15 years of benefits will be counted. This reflects the risk associated with adopting any new technology, namely that it may subsequently become obsolete.

The following graph contains the distribution of present values of costs at the industry level which are actually incurred in the increase conception rate scenario, given the adoption profile and investment period described above:

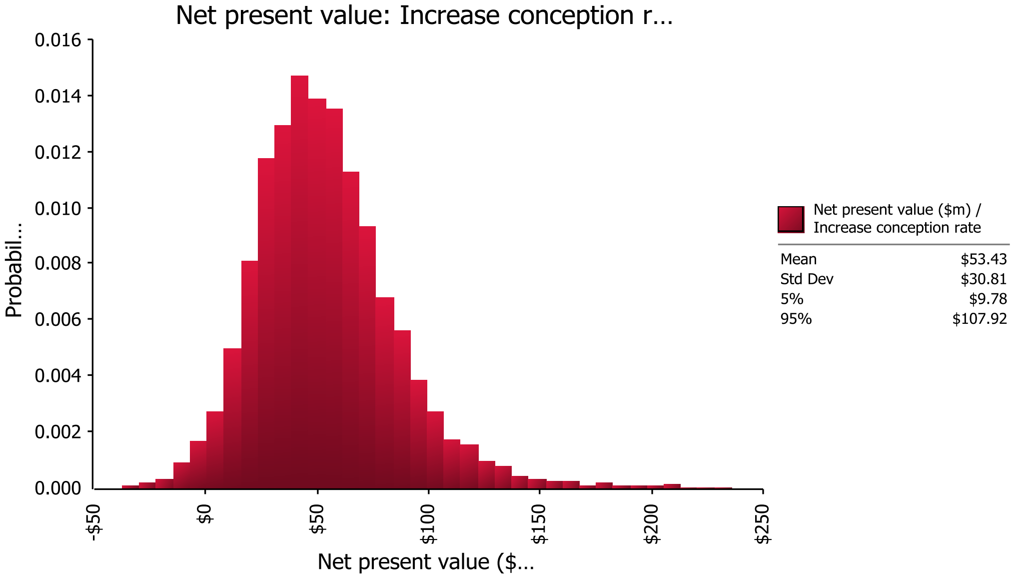


Below is the distribution of the present value of industry-level costs incurred in the decrease lamb mortality rate scenario:



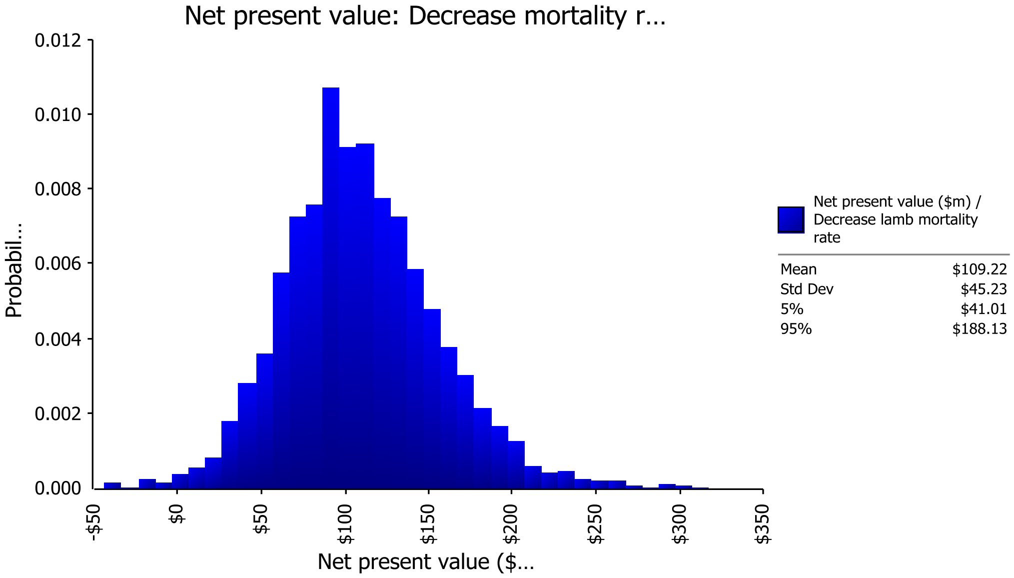
Net present values

The variable of interest in this analysis is the net present value to the Australian lamb industry of the new technologies. This net present value is defined as the present value of realised benefits associated with each technology minus the present value of realised development costs. This net present value has been estimated for 5,000 iterations of the discounted cash flow analysis. The graph below contains the probability density function which describes the distribution of possible net present values to the Australian lamb industry of the increase conception rate technology. Graphs of the cumulative distribution functions are shown in appendix 5.



The average net present value of the increase conception rate scenario to the Australian lamb industry is $53.4 million, and the 5th and 95th percentiles are $9.8 million and $107.9 million respectively. Overall, 2.2 per cent of the net present values in the distribution above are negative. These values occur because the value of development costs paid to adopt the technology is based on the average present value of benefits, but in some cases the actual benefits received are less than the average. When these relatively small present values of benefits coincide with relatively high present values of development costs, the result is a negative net present value. This reflects the danger of making investment decisions on the basis of average expected returns in a world of risk and uncertainty.

The distribution below is of net present values to the Australian lamb industry as a whole of the technology that decreases lamb mortality:



The average net present value generated by this technology is $109.2 million. The 5th and 95th percentiles are $41.0 million and $188.1 million, respectively. The proportion of negative values in this distribution is 0.6 per cent. These values occur for the same reason as they did in the increase conception rate scenario.

Research Costs

In the absence of detailed information about the particular technologies which will be used to bring about the changes to lamb farm systems represented in this analysis, it is impossible to quantify the research, development and extension costs which are likely to be associated with these technologies. However, a version of the surplus approach used in the farm-level modelling above can be employed to estimate the largest amount that could be spent on such RD&E while still representing a good use of research funds, given the expected net present values generated by these technologies.

In particular, given the net present values of the technologies shown above, there is a total present value of research, development and extension costs which can be incurred by a given research organisation to create these technologies, while maintaining a required rate of return on capital invested. *Ex ante*, the organisation does not know which of the possible net present values in the distribution will be realised; hence it is assumed that the decision to invest in RD&E will be made on the basis of the weighted-average net present value of the technology.

Given this investment rule, the maximum value of RD&E costs that can be incurred is the value which generates a zero net present value for the technology when discounted at the required rate of return. Two discount rates will be considered in this analysis. One is the discount rate used by MLA, namely 7 per cent per annum real. The other discount rate which has been used is 15 per cent per annum real. This discount rate is based on the opportunity cost of capital for research organisations such as MLA, and hence reflects the rates of return earned by past investments in agricultural research and development.

The following table contains the maximum present value of research, development and extension costs which could be incurred to create these technologies at each of the required rates of return. The probabilities that the realised net present value of the technologies could be less than the maximum value of costs paid are also shown.

	Maximum value of costs at 7% real ($m)	Probability that NPV is less than max value of costs:	Maximum value of costs at 15% real ($m)	Probability that NPV is less than max value of costs:
Increase conception rate	$53.4	54.3%	$6.5	53.0%
Decrease lamb mortality rate	$109.2	53.1%	$10.6	50.0%

If the technologies can be created and the expected rate of adoption can be achieved for less than these maximum costs, the rate of return earned by the funds invested will be greater than the relevant rate of return in the table above. However, even if costs incurred are less than those shown in the table above, there is no guarantee that the required rates of return will actually be earned, because the returns generated by these technologies (the industry-level net present values) are stochastic.

For example, as shown in the table there is a 54.3 per cent chance that the net present value of benefits earned by the increase conception rate scenario will be less than $53.4 million. Hence, if $53.4 million is invested in RD&E to create this technology, there is a 54.3 per cent chance that the rate of return earned by this investment will be less than 7 per cent per annum real. Similarly, there is also a 45.7 per cent chance that the realised present value of benefits will be more than $53.4 million, in which case the realised rate of return will be greater than 7 per cent if this amount is invested in research and development.

The point is that there is no guarantee the average net present value will occur, and so research organisations could benefit from using distributions such as those generated in this work to evaluate not only which technologies represent the best use of scarce research funds, but also to gain a better understanding of the risk associated with the various investments they can make. It is also possible to use these probabilities to identify the implications for risk and return of the various possible criteria which can be used for making investment decisions.

The ability to perform risk analysis is an important advantage of using a stochastic approach to analyse investments in new technologies. This kind of analysis is not possible in a non-stochastic framework. Performing sensitivity analysis can generate information about the consequences associated with the realised values of uncertain variables being different to their expected values, however the probabilities of the alternative values analysed in a sensitivity analysis are typically unknown, hence the outcomes of such analysis are of relatively little use for decision-making. In contrast, consideration of the risk and return associated with potential investments in research and development allows better-informed decisions to be made about which investments should be undertaken.

Part 3: The value of platform technologies to the Australian lamb industry

In this analysis, 'platform technologies' are defined as capital items that allow farmers to collect more timely and better quality information about livestock. For example, platform technologies such as walk-over weighing and individual measurement of feed intake would allow grazing management and supplementary feeding to be improved. Alternatively, a platform technology such as remote observation of animal behaviour would allow health problems to be identified earlier, allowing more effective treatment to be implemented. The findings of the Lifetime Ewe study suggest that sheep that are better fed and more healthy throughout their lives will be more productive. These technologies also reduce the amount of time spent observing livestock, and hence reduce overall labour requirements.

On the case study farm, pasture growth, grazing management and the stocking rate are such that most sheep have a condition score of at least 3 throughout the year. However, this is the average condition score across the whole flock, and there is a proportion of the flock that does not perform as well as this. For these sheep, the use of platform technologies would allow more targeted feed management, which in turn would improve the health of these sheep. Furthermore, where the health of sheep is being reduced by parasites, disease or some other problem, platform technologies would help the manager identify and resolve these problems more quickly, improving the morbidity of these sheep.

Scenario descriptions

The case study farm already has a sophisticated grazing system and uses little supplementary feed. Accordingly, the benefits derived from using platform technologies will primarily relate to improving the overall health status of the flock, not through improving the feeding regime. In scenario 3: ‘reduced morbidity’, the main way in which improved lifetime health will be represented is by increasing the age at which sheep are culled from 5.5 years to 6.5 years. Platform technologies allow this change to be made because reducing the morbidity of sheep throughout their lives allows them to be productive for longer. As shown below, this change reduces the number of ewes that must be purchased each year to replace culls.

While platform technologies are expected to improve the nutrition and health status of sheep in this analysis, they are not expected to reduce the mortality rate below the 3 per cent per year which applies in the base case. While sheep will be healthier on average with these technologies, they will continue to die from a variety of causes each year. Some of these causes will not be influenced by platform technologies, and others will not change because remedies are too costly or impractical to apply in extensive farm systems. Furthermore, the fact that in this scenario the flock now contains an older cohort of ewes means that any reduction in the overall flock mortality rate is likely to be negligible.

The use of platform technologies is also expected to reduce the amount of time required to monitor livestock, and hence reduce overall labour costs. Here, the annual labour cost is assumed to be 5 per cent lower with these technologies. Together, these changes to the farm system comprise scenario 3: reduced morbidity.

In addition to these changes, improving the lifetime health of sheep may alter other aspects of the farm system. For example, reducing competition with parasites for protein and other nutrients may allow increased wool and muscle growth. Reducing the diversion of resources to fight infections and other diseases may have the same effect. Improved gastrointestinal health may increase feed conversion efficiency. These additional benefits have been represented in scenario 4: ‘reduced morbidity plus’.

Specifically, scenario 4 was constructed by adding a 1 per cent increase in wool growth, the conception rate, lamb sale weights and pasture production to the changes represented in scenario 3. The quantity of pasture produced was increased by 1 per cent to represent the increased availability of energy to livestock with greater feed conversion efficiency because the parameters of livestock cannot be altered directly. The reduction in labour cost of 5% was also included in this scenario.

Scenario results

In the base case, all ewes that are 5 to 6 years old are culled after weaning in mid-December. These ewes are replaced in late December with 10-month old ewes. The replacement ewes are then joined at approximately 12 months of age in early March. In scenario 3, ewes are retained on the farm for one additional year, and are culled at 6 to 7 years old. As shown in the table below (Approximate ewe numbers by class), this reduces the number of sheep that are culled each year, and hence reduces the number of replacements that are purchased.

	Age class						Total
Scenario	1-2	2-3	3-4	4-5	5-6	6-7	
Base case	2,000	2,000	2,000	2,000	2,000	0	10,000
3: Reduced morbidity	1,667	1,667	1,667	1,667	1,667	1,667	10,000
4: Reduced morbidity plus	1,667	1,667	1,667	1,667	1,667	1,667	10,000

The data indicates that following this change, the proportion of ewes culled from the flock each year decreases from 20 per cent to 16.7 per cent. This change could be achieved in a number of ways, including a reduction in teeth wear as a result of better grazing management (Nolan and Black, 1970), a reduction in mastitis using chemical treatments (Croft *et al.*, 2000), or a reduction in worms through more precise targeting of chemical treatments or altered grazing management (Love, 2011). The use of all these approaches would be facilitated by platform technologies which provide farmers with more information about pastures and the health status of sheep.

These scenarios generate increased profit in two main ways: First, the cost of purchasing replacement ewes is reduced by around 15 per cent. Although the reduction in revenue from sales of culled ewes partially offsets this benefit, the net effect on farm profit of this change is a relatively large increase. The following tables (Number and value of culled ewes sold per year and Number and value of replacement ewes purchased per year) illustrate the magnitude of these changes:

Scenario	**Number of culled ewes sold**	**Revenue from cull sales**	**Change from base case**
Base case	1,802	$90,000	
3: Reduced morbidity	1,471	$73,500	-16,500
4: Reduced morbidity plus	1,471	$73,500	-16,500

Scenario	Number of replacement ewes purchased	Cost of replacement ewes	Change from base case
Base case	2,166	$282,000	
3: Reduced morbidity	1,837	$239,000	-$43,000
4: Reduced morbidity plus	1,837	$239,000	-$43,000

Given the relative magnitude of the decrease in revenue from cull sales, and the decrease in cost of replacement ewes, the net effect on farm profit is $43,000 – $16,500 = $26,500. This is the direct benefit of increasing the age at which ewes are culled from 5.5 to 6.5 years. If the case-study farm had a self-replacing flock, increasing the age at which ewes are culled would still generate an increase in profit, because it would reduce the number of ewe lambs kept as replacements (and hence not sold) each year. While somewhat less directly observable, if all the costs of raising replacement ewes on-farm are taken into account, this benefit is likely to be of a similar magnitude to that shown above.

The second way this change to the farm system increases farm profit is by increasing the overall reproductive performance of the flock. This occurs because reducing the number of replacements purchased each year reduces the number of 1-2 year old ewes in the flock. These maiden ewes have a lower weaning rate than older ewes; hence reducing the proportion of these ewes in the flock improves overall reproductive performance. Lamb is the largest single source of revenue on this farm, hence this change makes a significant contribution to farm profit. In scenario 4, the increase in reproductive performance is further increased by the 1 per cent increase in the conception rate which has been represented. The following table (Average number of lambs sold per year) summarises the effect on the number and value of lambs sold:

Scenario	Number of lambs sold	Value of lambs sold	Change
Base case	12,682	$1,324,000	
3: Reduced morbidity	12,803	$1,336,000	$12,000
4: Reduced morbidity plus	12,885	$1,352,000	$28,000

To clarify the effect of these scenarios on the number of lambs sold, the following table contains the average number of lambs per ewe across the whole flock at joining and marking. In scenario 3, the only cause of the change in the number of lambs per ewe is the reduced proportion of 1-2 year old ewes in the flock. Across the 10,000 ewes joined, the 0.01 increase in the number of lambs per ewe at marking corresponds to an increase of 100 lambs marked and subsequently ~ 100 extra lambs sold, which increases farm revenue by around $10,000 on average. In scenario 4, the increase in the number of lambs per ewe reflects both the reduced proportion of 1-2 year old ewes in the flock, and the 1 per cent increase in the initial conception rate relative to the base case.

	Lambs per ewe	
Scenario	Joining	Marking
Base case	1.61	1.28
3: Reduced morbidity	1.63	1.29
4: Reduced morbidity plus	1.64	1.30

Given that 12 months old is relatively young for joining, these scenarios were also run where replacement ewes are first joined at 24 months old. All other aspects of the farm system were kept the same. When this change was implemented, the value of the reduction in the cost of replacement ewes was similar to that achieved in scenarios 3 and 4; but the value of increased lamb sales was significantly larger. This occurs because when 1-2 year old ewes are not joined, reducing the proportion of ewes in this age group causes an even greater increase in the total number of lambs sold than when 1-2 year old ewes are joined, because even though 1-2 year old ewes have lower weaning rates than older ewes, they at least produce some lambs when joined. Running these additional scenarios confirmed that the estimated values of benefits associated with these scenarios are not unusually high because of this characteristic of the case study farm system.

In addition to these benefits, platform technologies are assumed to reduce total labour requirements by 5 per cent relative to the base case. The total annual cost of labour in the base case is $100,000 per year; hence this corresponds to an annual reduction in the cost of labour of $5,000. In each scenario, the annual cost of labour is linked to the stocking rate of the farm. Given that these scenarios both cause an increase in the number of lambs conceived, and hence increase the effective stocking rate, the actual difference in the annual cost of labour between the base case and the scenarios is somewhat less than $5,000. The following changes contain the weighted average annual stocking rate and labour cost for each scenario.

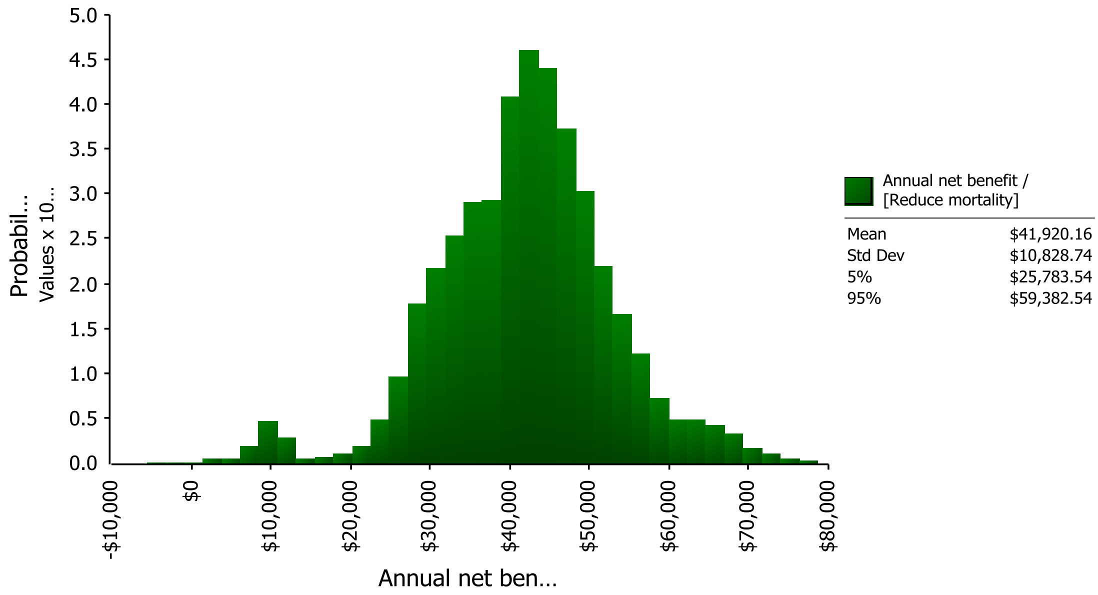
Scenario	Stocking rate DSE/ha	Annual labour cost	Annual labour cost change
Base case	24.48	$100,000	
3: Reduced morbidity	24.50	$95,074	-$4,926
4: Reduced morbidity plus	24.69	$95,819	-$4,181

The data in the six tables above describe the main benefits generated by these scenarios. Overall, the net effect of these changes on the farm profit is the annual benefit generated by these technologies. The following table (Average annual net benefits by scenario) contains the average value of these net benefits over the 40-year simulation period:

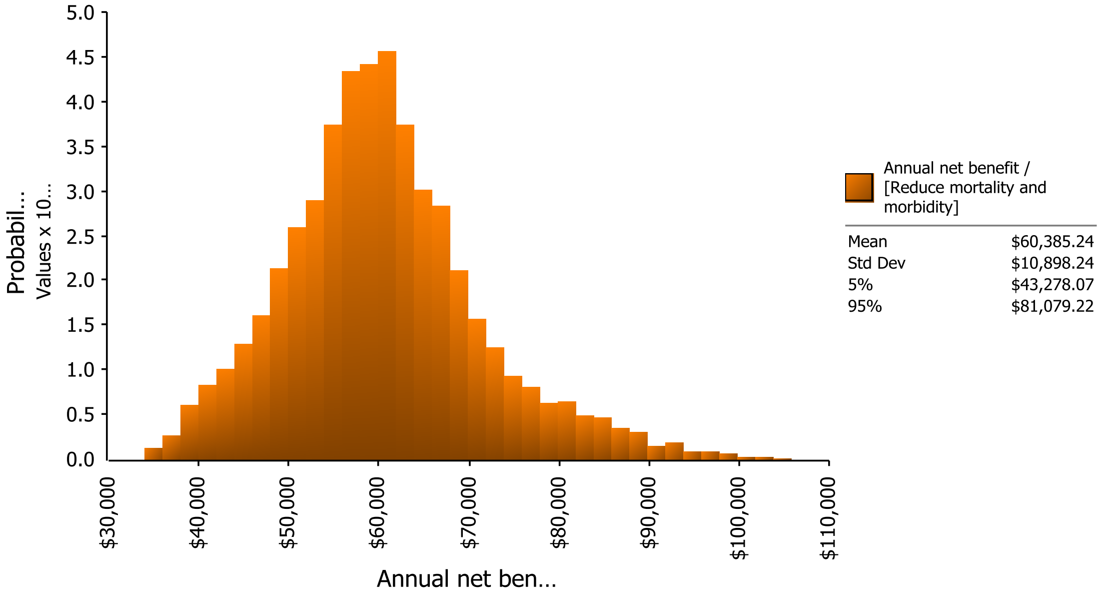
Scenario	Average annual net benefit
3: Reduced morbidity	$41,920
4: Reduced morbidity plus	$60,385

In any particular year, the value of benefits generated by each of these scenarios is stochastic: it varies from year to year depending on the number of ewes culled and replaced, on the number and weight of lambs sold, and on the change in the quantities of wool produced and supplementary feed used. The following figures contain the estimated distributions of annual benefits associated with each of these scenarios:

Annual net benefit: reduced morbidity



Annual net benefit: reduced morbidity plus



Development costs

Similar to scenarios 1 and 2, the development costs associated with the technologies represented here are not known. Accordingly, the surplus approach has again been used to estimate the largest value these costs could have for the change to still be worthwhile. First, the expected net present value of benefits generated over 15 years by each of these technologies is estimated. Using a 7 per cent per annum real discount rate, these expected NPVs are $381,804 for the reduced morbidity scenario and $549,981 for reduced morbidity plus scenario. These present values are the maximum amounts that could be paid now to obtain the benefits generated by each of these scenarios while earning a rate of return of 7 per cent on the capital invested.

The minimum costs that could be incurred to obtain each of these technologies are not known, but are likely to include capital investment, plus costs associated with attending training and altering various aspects of the farm system. Again, it is assumed the minimum value of costs is 30 per cent of the average present value of benefits received. Given this assumption, and the present values of benefits described above, the minimum costs associated with these scenarios are $114,541 for the reduced mortality scenario and $164,994 for the reduced morbidity plus scenario. The uniform functional form will again be used to represent the distribution of possible costs that may be incurred to implement these technologies. In this distribution, every possible value between the minimum and maximum costs has the same probability of occurring. The following table (Distributions of development costs incurred by case-study farm) contains summary statistics for these distributions:

Scenario	Minimum	Mean (also median)	Maximum
3: Reduced morbidity	$114,541	$248,172	$381,804
4: Reduced morbidity plus	$164,994	$357,488	$549,981

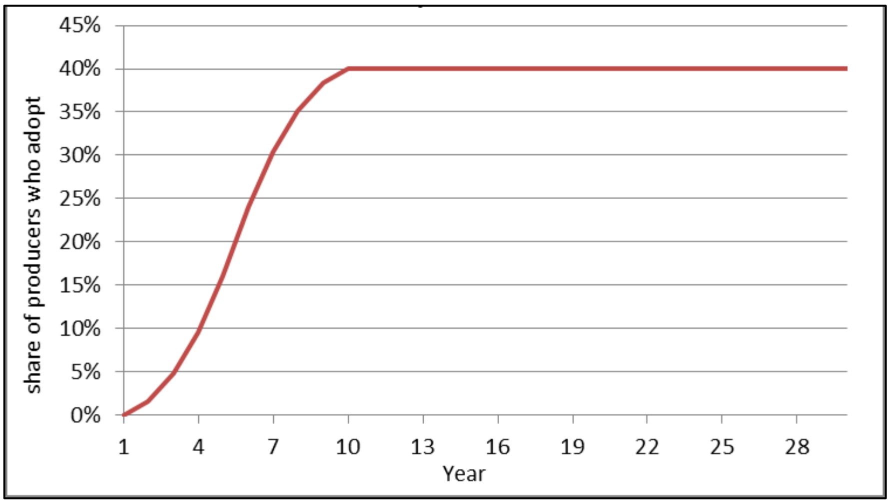
As noted for scenarios 1 and 2, defining costs in this way does not mean that investing in these technologies will always generate a 7 per cent rate of return. In each iteration of the simulation, individual benefits and costs will be drawn from the distributions of possible values these variables can take. These distributions are not related to one another, hence relatively low costs can be associated with high benefits and vice versa. Accordingly, the rate of return on capital invested in these technologies may be greater or less than 7 per cent per annum real. Furthermore, it has again been assumed that no extra annual costs are incurred to use these technologies. Including such costs would reduce the present value of benefits, and hence reduce the maximum possible value of development costs associated with these technologies. Given that little is known about these technologies, differentiating between development and ongoing costs is not considered useful.

Industry-level benefits and costs

The lamb industry equilibrium displacement model has been used to estimate the value of platform technologies to the Australian lamb industry as a whole. The structure of this model and the data which has been used to calibrate it were described in the report for scenarios 1 and 2. To estimate industry-level benefits, the first step is to convert the distributions of possible net benefits into percentage changes in annual profit, which are equivalent to percentage changes in the cost of producing lambs. These percentage changes are called K-shifts. Distributions of K-shifts for the benefits generated by the two platform technologies are shown in appendix 6. The distributions of industry-level annual net benefits are shown in appendix 7.

The platform technologies are expected to generate benefits for a number of years into the future. To find the present value of these technologies to the Australian lamb industry, assumptions must be made about the effective life of the technologies and the proportion of producers expected to adopt them over time. Similar to scenarios 1 and 2, it is assumed the platform technologies will have an effective life of 30 years before becoming obsolete. Furthermore, the same adoption profile is expected to apply for these two scenarios as applied for scenarios 1 and 2. Specifically, it is assumed that at full adoption, farmers that account for 40 per cent of the total value of lamb produced in Australia will adopt these technologies. The following graph illustrates the expected adoption profile:

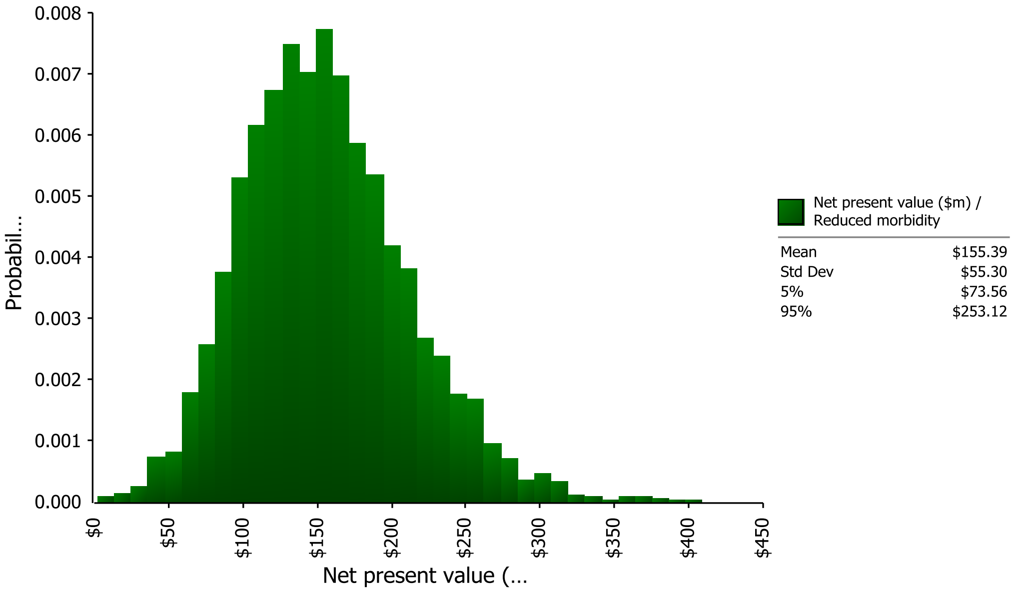
Expected adoption profile



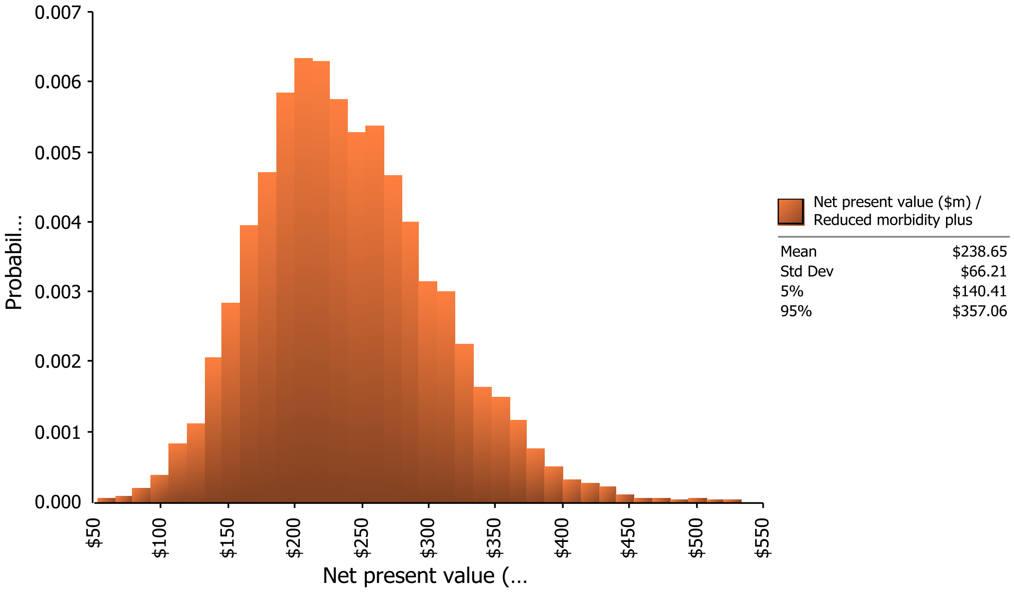
Uncertainty about the likely adoption of these technologies has been included in the analysis by using a uniform probability distribution to represent the peak level of adoption that is achieved after 10 years. This distribution has minimum and maximum values of 30 and 50 per cent, respectively. The platform technologies are assumed to be replaced after 15 years, hence it is assumed that farmers who adopt these technologies re-incur the development cost 15 years after first adopting.

Given this adoption profile and the annual industry benefits shown in appendix 8, the present value of realised industry benefits and costs are derived. The distribution of these values is shown in appendix 10. Similarly, given this adoption profile (including the assumption that adopters re-incur the development cost after 15 years) and the distributions of industry development costs shown in appendix 9, the present value of realised industry costs can be estimated. These distributions are shown in appendix 11. For each iteration of the model, the difference between the present value of realised industry benefits and realised industry costs is the net present value of the technology to the Australian lamb industry. The following figures contain the distributions of net present values associated with the two platform technologies:

Net present value: Reduced morbidity



Net present value: Reduced morbidity plus



The above two figures show the platform technologies have average net present values to the Australian lamb industry of $155.39 million for the reduced morbidity scenario, and $238.65 million for the reduced morbidity plus scenario. These average net present values are both larger than the net present values generated by the improved reproductive performance technologies, namely $53.43 million for the increased conception rate scenario, and $109.22 million for the decrease lamb mortality rate scenario. The relatively large net present value to the lamb industry of the platform technologies reflects the relatively large increase in farm profit the platform technologies are expected to generate. In particular, increasing the number of years ewes can be retained on the farm before culling has the potential to generate a significant increase in farm profit.

Research costs

The research costs associated with producing platform technologies of the kind that could generate the farm-level benefits represented in this work are not known. Below, the maximum value research costs could have while still producing an acceptable rate of return on capital invested have been estimated for each scenario. This has been done by estimating the net present value to the Australian lamb industry of these technologies at two discount rates: 7 per cent per annum real, and 15 per cent per annum real. Arguments can be made that either of these discount rates represent the opportunity cost of capital invested in agricultural research and development. The following table contains the estimated maximum value of research costs at each of these discount rates.

Scenario	Maximum value of costs at 7% real (m)	Probability that NPV is less than max value of costs:	Maximum value of costs at 15% real (m)	Probability that NPV is less than max value of costs:
3: Reduced morbidity	$155.39	53.2%	$18.80	51.3%
4: Reduced morbidity plus	$238.65	53.7%	$39.04	52.2%

The above table shows that reflecting the relatively large estimated value of platform technologies to the Australian lamb industry, the maximum amount that could be spent on research and development to produce these technologies is relatively large. By comparison, analysis of improved reproductive performance indicated that at a 7 per cent discount rate the maximum values of research costs were $53.4 million to increase the conception rate, and $109.2 million to reduce the lamb mortality rate. At a 15 per cent discount rate, maximum values for the improved reproduction performance scenarios were $6.5 million and $10.6 million, respectively.

The above table also contains the probability that the net present value of each technology will exceed the maximum research cost estimated for each discount rate. This probabilistic information provides some insight into the likelihood of earning the required rates of return if the maximum research cost is incurred. In particular, if the expected net present value of the technologies is used to determine how much can be spent on research and development, the variation in possible net present values shown in the above two figures means that there is a risk that the required rate of return on capital will not be earned. Information about the risk associated with particular investments in research and development allows more informed investment decisions to be made than consideration of expected returns alone.

Part 4: Comparison of alternative R&D evaluation models: Vic DPI and MLA

DPI Victoria (DPIV) and MLA both use economic models to estimate the value to Australian agricultural industries of new technologies that are produced by research and development. Key components of both these models are procedures for estimating the effect of the new technology on farm profit, and for finding the value of this change in profit to the industry as a whole. Estimates of the value of new technologies are used to inform decisions about investments in the research and development required to produce them. The purpose of this part of the report is to compare the models used by DPIV and MLA to value new technologies in the Australian lamb industry.

Brief model descriptions

The models used by DPIV and MLA quite different. As described in the report for milestone two of this project, DPIV uses a whole-farm economic model of a case-study lamb farm to estimate the effects on farm profit of new technologies. This involves representing the effects of the new technology on the quantities of inputs used and outputs produced by the model farm. This method uses the whole farm approach and applies marginal analysis, which is the correct approach according to farm management economic theory. An equilibrium displacement model and discounted cash flow analysis is then used to estimate the net present value of these technologies to the Australian lamb industry as a whole.

MLA uses the Rendell-McGuckian (RMcG) model. This model contains a set of four representative farms, each of which represents a particular enterprise type within the Australian sheep industry (fine merino, medium merino, terminal sire, pastoral). The effect of new technologies is represented by changing various biophysical aspects of these representative farms. The whole farm approach is not used; a partial, linear approach is used which violates the fundamental principles of farm management economics (this is discussed in more detail below). Using this model, the effect of a change in a biophysical aspect of a farm system on farm profit is calculated and converted to a per DSE equivalent. The expected annual benefit generated by the technology is estimated by multiplying the change in profit per DSE by the total number of DSE in the industry that are expected to be affected by the technology. Similar to the DPIV model, discounted cash flow analysis is used to estimate the net present value of the technology.

In both of these models, the expected adoption of new technologies by farmers over time is a critical determinant of the value of a particular technology. In particular, estimates of realised annual industry benefits are obtained by multiplying total expected annual benefits by the proportion of producers expected to adopt the relevant technology. As discussed in more detail below, DPIV uses estimates of adoption obtained from the ADOPT tool which was developed by CSIRO. The RMcG model contains a questionnaire that can be used to predict adoption, or estimates obtained from elsewhere can be manually entered.

Estimating the value of annual benefits

In the DPIV model, the annual value of benefits generated by a new technology depends on the magnitude of the change in farm profit it is expected to generate (expressed as a change in cost of production), and on the value of the lamb industry at the farm gate. Specifically, the annual benefit generated by a new technology is the overall saving in the cost of production that the technology generates. This is approximately equal to the product of the average change in the cost of production achieved across the whole industry, and the farm value of the industry. The equilibrium displacement model is used to estimate this value precisely, including how it is shared by the various components of the lamb industry supply chain: producers, other input suppliers and consumers.

In the DPIV approach, the change in the cost of production generated by a new technology is obtained from stochastic simulation of the farm model, and depends on the characteristics of the technology being evaluated. In the equilibrium displacement model, the value of the Australian lamb industry at the farm gate is $1,668 million. This value is the product of the average total carcase-weight quantity of lamb sold in Australia over the four years to 2009-10, and the average real carcase-weight saleyard price of lamb over the same period. Given this value, if a technology generated an average reduction in the cost of production on farms of 1 per cent, the annual value of benefits generated by this technology is approximately $16.7 million (1 per cent of $1,668 million).

The RMcG model uses a broadly similar procedure to estimate the value of new technologies to the lamb industry. First, a farm model is used to estimate the change in profit generated by the technology, and then an industry model is used to find the total annual value of this change in profit to the industry. An important difference between the DPIV and RMcG models relates to the estimation of annual industry benefits.

In the RMcG model, the total annual value of the change in profit generated by a new technology is obtained in three steps. First, the change in farm profit per ewe is obtained from the farm models that represent each segment of the sheep industry (fine merino, medium merino, pastoral and terminal sire). Second, these estimates are multiplied by the number of ewes in each segment. Finally, the sum of benefits across all segments is calculated. The quantity of lamb (and other commodities) produced per ewe on each representative farm has been calibrated so that the total quantity of lamb (and other commodities) produced by each industry segment is similar to that observed in the ABS survey results for 2009-10. This calibration creates a link between the farm and industry components of the RMcG model. As discussed below, the DPIV model does not have such a link, and this difference has some advantages and disadvantages for estimating the value of new technologies.

More generally, the main difference between these two industry models is the use of an EDM by DPIV. Using this model means that the effects of the new technology on parts of the lamb industry other than the farm sector (namely other input suppliers and consumers) can be estimated. This is important because producers do not receive all the benefits generated by the adoption of a new technology. In this analysis, only total benefits (i.e. benefits received by all three components of the lamb industry supply chain) are considered, but it is recognised that if only producer benefits were of interest, these could only be obtained from the DPIV model.

Furthermore, the DPIV model accounts for the flow-on effect on the price of lamb that is likely to be caused by the adoption of a new technology, since this will alter the quantity of lamb produced by the industry. The model also accounts for the effect of adopting the new technology on the quantity and price of other inputs used in the production of lamb. This cannot be done in the RMcG model.

Another important difference is that the DPIV industry model requires less data for calibration. Specifically, data is required on the prices and quantities of lamb at the farm gate, for domestic consumers, and for export consumers. This information is readily available. In contrast, the RMcG model requires estimates (or assumptions) describing the number of ewes in each segment of the sheep industry, the amounts of lamb and wool produced by these ewes, stocking rates, and operating costs. This greater data requirement means the RMcG model will be more costly to update over time.

Comparison of estimated benefits

To compare the estimated values of industry benefits obtained from the DPIV and RMcG models, the two improved reproductive performance scenarios represented in the report for milestone two of this project were represented in the RMcG model.

Both of these technologies involve increasing the number of lambs sold per ewe. Accordingly, they have been represented in the RMcG model by altering the weaning rate in each of the lamb-producing representative farm systems. The case-study farm represented in the DPIV farm model is closest to a terminal sire enterprise in the RMcG model. However, the medium merino and pastoral segments in the RMcG model also produce lambs, and so to estimate the industry-wide value of these technologies, their effects must also be represented in these sectors of the RMcG model. The fine merino segment does not produce lambs for slaughter, and hence has been excluded.

In the DPIV analysis of the ‘increase conception rate’ scenario, the main effect caused was an increase in the number of lambs sold from 12,682 to 12,865 – an increase of 183 lambs from the 10,000 ewes joined. This represents an increase in the effective weaning rate of 1.83 *percentage points*. In the RMcG model, the effect of new technologies is represented as a *per cent change* to the relevant variable from the initial value that applies in each farm system. In the terminal sire farm system, the initial weaning rate is 100 per cent, and so an increase of 1.83 percentage points is equivalent to a 1.83 per cent increase in the weaning rate. In the medium merino farm system, the initial weaning rate is 75 per cent, hence an increase of 1.83 percentage points is equivalent to a 2.4 per cent increase from the initial weaning rate.

The same approach was used to define the effects of the ‘decrease lamb mortality rate’ scenario. Following the DPIV analysis, the effects of this latter technology on the effective weaning rate are larger than for the ‘increase conception rate’ scenario. In both cases, only the weaning rate is assumed to change when representing these scenarios in the RMcG model. It would be possible to alter other aspects of the farm system in the RMcG model, such as the mortality rate of ewes and the sale weight of lambs. In this analysis, the magnitude of changes in these other variables that can be expected to occur following the adoption of the technologies are trivial, hence they have been left unchanged. This highlights one advantage of the DPIV approach (in which the quantities of inputs used and outputs produced by the model farm are obtained directly from a biophysical model), namely that follow-on effects of changes to the farm system are captured in the inputs and output of the farm system without requiring estimates of the per cent change in these variables from the base case to be constructed.

One follow-on effect that is captured in the RMcG model is that increasing the weaning rate causes the overall demand for energy by livestock in to increase. The RMcG model does not contain an energy budget in which the supply of energy from various sources is balanced with the demand for energy from livestock. Instead, the increase in energy demand caused by the new technology is accounted for in one of two ways: one is to reduce the number of ewes on the farm so that the total demand for energy is unchanged after the new technology is adopted. The alternative is to assume the ‘carrying capacity’ of the farm increases when the new technology is adopted, such that there is no overall effect on the energy balance of the farm.

A fully-compensatory increase in carrying capacity following an increase in the weaning rate is possible, although not likely. In the biophysical simulation of these scenarios using GrassGro, the whole-farm quantity of supplementary feed used increased substantially when the weaning rate was increased, indicating that whatever response in pasture production occurred following the adoption of this technology, it was insufficient to meet the entire increase in energy demand. Accordingly, in this analysis, the number of ewes in the RMcG model was reduced so that the energy balance of the farm is unchanged following the adoption of the technologies.

Farm annual benefits

Comparing the estimated magnitude of the change in farm profit that is generated by these technologies in the DPIV and RMcG models is fraught because the farm systems in which they are represented are very different. Of the available enterprise types, the DPIV model farm is most comparable to an extra-large specialist terminal sire enterprise. These farms are defined as those with an estimated value of agricultural operations of greater than $500,000 and approximately >10,000 head of stock. This farm system is not particularly similar to the case study farm. For example, the average number of ewes on extra-large specialist terminal sire enterprises in the RMcG model is approximately 5,500 and the initial weaning rate is 100 per cent. The DPIV case study farm has 10,000 ewes and an initial weaning rate of 130 per cent. Given these and other significant differences between the model farms, a given technology is bound to have different effects on farm profit in each model.

This expectation is borne out in the results. For the increase conception rate scenario, the expected increase in farm profit in the extra-large specialist terminal sire enterprise of the RMcG model is $8,157, while in the DPIV model the equivalent benefit is $12,803. For the decrease mortality rate scenario, the RMcG model predicts an average increase in farm profit of $17,451 and the DPIV model predicts an increase of $30,577. Given the differences between the model farms, the existence of these differences is unsurprising. Furthermore, given the objective of this analysis is to estimate the industry value of these technologies, differences in farm values are of relatively little interest. This is because the different structure of the industry models means that differences in farm profit may not necessarily translate to differences in estimated industry values.

Industry annual benefits

Estimates of the annual value of these scenarios to the lamb industry as a whole are automatically generated by the RMcG model. As noted above, this is done by multiplying the change in profit per ewe estimated in each of the model farms, by the number of ewes in the segment of the sheep industry that is represented by that farm. Estimated annual benefits for each of these industry segments were summed to obtain the total annual value of industry benefits. These values are shown in the table (Annual industry benefits) below, as well as those obtained from the DPIV model for the same scenarios.

Scenario	DPIV	RMcG
Increase conception rate	$34.72 million	$37.94 million
Decrease mortality rate	$76.52 million	$81.58 million

As shown, that the DPIV and RMcG models generate comparable estimates of the total annual industry benefits generated by these technologies. The similarity of these numbers reflects the use of the similar base data to calibrate both the industry models, and the fact that these scenarios can be represented relatively simply, by adjusting the weaning rate. More complicated technologies would be more difficult to represent in the RMcG model because of the limited number of biophysical variables that can be altered.

Adoption

The values shown in the table above are estimates of the total annual value of benefits to the lamb industry of these technologies if they are adopted by all producers. Given these total values are similar, provided that the same assumptions are made about adoption in both models, the value of *realised* annual benefits will also be quite similar.

In the RMcG model, the expected adoption profile (the proportion of producers who are expected to have adopted the technology in each year of its life) for each technology can be constructed by scoring it on a 5-point scale against several criteria which are known to influence adoption. Alternatively, an adoption profile obtained from outside the model can be manually entered. Here, the adoption profile used in the DPIV model was manually entered in the RMcG model.

The inclusion of a mechanism within the RMcG model for estimating adoption profiles is a useful feature. In the DPIV model, the expected adoption profile for each technology is obtained externally from the ADOPT tool. This tool was developed by the CSIRO, and also relies on scoring technologies on a 5-point scale against various criteria to predict adoption. While ADOPT contains more criteria than are in the RMcG model, it is still a fairly imprecise approach. This is appropriate because it reflects the limited extent to which many determinants of adoption can be quantified *ex ante*.

For both technologies considered here, cumulative adoption is expected to follow a logarithmic curve from zero in the first year after the research is completed, to full adoption of by producers who account for 40 per cent of total lamb output by year 10. In the RMcG model, the adoption profile is specified in terms of the number of businesses that adopt the technology, and the number of ewes that are affected. Setting the latter proportion equal to 40 per cent at full adoption ensures that both models contain similar assumptions about adoption.

Given this adoption profile, the expected annual *realised* benefits of the two technologies at full adoption are shown in the table (realised annual industry benefits) below:

Scenario	**Vic DPI**	**RMcG**
Increase conception rate	$13.88 million	$15.17 million
Decrease mortality rate	$30.60 million	$32.63 million

As shown, the estimated values to the Australian sheep industry of the realised annual benefits generated by these two technologies are quite close.

Disaggregation into industry segments

In representing these two technologies in all lamb-producing sectors of the RMcG model, it is implicitly assumed that the technologies are generic, and hence could be applied on any lamb-producing farm. If the technology was specific to terminal sire operations, this assumption could not be made.

If the technologies could only be used on terminal sire operations, this would be accounted for in the DPIV model by reducing the maximum adoption level. For example, rather than assuming that producers who account for 40 per cent of total lamb production adopt these technologies, the maximum adoption rate would have been reduced to 40 per cent multiplied the proportion of total lamb produced by terminal sire operations.

Furthermore, by applying the same-sized increase in the weaning rate across all enterprise types, it is assumed that the technologies have the same effect on farms in other lamb-producing segments of the sheep industry as they do in the terminal sire industry. It is also assumed that the same proportion of producers in each segment adopt the technology. Here, these assumptions are justified by the fact that the technologies which are being evaluated have not been explicitly defined (only their expected effects), and as such there is no reason to think they will apply any more or less in particular segments of the sheep industry.

If the technologies being evaluated were more specific to individual enterprise types, these assumptions may not be appropriate. To represent such technologies in the RMcG model, the effect of the technologies would have to be separately estimated for each enterprise type, and separate adoption profiles would need to be constructed. The RMcG model is well-suited to explicitly representing these differences between enterprise types. However, it seems likely that constructing such a representation would often involve either over-stating the extent to which the effects of a particular technology on different farm systems could be predicted, or performing a very large amount of *ex ante* analysis. This is undesirable because the large number of research projects conducted by MLA means that *ex ante* investment analysis tools need to be applicable at relatively low cost.

The DPIV approach does not differentiate the sheep industry into enterprise types. As such, it is best-suited to representing technologies that apply equally to all sectors of the sheep industry. However, technologies that are only relevant to one enterprise type can be represented by altering the expected industry-wide adoption rate. In cases where a specific technology is expected to have different effects on farm profit depending on enterprise types, these effects would be estimated in separate farm models, and the weighted-average change in the cost of production would be applied in the industry model.

In summary, disaggregation of the sheep industry into production systems and locations in the RMcG model provides a more explicit way of accounting for differences in the applicability of technologies to particular segments of the sheep industry than that used in the DPIV approach. However, a disadvantage of this approach is that it greatly increases the data requirements of the model, increases the complexity of analysis, and increases the cost of keeping the model up to date. Whether or not this additional cost is worthwhile depends on how useful the ability to directly represent different types of sheep enterprises is perceived to be. The DPIV approach is somewhat more approximate, but also much simpler.

Net present value of benefits

The final step in both the DPIV and RMcG models is to estimate the net present value of the technology to the industry. This process has several steps. First, the expected stream of realised annual benefits is converted into a present value. Second, the present value of development costs incurred by farmers to obtain the benefits is estimated. Third, the net present value of the technology is obtained by subtracting the present value of development costs from the present value of expected benefits. This process is a fairly straightforward application of discounted cash flow analysis.

For the technologies considered here, given that the estimates of realised annual benefits obtained from the RMcG and DPIV models are similar, the estimated present values of these benefits will also be similar. The development costs associated with these technologies are not known, but a method similar to that used in the DPIV modelling could be used to estimate these costs in the RMcG model. This could be done at either the farm or industry levels of the model.

Once the present value of benefits and development costs have been estimated, the net present value of the technologies can be obtained. These estimates can be compared to the expected cost of performing the research required to generate the technologies. The RMcG model contains detailed spreadsheets for entering information about R&D funding and for estimating the implied rates of return on these funds. In the DPIV model, similar spreadsheets and techniques are used to perform this analysis.

General comments

One important difference between the DPIV and RMcG models is that the DPIV model has greater flexibility in representing new technologies. Specifically, the DPIV farm profit budget uses estimates of the inputs and outputs of the farm system to represent the effects of a new technology. These inputs and outputs include the number of ewes joined, the number of replacements purchased, the number of lambs sold, the weight of lambs sold, and so on. These estimates are obtained from the biophysical simulation model GrassGro, and hence can reflect any technology that can be represented in GrassGro. In contrast, the RMcG model contains far fewer variables that can be adjusted to represent new technologies. This means some effects of new technologies on the farm system can only be approximately represented.

More generally, the RMcG model is less flexible than the DPI model because the representative farm models it contains cannot be altered without upsetting the calibration of the industry model. By separating the farm and industry models, different farm systems can be represented in the DPIV approach without causing any change to the industry model. Furthermore, the DPIV farm model can be calibrated using 'real' farm data, reducing exposure to the potential problem whereby the estimated effects of new technologies only apply in the hypothetical 'representative' farm system. The cost of this greater flexibility is that assumptions have to be made about the extent to which the results from the DPIV farm model apply throughout the industry. These appear to be no more restrictive than the assumptions required to apply the RMcG model.

The DPIV model does not disaggregate the lamb industry by farm size or location. Accordingly, if benefits for these sub-sectors of the industry were required, the DPIV model would need to be extended to include consideration of industry structure. This could be done by multiplying the total value of the new technology to the lamb industry by the proportion of total lamb output generated by the sub-sector of interest. This is equivalent to the mechanism used to do this in the RMcG model.

An advantage of the DPIV approach is that it allows the question 'where do the benefits go?' to be answered. Specifically, while the RMcG and DPIV models produce similar estimates of the total value of new technologies, the DPIV model can also quantify the proportion of these benefits that are received by farmers, other input suppliers and consumers. The RMcG model cannot quantify these proportions because it does not have a mechanism for estimating the flow-on effects of new technologies on prices and quantities throughout the lamb industry supply chain.

Another drawback of the RMcG model is that it does not allow different kinds of farm systems to be represented. This limits the kind of technologies that can be represented. In particular, the RMcG model has been set up to represent the 'average' farm in each sub-sector of the industry. On an average farm, adoption of already-existing technologies would increase farm profit. Accordingly, a model of such a farm is well-suited to representing interventions such as extension. Conversely, to measure the benefits associated with new, yet to be developed technologies, it would be best to represent a farm system that is already using all currently-available technology, so that the estimated increase in profit following the adoption of a new technology reflects an expansion of the production possibilities frontier (i.e. technical change) rather than a move towards the frontier (i.e. increasing technical efficiency). The best type of farm system to represent in the model depends on the purpose of the model. In this regard, the fact that the farm systems represented in the RMcG model cannot be altered is a limitation.

The DPIV model also contains an explicit representation of the risk associated with *ex ante* predictions of the value of new technologies. Because future commodity prices and seasonal conditions are unknown, even if the effects of a new technology were known with certainty, the value to the industry as a whole of the technology is a stochastic variable – it could take any one of a number of values. When uncertainty about the effects of the new technology on farm profit is included, the variability of possible values increases further. Representing these sources of variation in the DPIV model allows distributions of possible values of new technologies to be produced. These distributions allow both the expected value of benefits generated by a technology, and the risk associated with that value to be taken into account when making R&D funding decisions. This cannot be done using the single expected values that are produced by the RMcG model.

Perhaps the most important difference between the DPIV and RMcG models is that the DPIV model is technically sound and consistent with the fundamental principles of farm management economics, while the RMcG model is not. In particular, the use of the change in average farm profit as an estimate of the marginal benefit generated by a new technology is flawed. Having overheads attributed as a cost that changes directly with changes in a variable input (DSE) is incorrect, and using this when defining the strange measure called 'average profit per DSE' produces technically incorrect estimates of change in profit from a change in the farm system.

An important reason for this is that doing so does not account for the law of diminishing returns, which in this context means that when one aspect of the farm system is improved, the increase in farm profit that occurs is not a constant value, but changes depending on the magnitude of the increase being considered. Nor are benefits of spreading overhead costs over greater output captured. To capture properly non-linear marginal effects, and other important economic effects of new technologies such as reducing overhead cost per unit of output (economies of size), a whole-farm economic model with marginal changes analysed, of the kind used by DPIV, is required.

Despite this difference between the models, relatively similar estimates of the value of the two reproductive performance technologies are obtained from the DPIV and RMcG models. This reflects the relatively small changes in the weaning rate that were represented, and the fairly low initial weaning rates that apply on the representative farms of the RMcG model. For these technologies, the change in average farm profit is a reasonable approximation of the marginal benefit obtained. Furthermore, the effect of these technologies on the variability of farm profit (risk) is relatively small; hence the inability of the RMcG model to represent any such changes is of little importance. This will not always be the case, and so a more comprehensive farm economic model would be a desirable addition to the RMcG model.

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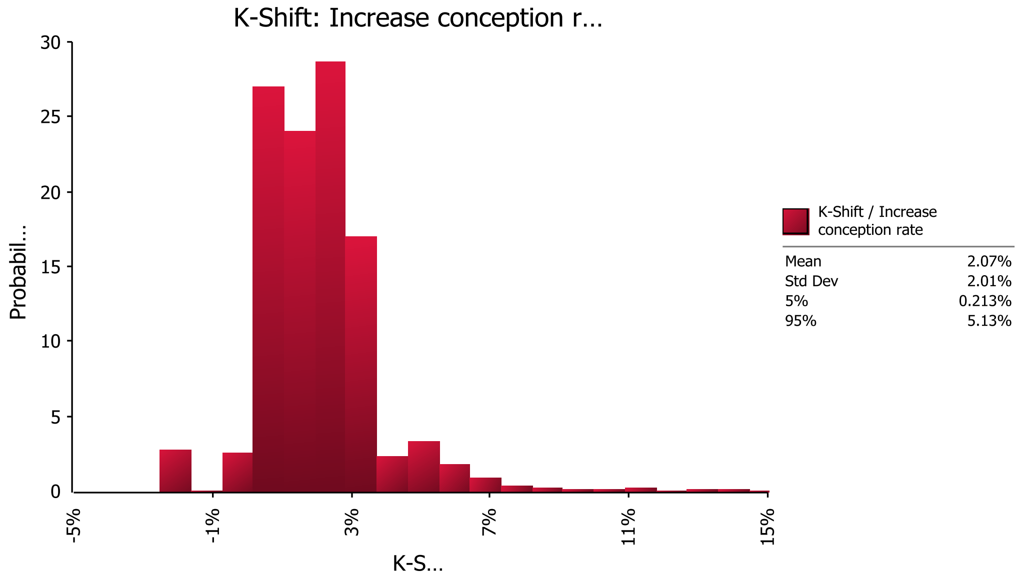
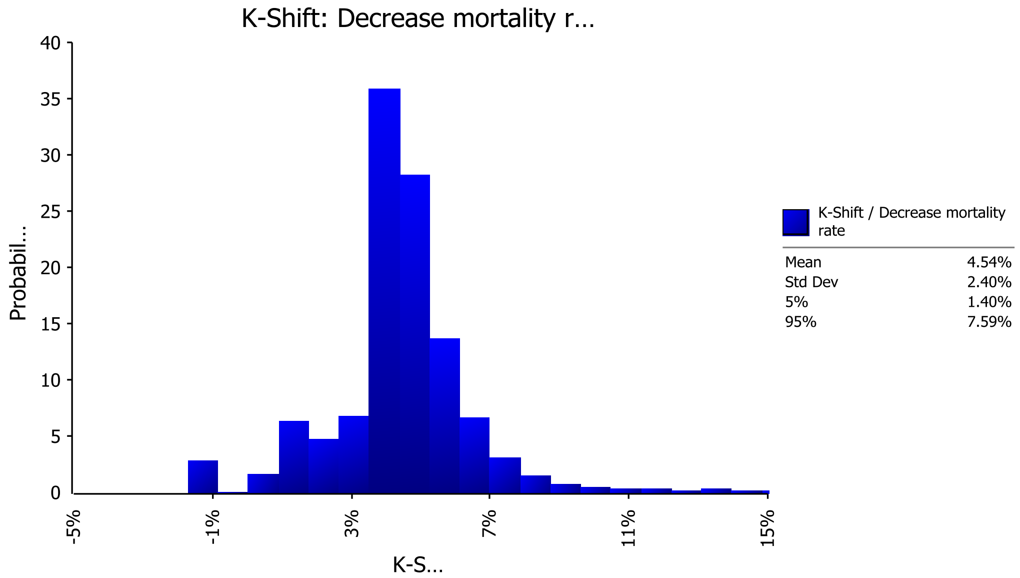
Appendix 1

The following graph contains the distribution of K-shifts which represent the change in operating profit brought about by the increase conception rate technology:



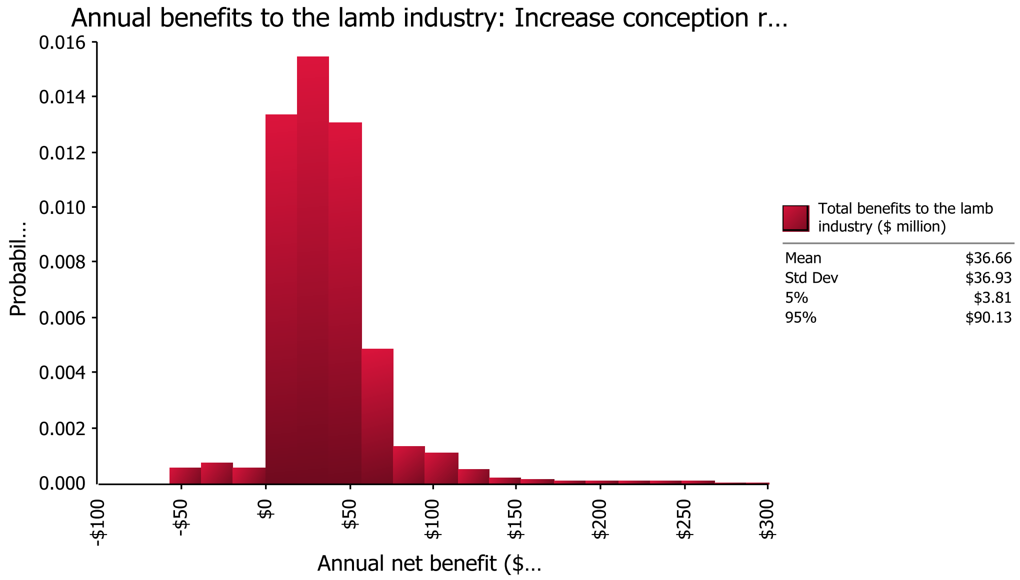
The average change in annual operating profit generated by this scenario is 2.1 per cent, and 90 per cent of values fall in the range 0.2 to 5.1 per cent. Following the distribution of absolute changes in operating profit for this technology, the majority (96.3 per cent) of changes in operating profit associated with this technology are positive. The following graph contains the distribution of K-shifts generated by the change that achieves decreased lamb mortality:



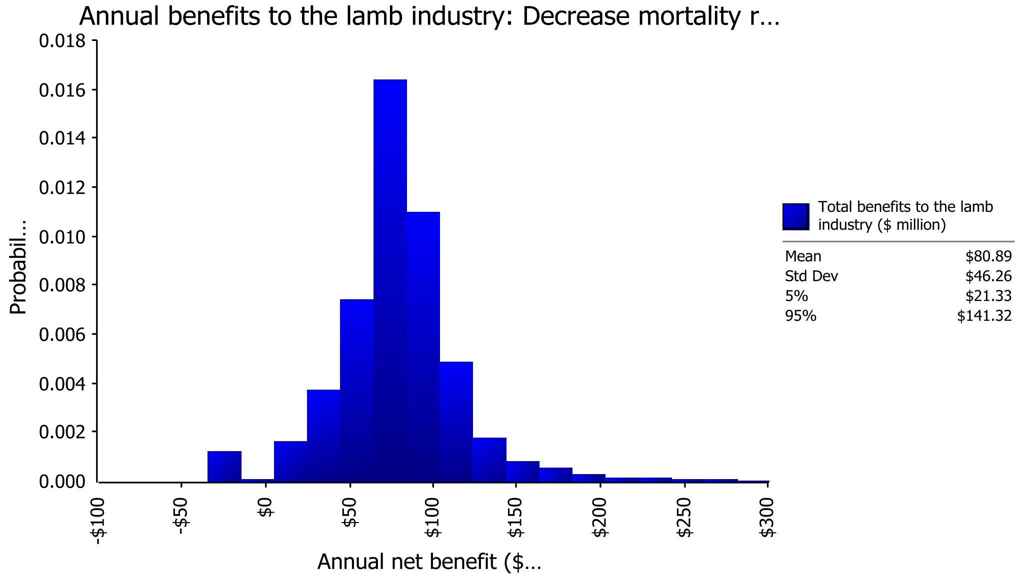
The average change in operating profit generated by this scenario is 4.5 per cent, and 90 per cent of values fall in the range 1.4 to 7.6 per cent. 97.6 per cent of the K-shifts in this distribution are positive.

Appendix 2

The increase conception rate technology is expected to generate the following distribution of annual benefits to the Australian lamb industry as a whole:



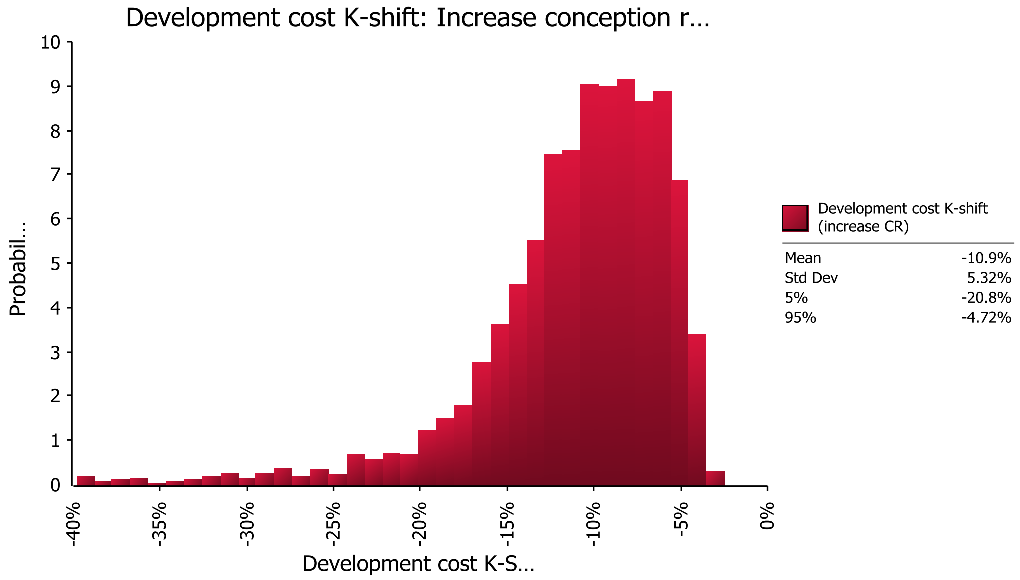
The average expected annual benefit is $36.7 million and 90 per cent of possible annual benefits fall in the range $3.8 to 90.3 million. Furthermore, 3.7 per cent of values in the distribution of annual benefits are negative. These negative annual benefits are realised when the K-shift is negative. As explained above, this reflects the fact that there are some (rare) combinations of seasonal conditions and commodity price which cause farm profit to be lower with this technology than without it. The graph below contains the distribution of expected annual benefits generated by the decrease lamb mortality rate scenario:



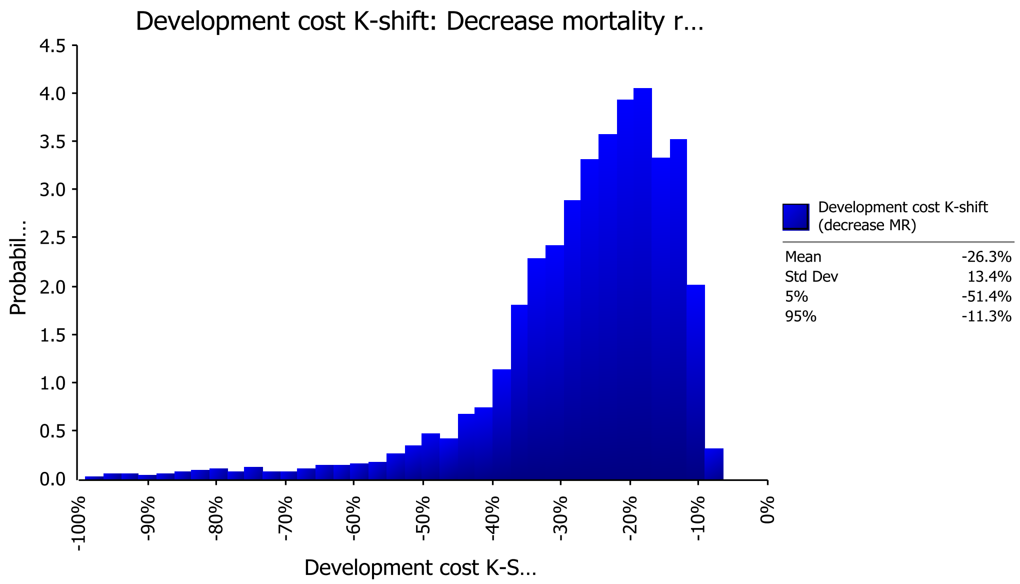
The average annual benefit associated with this technology is $80.9 million. Again, for this technology, 2.4 per cent of annual net benefits are negative.

Appendix 3

The graph below contains the distribution of K-shifts generated by the development costs of the increase conception rate technology:



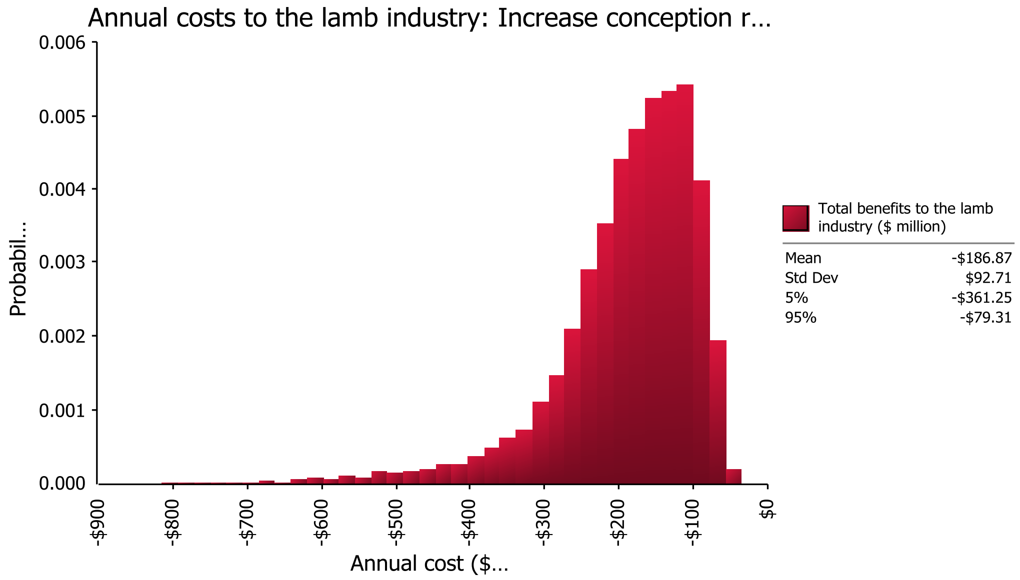
The average development cost K-shift associated with this technology is -10.9 per cent. In iterations where operating profit in the base case is close to zero, regardless of the absolute value of costs, the estimated magnitude of the K-shift can be very large simply because the denominator is a small number. However, the occurrence of these values is relatively rare: 90 per cent of K-shifts in the distribution above fall in the range -20.8 to -4.7 per cent. The next graph contains the distribution of K-shifts generated by the development costs of the decrease lamb mortality rate technology:



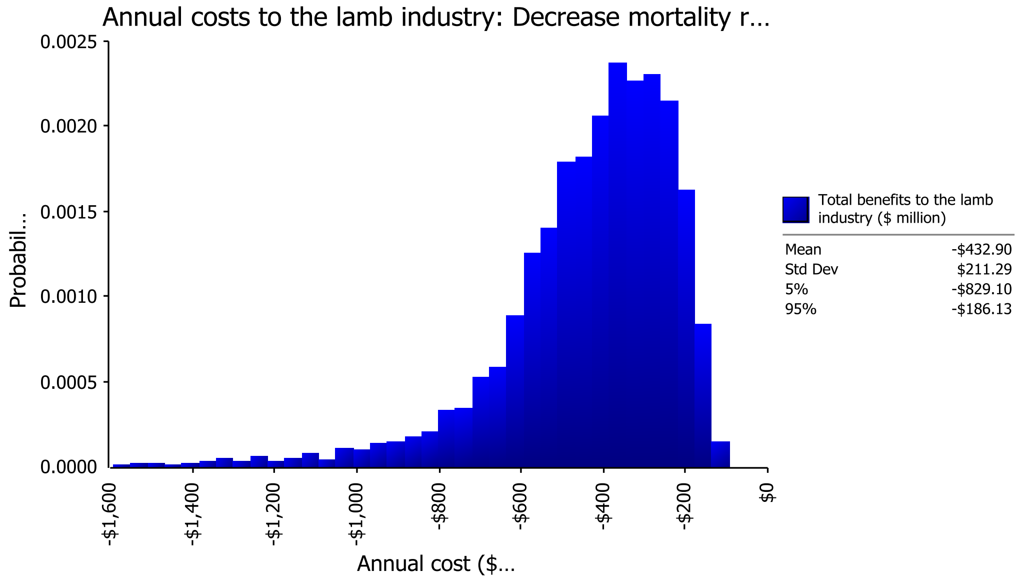
The average development cost K-shift for this technology is -26.3 per cent, and 90 per cent of values fall in the range -51.4 per cent to -11.3 per cent.

Appendix 4

The graph below contains the distribution of annual development costs to the entire Australian lamb industry that are associated with the increase conception rate technology:

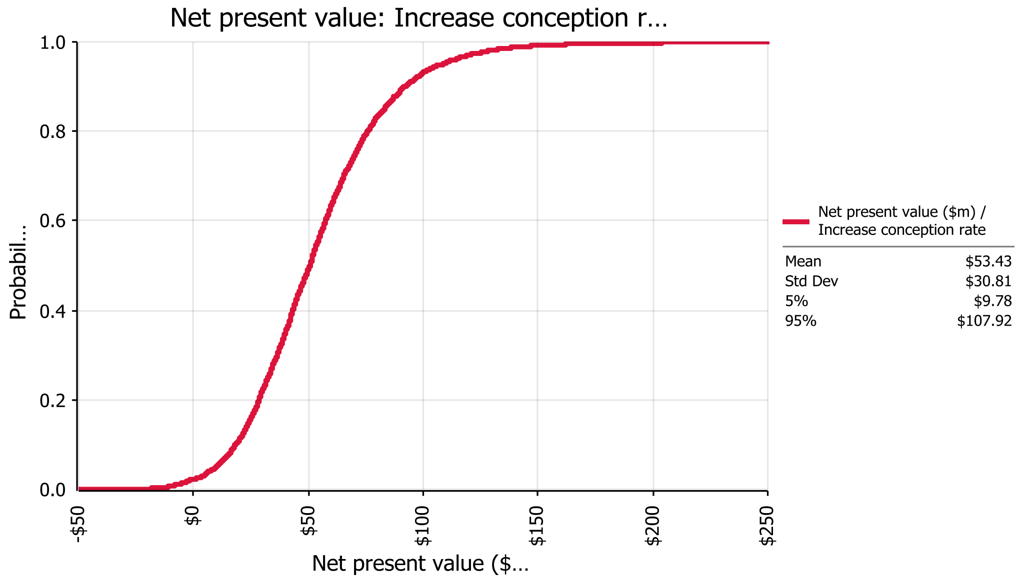


The following graph contains the distribution of industry-level development costs associated with the decrease lamb mortality rate technology:

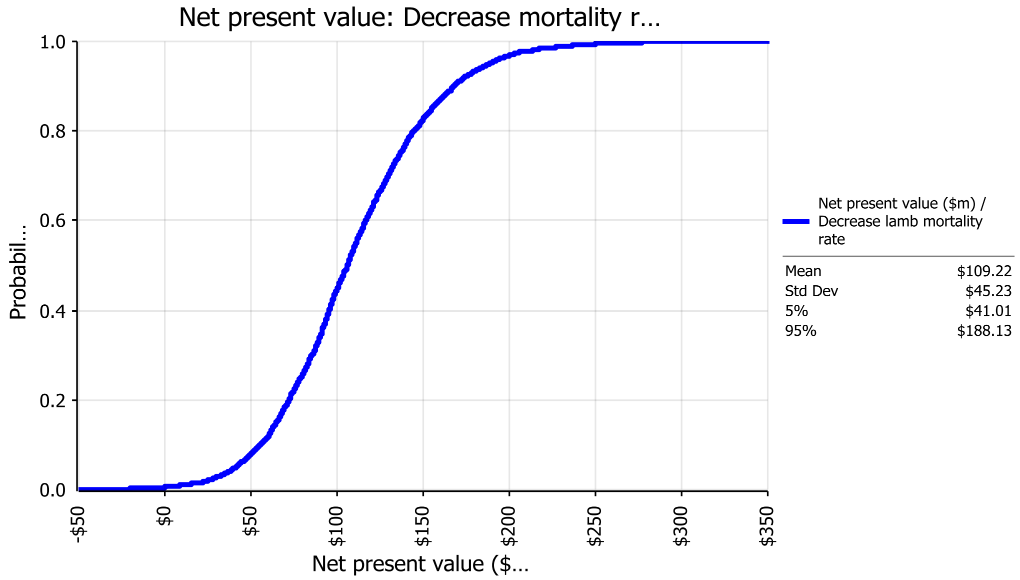


Appendix 5

The cumulative distribution function (CDF) which describes the distribution of possible net present values generated by the increase conception rate technology is shown below:



For the decrease lamb mortality rate scenario, the CDF of possible net present values is:



Appendix 6: Farm benefit K-Shifts

Figure A6.1 K-Shifts: Reduced morbidity

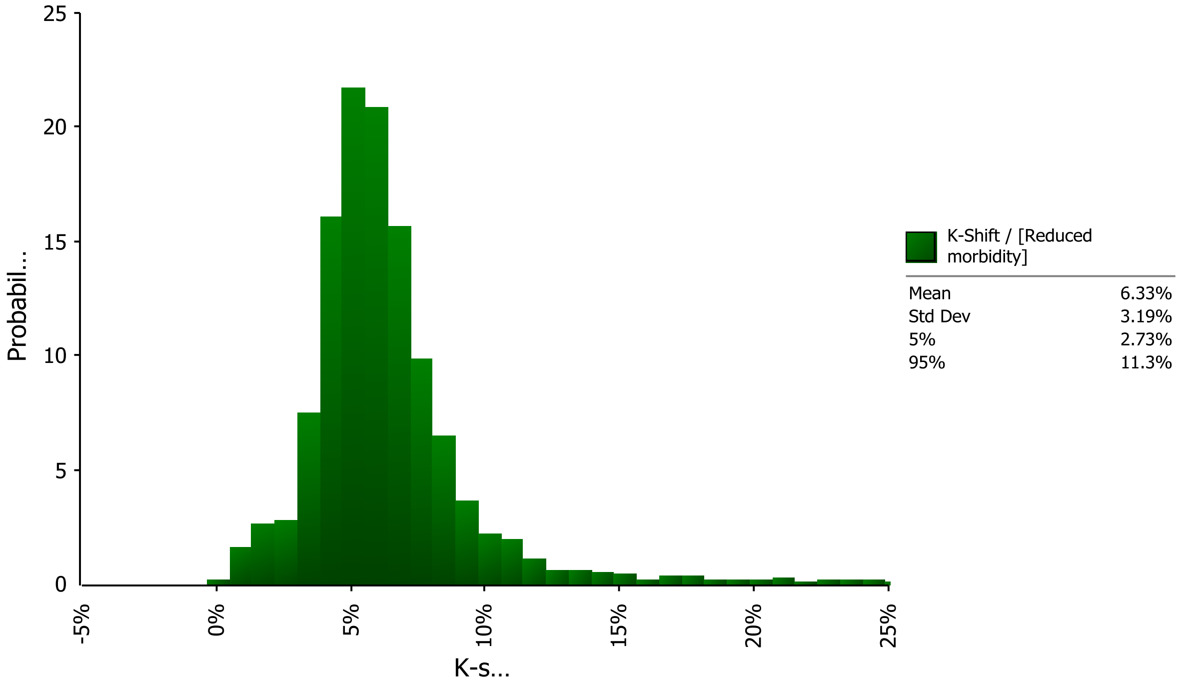
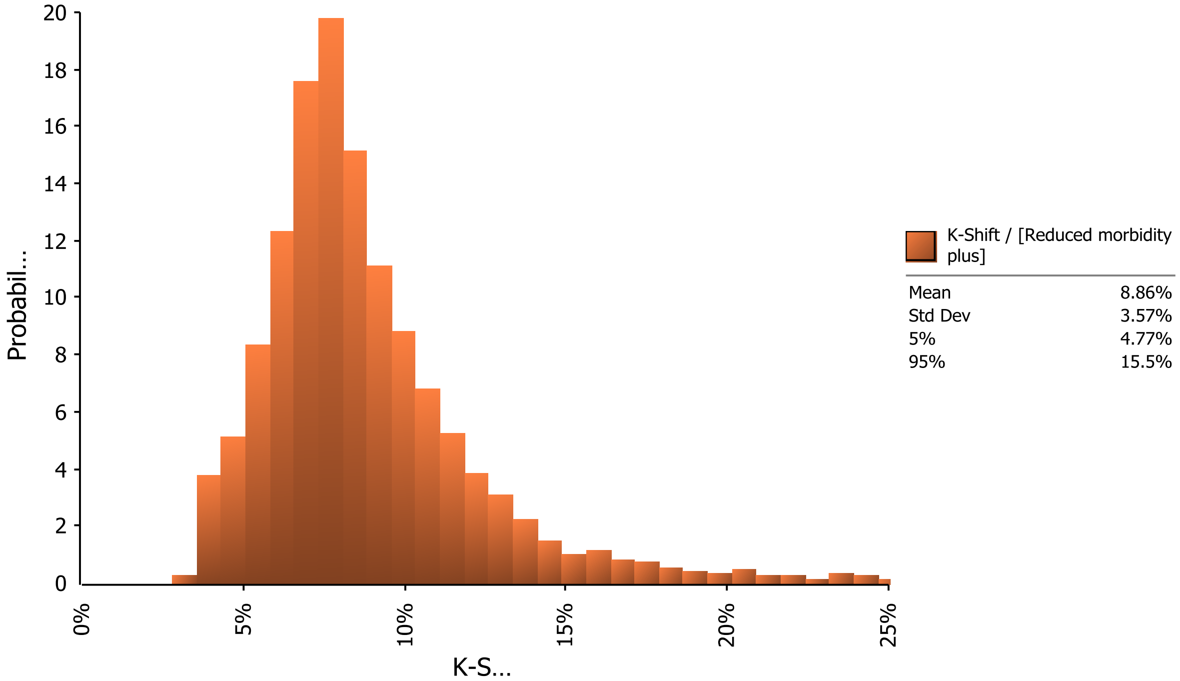


Figure A6.2 K-Shifts: Reduced morbidity plus



Appendix 7: Farm development cost K-Shifts

Figure A7.1 Development cost K-Shifts: Reduced morbidity

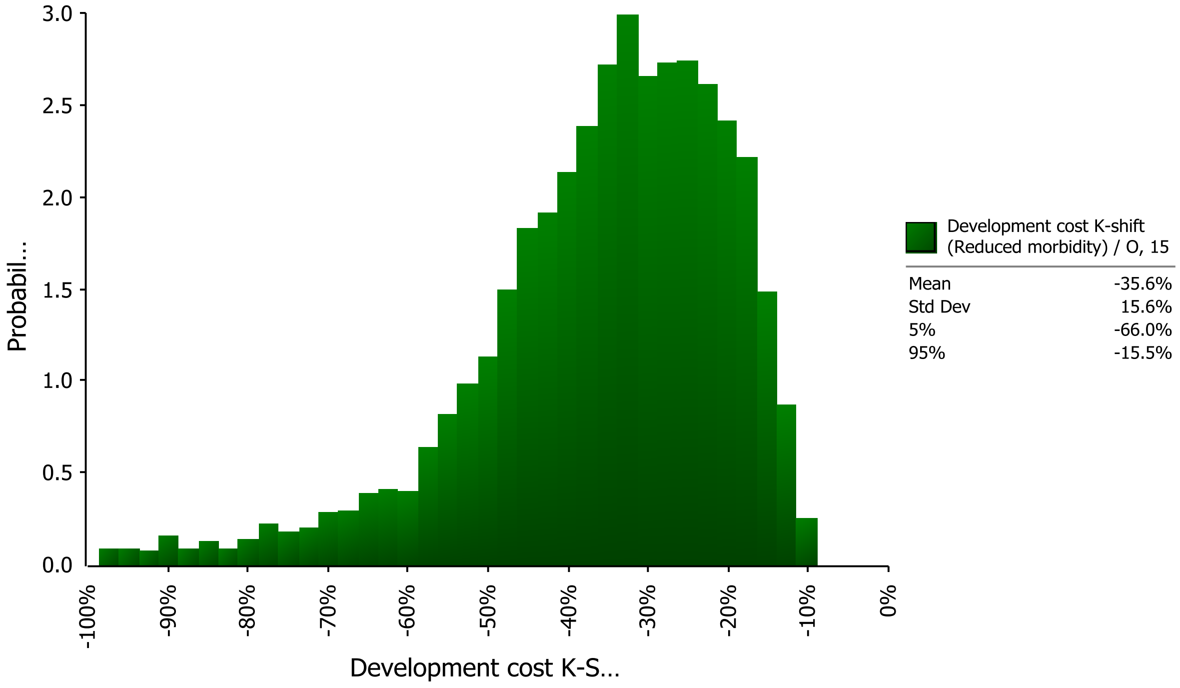
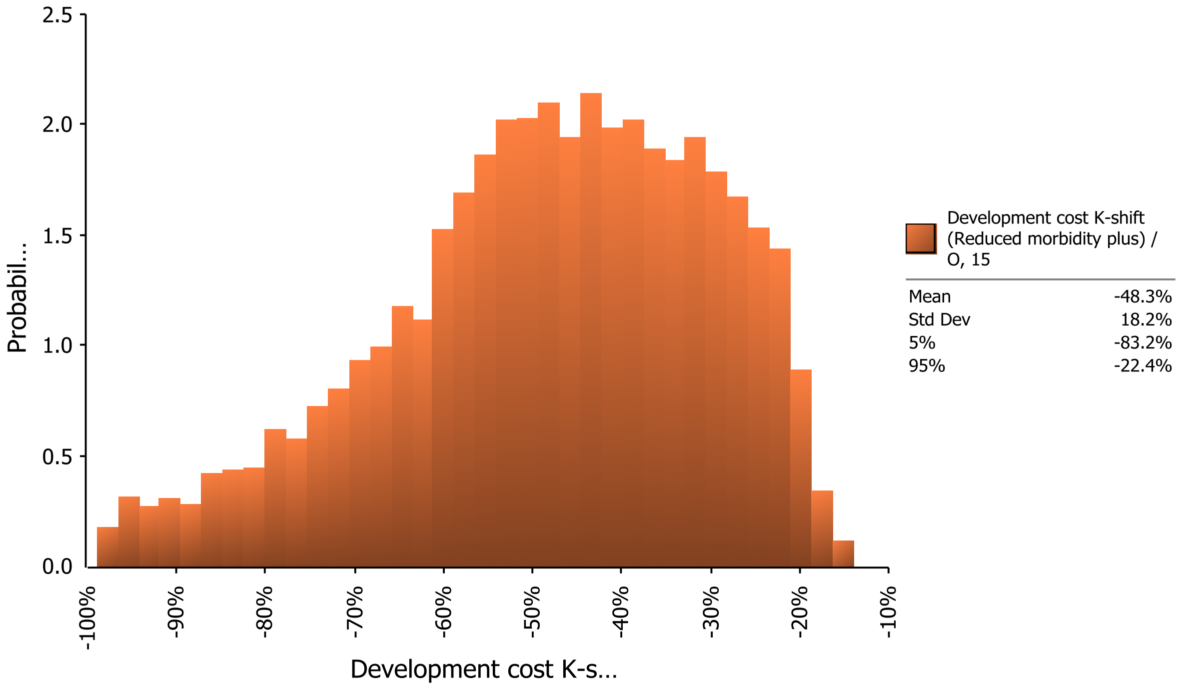


Figure A7.2 Development cost K-Shifts: Reduced morbidity plus



Appendix 8: Industry annual benefits

Figure A8.1 Annual benefit to lamb industry: Reduced morbidity

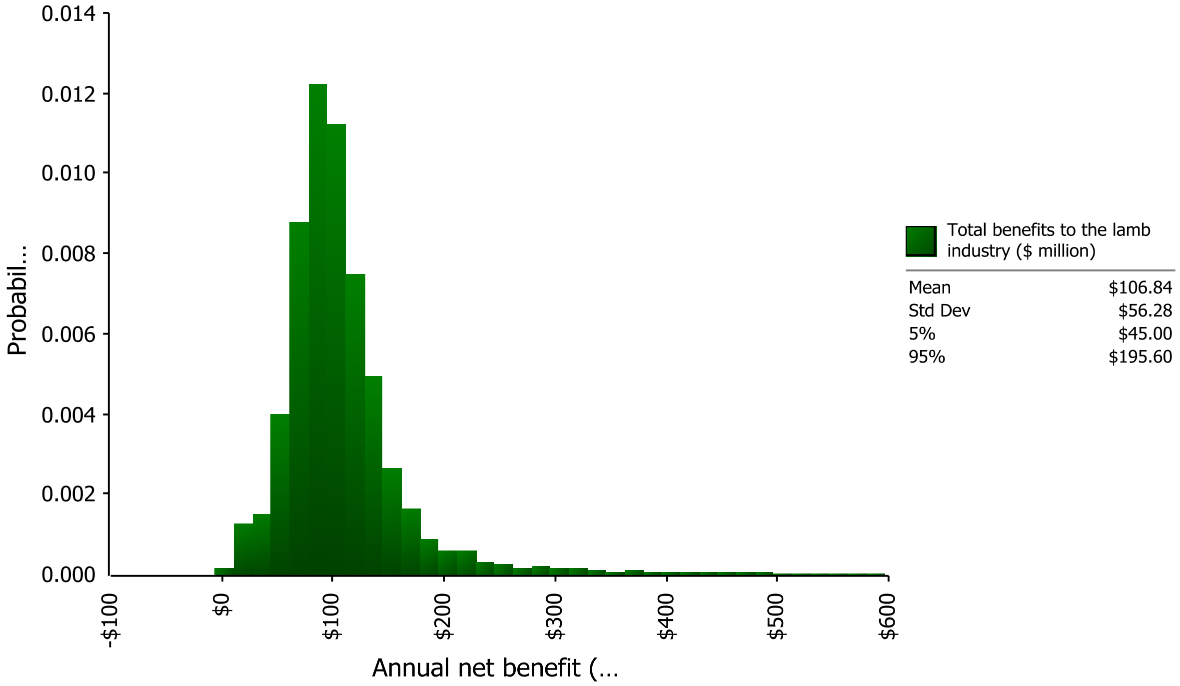
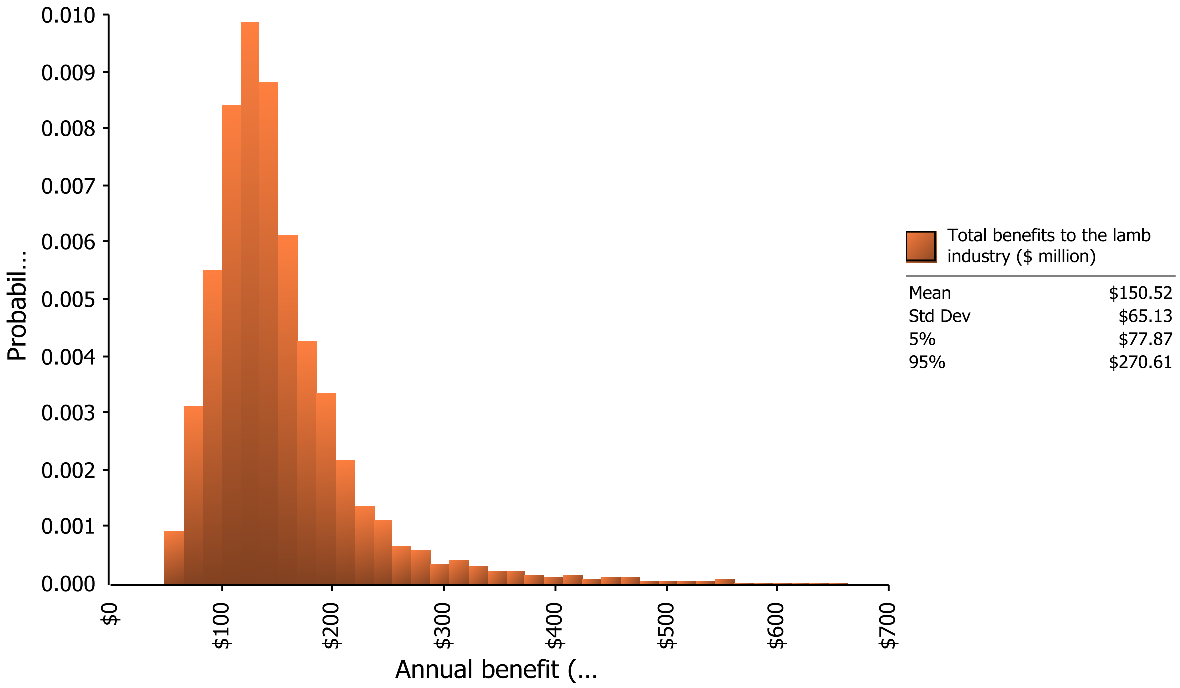


Figure A8.2 Annual benefit to lamb industry: Reduced morbidity plus



Appendix 9: Industry development costs

Figure A9.1 Development cost to lamb industry: Reduced morbidity

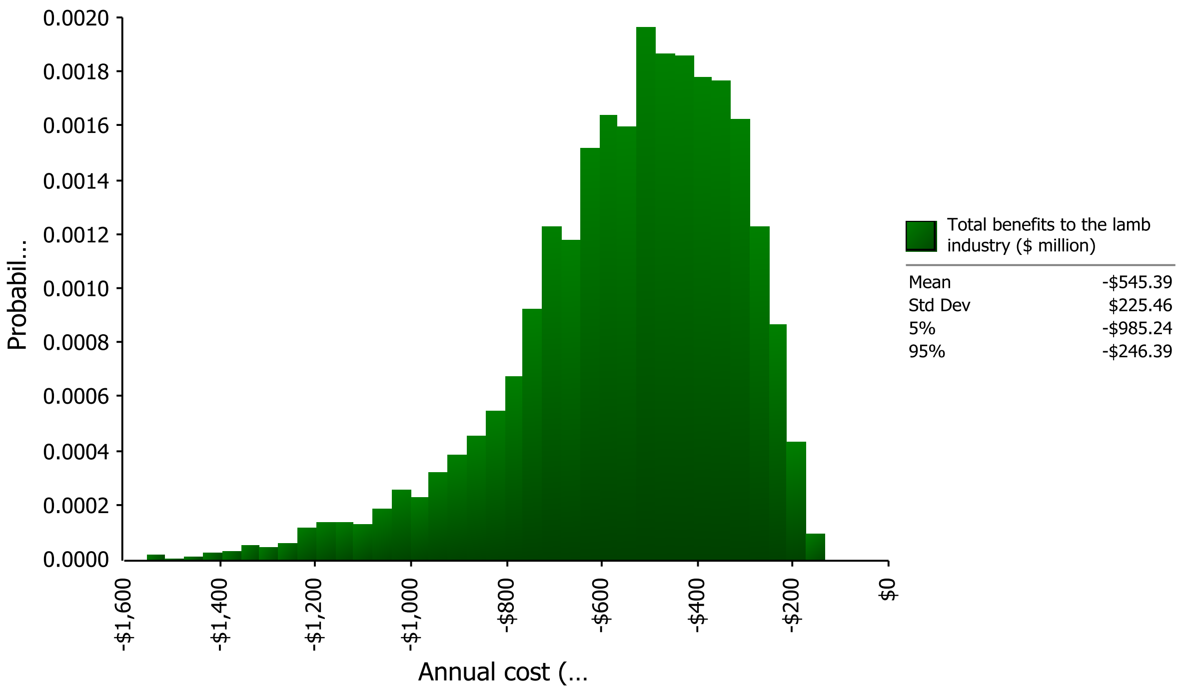
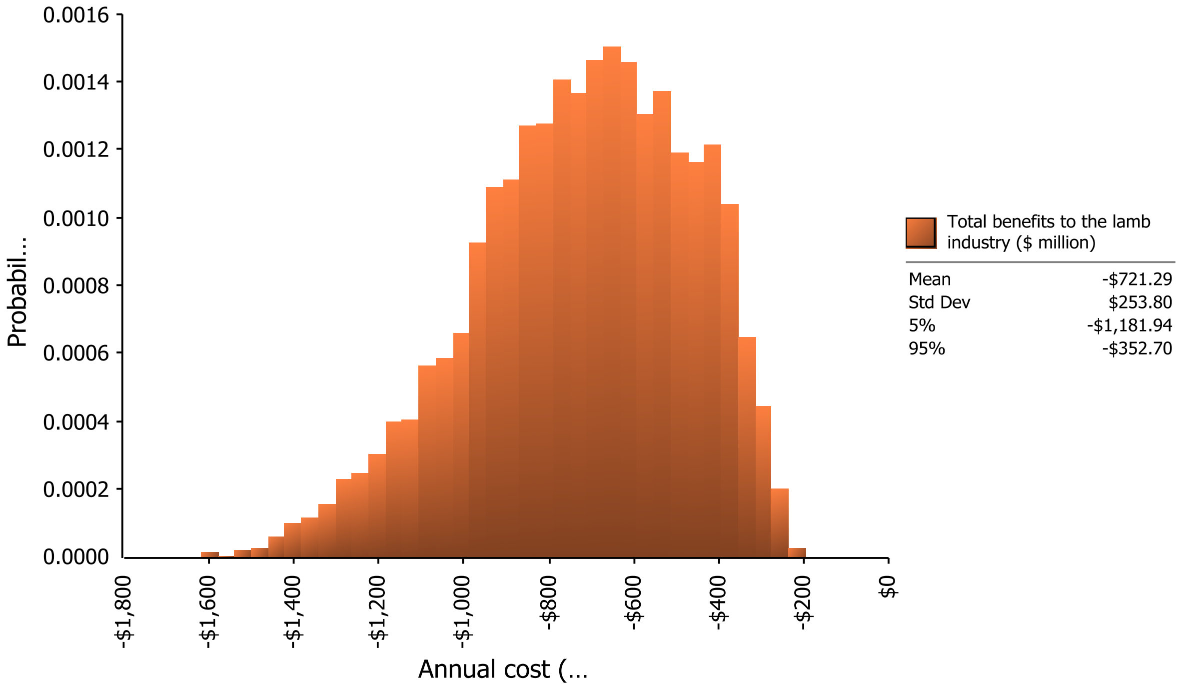


Figure A9.2 Development cost to lamb industry: Reduced morbidity plus



Appendix 10: Realised industry benefits

Figure A10.1 Present value of realised industry benefits: Reduced morbidity

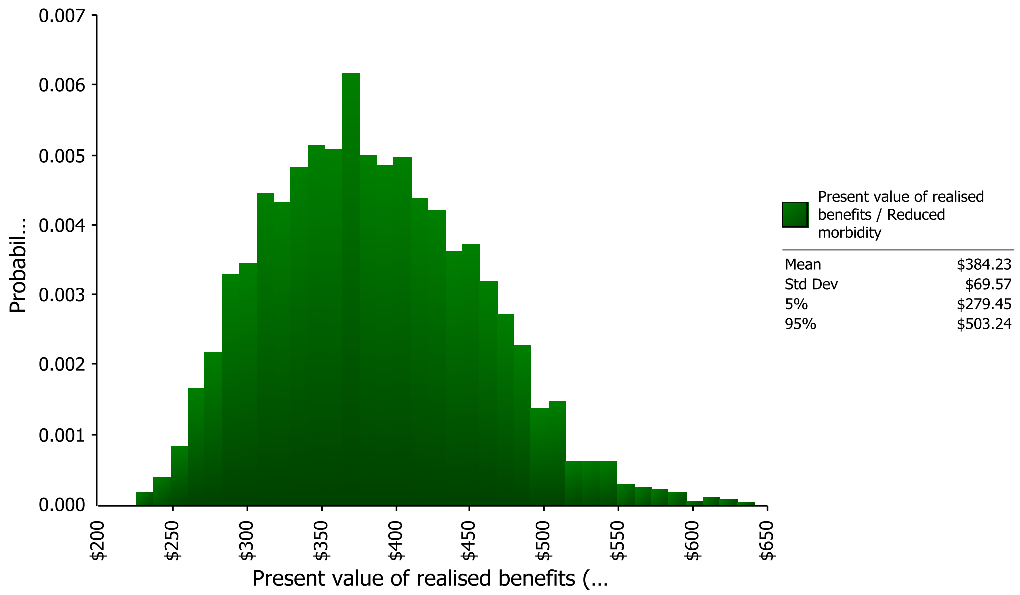
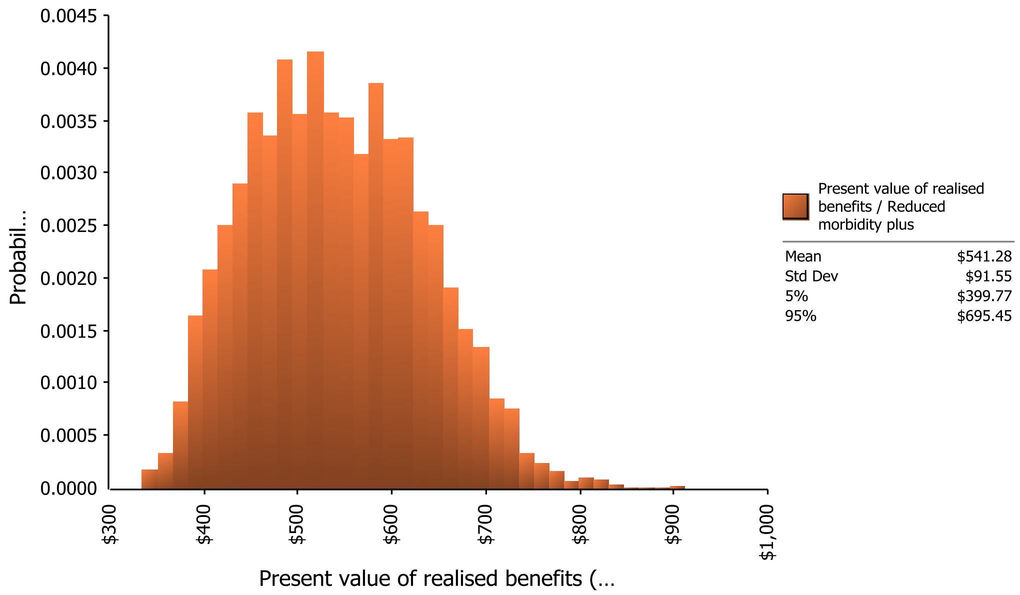


Figure A10.2 Present value of realised industry benefits: Reduced morbidity plus



Appendix 11: Realised industry costs

Figure A11.1 Present value of realised industry costs: Reduced morbidity

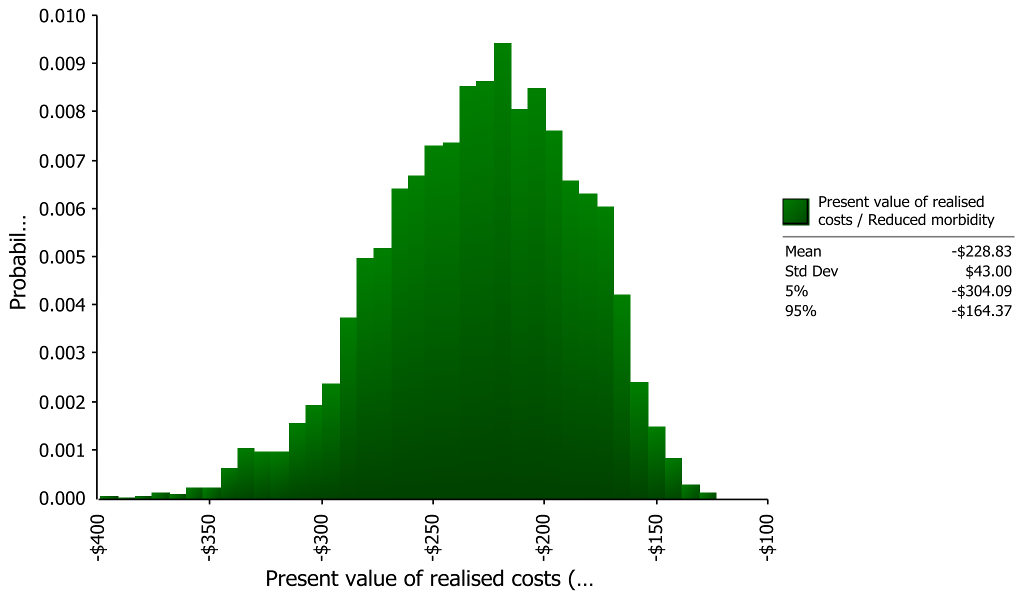


Figure A11.2: Present value of realised industry costs: Reduced morbidity plus