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How Did We Go? Revisiting the Ex Ante Economic Impact Assessment of the CRC for Beef Genetic Technologies, as at the Cessation of Funding[1]

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Abstract

The Cooperative Research Centre (CRC) for Beef Genetic Technologies operated for its third successive 7-year term from July 2005 to June 2012. It targeted an additional 1.5 per cent in gross revenue of the Australian beef industry over 25 years to 2030. This was to be achieved by developing a package of new genetic and genomic technologies and non-genetic “products” (practices, processes, tools and technologies) to improve profitability, productivity, animal welfare and responsible resource use of Australian beef businesses. The economic analyses underpinning the 2004 business case for the CRC’s third term were published by Griffith *et al.* (2005) and Griffith (2009).

In re-assessing the original estimates of economic benefit as at the end of the CRC investment phase, the most prominent issues to consider were the potential total productivity growth available to the beef and cattle industries as a result of CRC technologies, how each research program contributed to the overall productivity gain, the level of adoption of the technologies by industry and the time lag of this adoption. This paper has reviewed the impact of adjusting these variables on the total economic benefit of the CRC to the Australian beef and cattle industry, given information available in June 2012. A reduction in potential productivity gains (due primarily to slower-than-anticipated delivery of new genomic technologies that also impacted on industry adoption times) had the largest impact on benefit to industry, followed by a reduction in the expected maximum level of adoption. Research program components of growth, R&D lags and adoption lags had more marginal impacts.

Whilst the estimated economic benefits of the Beef CRC to industry varies substantially according to the mix of assumptions used relating to the key parameters, even under the most adverse scenario the Beef CRC is still expected to generate a total benefit to the industry of $784 million, which is more than 50 per cent higher than the “without-CRC” scenario ($516 million). The most likely scenario delivers an expected industry benefit of $1,004 million, which is almost twice that of the “without-CRC” scenario, and provides a return on investment of more than $8 for every $1 invested into the Beef CRC.

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Introduction

The Cooperative Research Centre (CRC) for Beef Genetic Technologies operated for its third successive 7-year term from July 2005 to June 2012. It targeted an additional 1.5 per cent in gross revenue of the Australian beef industry over 25 years to 2030. This was to be achieved by developing a combination of new genetic and genomic technologies and non-genetic "products" (practices, processes, tools and technologies) to improve profitability, productivity, animal welfare and responsible resource use of Australian beef businesses.

The economic analyses underpinning the 2004 business case for the CRC's third term were published by Griffith *et al.* (2005) and Griffith (2009). Those analyses were based on a broad "top-down" modelling approach, supported by detailed "bottom-up" analyses of specific project areas. During the course of the CRC, the Commonwealth Government requirements for monitoring and evaluation of CRCs became more rigorous and prescriptive. An Excel-based software package known as the "Impact Tool[2]" was developed and mandated for use by all CRCs when submitting bids for funding, reporting annual progress against milestones and final reporting and evaluation of achievements against objectives. The Impact Tool is simply a template that collects and aggregates a range of data across all output and outcome areas specified by the CRC. As such it relies on very detailed bottom-up analyses of all of these areas.

The purpose of this and a related paper (Griffith and Burrow, 2013) is to determine how well the third-term Beef CRC met its objectives, as at the end of its funding period. Because a rigorous top-down analysis had been undertaken for the 2004 business case and the Beef CRC had been routinely reporting to the Commonwealth using the Impact Tool since 2010, a three-pronged approach was adopted to evaluate the impact of the Beef CRC.

First, a number of detailed economic analyses were conducted of the potential impacts of most of the specific outputs that the CRC had targeted. These were new "products" such as Estimated Breeding Values (EBVs) to identify genetically superior cattle for breeding, DNA-based diagnostic tests, decision support tools and information packages etc. Many of these analyses are reported in the companion paper.

Second, these product analyses were used as inputs into the Impact Tool, where they were aggregated and used to generate return on investment values. This level of analysis is reported in Griffith and Burrow (2013).

Third, the 2004 business case was repeated using exactly the same model and simulation processes, but substituting parameter values based on 2012 information from the Impact Tool and the detailed studies behind it, replacing the 2004 estimates. That third level of evaluation is reported in this paper. The focus is on how the new information generated by the CRC's R&D activities between 2005 and 2012 has impacted on the predicted overall outcome of the CRC, as defined in the original business case (Griffith, 2009).

Background to the science

Investing in the CRC for Beef Genetic Technologies was always both a long-term and an uncertain investment due to the fundamental nature of the "gene discovery and gene expression" research being undertaken. Some optimistic claims were made about projected outcomes, but claims that were well justified by the information available at the time the business case was written in June 2004. To quote from the prospectus:

"The explosion in knowledge of genetics, best evidenced by completion of the Human Genome Project (HGP), probably the world's most ambitious and far-reaching biological experiment, started only in 1990 and completed 2 years ahead of schedule in April 2003. The technology developed by the HGP and subsequent genomics research can be applied directly to cattle. One huge outcome of this application of genomics to cattle will be the completion in December 2005 of the "Bovine Genome Project". By combining the publicly available bovine genomic sequence with Australian expertise in genomic technology and the CRC's unique genotypic and phenotypic databases, we will be able to understand the genes that control basic biological processes in cattle. The resulting technologies will be easier to apply to cattle than to humans because it is not unethical to control the breeding, growth

[2] https://www.crc.gov.au/Information/ShowInformation.aspx?Doc=16th_Selection_rounds&key=bulletin-board-selection-rounds_16&Heading=16th%20CRC%20Selection%20Round#16thApplicationPack

and development of cattle. Australian beef research will not have another such opportunity this century." (CRC for Cattle and Beef Quality, 2004).

The reality is that while the optimism about the eventual outcome remains and is now beginning to be realised, the discovery process took much longer and was very significantly different than was anticipated in the 2004 business case.

The optimism was based on three factors. First, in 2002, the second-term Beef CRC filed a patent application for DNA markers for beef tenderness (Barendse, 2002) based on "gene discovery" or gene mapping approaches. The application was made on the basis that one of the markers (an allele of the gene encoding Calpastatin), together with two additional markers in the complementary Calpain system, collectively accounted for 6-8 per cent of the genetic variation for beef tenderness. Based on this example, it was the Beef CRC's expectation in 2004 that a small number of DNA markers (e.g. 5-10), each of large effect, would collectively control around 50 per cent of the genetic variation in most economically important traits in beef cattle. Thus, DNA diagnostic tests would likely be used as a drafting tool (i.e. keep the animals with the "right" genes and dispose of the others to the extent possible) and thereafter EBVs based on pedigree and animal measurements would be used to select for breeding purposes.

At that same time, "gene expression" research based on newly-emerging microarray technology was also in its infancy and appeared likely to provide a complementary approach to "gene discovery", allowing researchers to identify gene networks associated with economically important traits. This would in turn enable discovery of causal mutations and intervention points that would allow development of non-genetic treatments which controlled the expression of the genes.

And third, based on its two previous CRC terms, in 2004 the Beef CRC knew it had the world's largest and most comprehensive database of hard- and expensive-to-measure "phenotypes" that were necessary to underpin "gene discovery" and "gene expression" research in beef cattle.

However when the bovine genome sequence became available in 2006 (Gibbs *et al.*, 2009; Elsik *et al.*, 2009), it very quickly became apparent that these assumptions were no longer valid. Rather than the very small number of genes with major effects that were hypothesised in 2004 to control the basic biological processes in cattle, it was clear that hundreds of thousands of genes, each of very small effect, controlled most economically important traits. Further, development of new panels of DNA markers based on Single Nucleotide Polymorphisms (SNP panels) released around the time of the bovine sequence largely replaced microarray technology as the technology of choice for gene discovery, leaving a large void in identification of causal mutations. And most importantly, it quickly became apparent that even with the world's largest database of beef cattle phenotypes, the Beef CRC only had access to a fraction of the number of phenotypes that would be needed to deliver its planned outcomes. The complexity of the challenges that had to be overcome by the Beef CRC as a result of the very rapidly changing genomics technologies during a period that was arguably the most rapidly changing research environment in the history of biological science are described in Goddard and Hayes (2009) and Goddard (2010).

The original business case (June 2004)

A summary of the original business case is given in Appendix 1. Interested readers may seek further details in Griffith *et al.* (2005) and Griffith (2009).

Omission in original business case

Subsequent to the publication of the original business case (Griffith *et al.*, 2005; Griffith, 2009) and based on the detailed "bottom-up" analyses reported in the Impact Tool companion paper (Griffith and Burrow, 2013), it became clear there was an omission in the original analyses. In particular, using a gene flow spreadsheet to accurately track the rate of genetic gain from the more accurate EBVs showed that in the original analyses, the underlying rate of genetic progress already in train from past R&D investments was not properly excluded. The with-CRC case as summarised in Table A2 was therefore overstated to the extent that the assumed "with" potential total factor productivity (TFP) (9 per cent) includes the base rate of TFP due to genetic progress in the business-as-usual case (assumed to be 2.5 per cent). The reason that this is important for the genetics part of the business-as-usual case and not the non-genetics part is that genetic progress is dynamic and cumulative whereas for the most part non-genetics interventions are one-off improvements.

Therefore to properly assess the end-of-CRC outcomes, the "with-CRC" scenario needs to be re-examined using the net rate of potential TFP for the genetic component. All of the potential productivity improvement parameters in the supply side scenarios need to be reduced by 2.5 per cent to appropriately reflect the genetic improvement derived from earlier R&D investments. When this is done, the revised NPV is $1.355 billion ($1.453 billion - $98 million) and the revised BCR is 14.8:1 ($1.453 billion/$98 million). Thus when the underlying rates of genetic gain were appropriately accounted for, the revised assessment suggested the research portfolio of the CRC for Beef Genetic Technologies was expected to return around $14.80 to the Australian beef industry for every $1 invested from all sources (*cf.* the original estimate of around 20:1).

The implications of making this change on the annual time path of gross benefits is shown in Figure 1, where the original values from the with-CRC business case are compared with the values using the revised genetics assumption, and also with the most likely estimates from the 2012 reassessment, as detailed below. The revised genetics assumptions reduces the annual benefit by more than $40m after full adoption, and when discounted sums to the $575m difference in NPV between the two estimates.

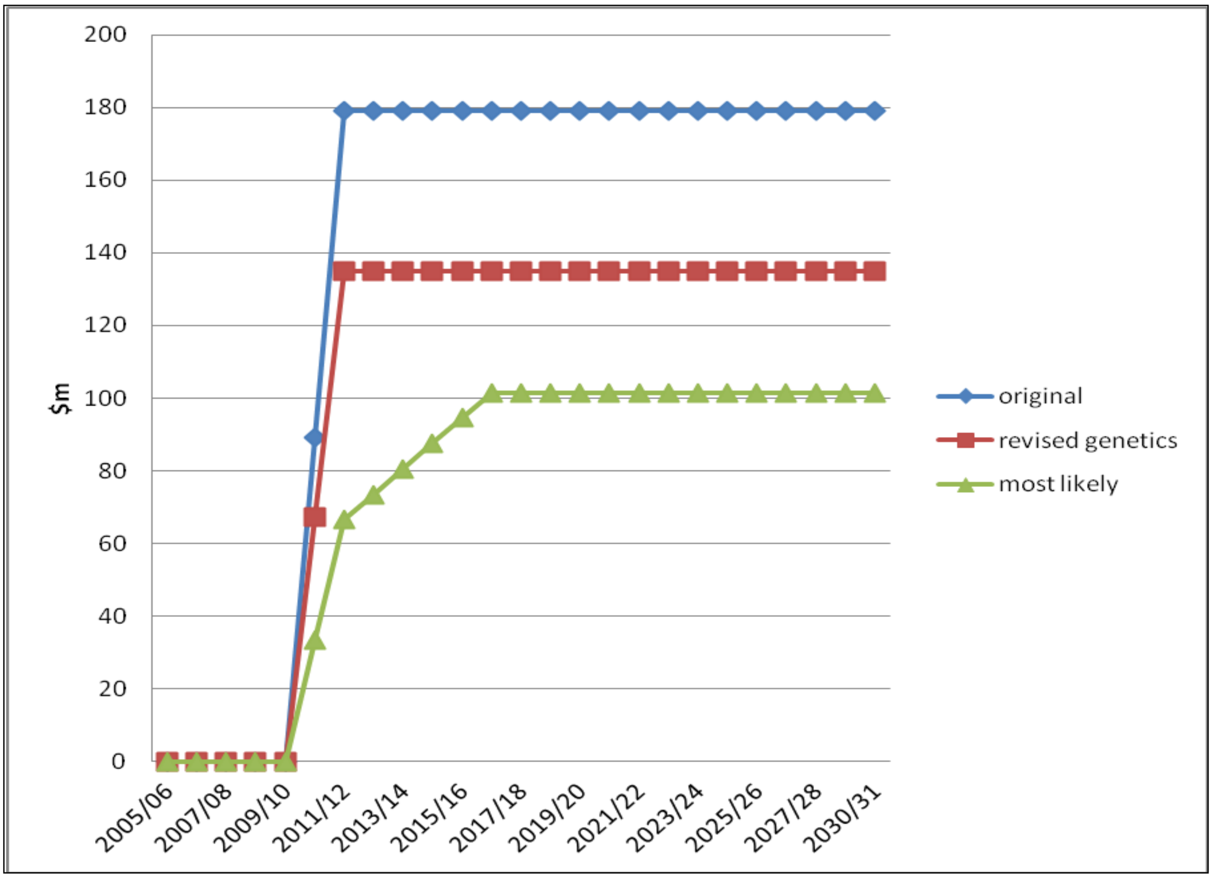

Figure 1. Annual gross benefits, original business case, revised genetics assumption and most likely estimates from 2012 reassessment, 2005/06-2030/31, $m, not discounted

Re-assessing the original business case in June 2012

A detailed explanation of the changes made to the 2004 base assumptions is given in Appendix 2. Some of these changes were introduced in the CRC mid-term review in 2007/08, while others reflect the new information available in mid 2012 as well as the changes required due to the error in the original analysis.

Any changes made to the initial assumptions have to be couched in terms of changes to one of the four key parameter values identified in Appendix 1. However, it is clear that the majority of the changes related to uncertainties about the expected timeline and outputs stemming from the "gene discovery and gene expression" research program and the consequent use of DNA-based diagnostic tests by the seedstock sector and commercial beef producers to generate industry benefits. These issues were documented in successive CRC annual reports and in a large number of research papers as specified in Appendix 2. A summary of the new assumptions is given in Table A4, separated by type of parameter (potential total factor productivity improvement, R&D lag, adoption lag, maximum adoption level), type of outcome (genetic or non-genetic), type of impact (supply or demand) and type of scenario (worst case, most likely or best case).

Results from re-assessing the original business case in June 2012

The results of re-assessing the original business case are shown in Table 1 by scenario, source of impact and market segment.

Although there are a wide range of potential outcomes shown in Table 1, all scenarios offer an improved level of benefit to the beef and cattle industry over the "without-CRC" scenario in the original business case. The worst case scenario provides net benefits to the beef industry almost 50 per cent greater than the estimated business-as-usual case, the most likely case provides close to double the base case and the optimistic best case generates over $670 million more than the base case. The most likely and best case scenarios also generate greater returns per dollar spent on R&D than the business-as-usual case.

Table 1. Results from the DREAM analysis (given 2012 information based on 2001 model version), by scenario, type of impact and market segment ($ million Present Value over 25 years discounted at 4 per cent real)

Scenario and Component	Producer benefit	Consumer benefit	Total benefit	Total cost	NPV	BCR
Without-CRC original analysis	316	200	516	58	458	8.9
Current data/worst case						
Genetic Supply	140	44	184			
Non-genetic Supply	266	84	350			
Non-genetic Demand	136	114	250			
Total	542	242	784	111	673	7.1
Most likely case						
Genetic Supply	218	68	287			
Non-genetic Supply	308	97	405			
Non-genetic Demand	170	143	313			
Total	696	308	1004	111	893	9.0
Best case						
Genetic Supply	250	78	328			
Non-genetic Supply	410	129	537			
Non-genetic Demand	204	171	375			
Total	864	378	1242	111	1131	11.2
With-CRC original analysis	(new*) 817	635	1453	98	1355	14.8
	(original*) 1182	748	1930	98	1832	20.0

Note: * new analyses do not include the underlying rates of genetic gain derived from previous investments; original analyses inadvertently include genetic gains that continued to accrue from past investments

However even the best case falls short of the (new) 2004 estimate for net benefits by just over $200 million. This is the net effect of the difficulties arising from the rapidly changing genomic technologies and the lack of access to adequate numbers of animals with accurate measurements for the hard- or expensive-to measure, economically important traits. These difficulties could not be overcome with simple adaptations to genomic work plans or readjustment towards the non-genetic components of the CRC's RD&E portfolio.

The annual time path of gross benefits from the worst case, most likely case and best case are shown in Figure 2.

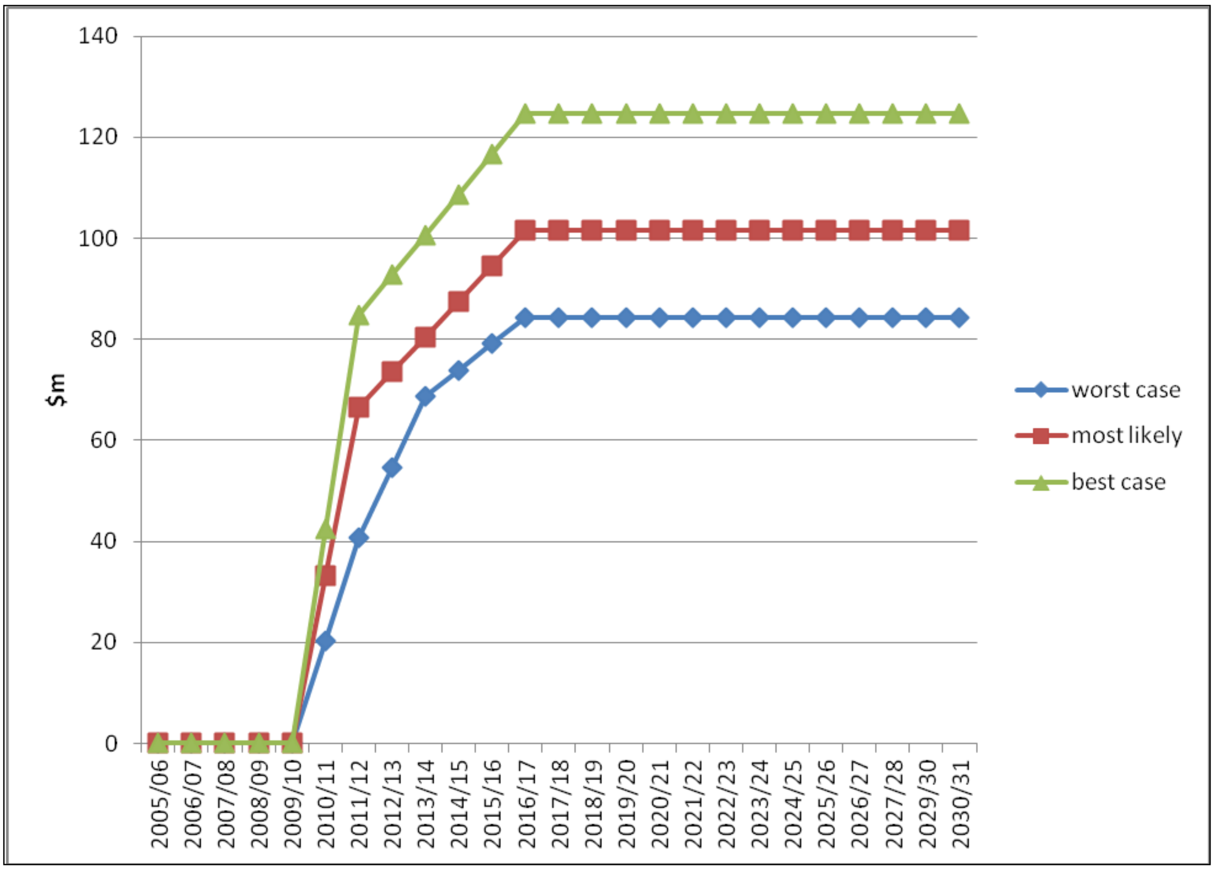

Figure 2. Annual gross benefits, worst case, most likely case and best case estimates from 2012 reassessment, 2005/06-2030/31, $m, not discounted

It could also be argued that the "without-CRC case" shown in Table A3, with an implied level of genomic EBV accuracy of 20 per cent, is probably over-stated given current information. The only beef genomics research that would have been ongoing in Australia in the absence of the CRC was through a major international pharmaceutical company that did not have access to the very large Australian cattle databases needed to deliver genomic EBVs with any level of accuracy for use by the Australian beef industry. So maintaining a 2.5 per cent underlying potential TFP growth rate over a long period of time is most likely also over-stated. If that is the case then all the scenarios shown in Table 1 would deliver greater net benefits relative to the without-CRC original analysis. However, given the nature of counter factual scenarios, such suppositions cannot readily be justified, therefore no such adjustments have been made.

A wide range of additional sensitivity analyses were undertaken to support this study, although they are not reported here. As expected, the calculated benefits increase with increasing potential productivity, increasing maximum adoption level and decreasing adoption lag. The lowest NPV is $673 million for the lowest aggregate potential productivity growth (8.5 per cent), the lowest set of maximum adoption levels (35 and 20 per cent, respectively for genetics and non-genetics) and the longest adoption lags (5 and 4 years, respectively). The highest NPV is $1131 million for the highest aggregate potential productivity growth (10 per cent), the highest set of maximum adoption levels (40 and 25 per cent, respectively) and the shortest adoption lags (5 and 2 years, respectively). The results are most sensitive to potential productivity gain and adoption level and less sensitive to adoption lag, given the low discount rate used.

In terms of which source of productivity growth contributes and which segment of the industry benefits, the non-genetic supply component contributes over 40 per cent of the benefits across all scenarios. This is consistent with the results from the Impact Tool, where in the first 15 years of the benefits stream the non-genetic components heavily outweigh the genetic components (Griffith and Burrow, 2013). Improved market access provides a little over 30 per cent, and genetic improvements in aggregate contribute slightly less than 30 per cent across all scenarios. In aggregate, both beef producers and beef consumers gain, with producers receiving about 70 per cent of the aggregate benefits across all scenarios when beef "consumers" are defined as all participants in the post farm-gate value chain.

The relative contributions of the three sources of productivity growth are shown in Figure 3.

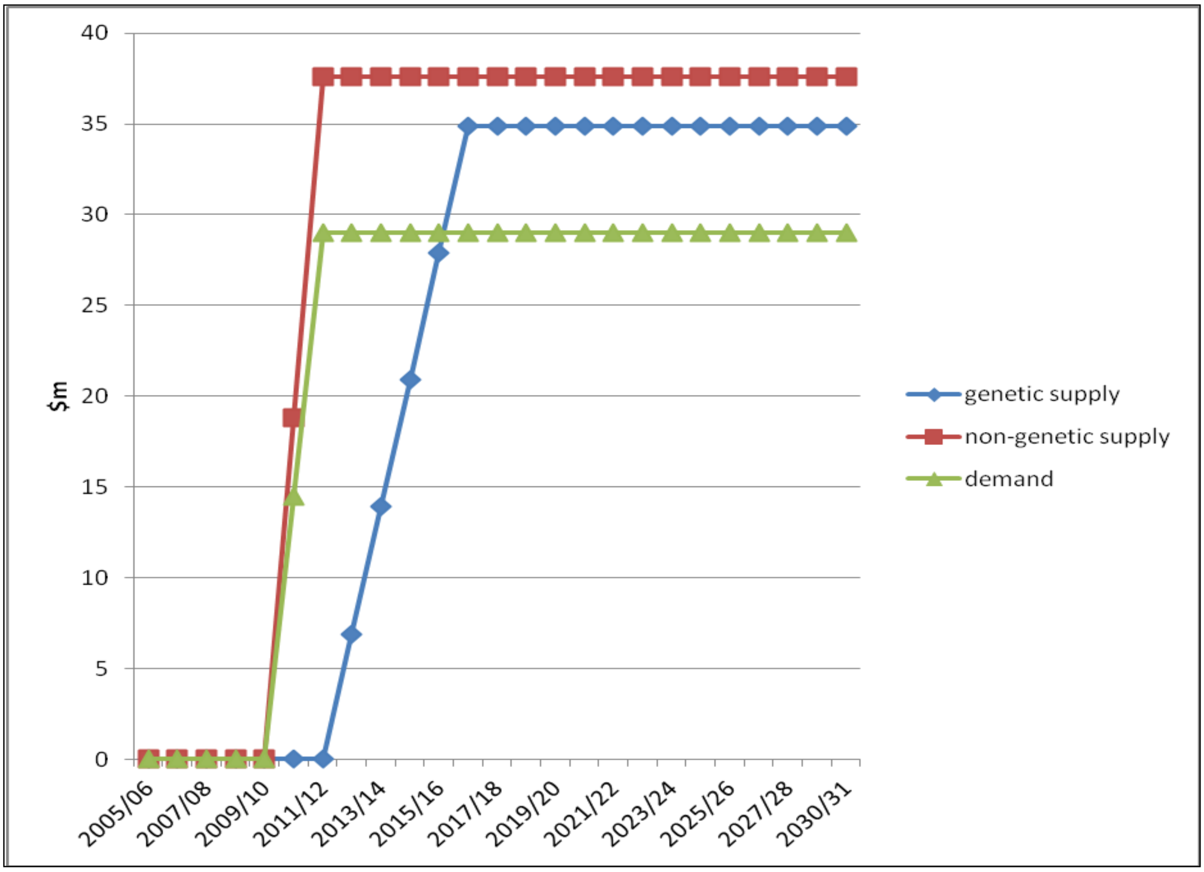

Figure 3. Annual gross benefits due to genetics, non-genetics and demand sources of productivity growth, most likely case estimates from 2012 reassessment, 2005/06-2030/31, $m, not discounted

An alternative way of examining the results is shown in Table 2. Here, for the most likely scenario, the aggregate gross benefit of approximately $1 billion is broken down by source of impact, market segment and region.

In aggregate, southern Australian beef producers gain about 55 per cent of the returns from genetic supply and non-genetic supply impacts, with northern Australian beef producers picking up about 45 per cent. Australian consumers gain almost no benefit and consumers in the major international markets gain, but at the expense of beef producers in those markets. This is a typical pattern for a cost reducing type of technology: producers who cannot or do not adopt the technology suffer the consequences of the inevitable price decline but do not have the savings from the technology to offset it.

The increased willingness to pay (WTP) from the market access scenario leads to price rises in all markets. Foreign consumers gain because their increased WTP is greater than the price rise and foreign beef producers gain as it is now more profitable to supply beef. Australian producers also benefit but not greatly, as price changes are not transmitted perfectly around the world. However Australian consumers are harmed as prices rise but their WTP is not greater in this scenario.

Table 2. Results from the DREAM analysis (using most likely case from Table 1 and 2012 information based on 2001 model version) by type of impact, market segment and region ($ million Present Value over 25 years discounted at 4 per cent real)

Component	Region	Producer Benefit	Consumer Benefit	Total Benefit
Genetic Supply	Southern Australia	152	1	153
	Northern Australia	131	0	131
	Export markets	-64	67	3
	All markets	218	68	287
Non-genetic Supply	Southern Australia	230	2	232
	Northern Australia	169	0	169
	Export markets	-91	95	4
	All markets	308	97	405
Non-genetic Demand	Southern Australia	5	-3	2
	Northern Australia	5	-1	5
	Export markets	160	146	306
	All markets	170	143	313
All Sources		696	308	1004

Conclusions

In re-assessing the original estimates of economic benefit from funding the CRC for Beef Genetic Technologies, the most prominent issues to consider were the potential total productivity growth available to the beef and cattle industries as a result of CRC technologies and how each research program contributed to the overall potential productivity gain, the level of adoption of the technologies by industry and the time lag of the R&D and the adoption.

This paper has reviewed the impact of adjusting these four variables on the total economic benefit of the CRC to the beef and cattle industry, given information available in June 2012. A reduction in potential productivity gains (due primarily to slower-than-anticipated delivery of new genomic technologies that also impacted on industry adoption times) had the largest impact on benefit to industry, followed by a reduction in the expected maximum level of adoption. Research program components of growth, R&D lags and adoption lags have more marginal impacts.

Whilst the estimated economic benefits of the Beef CRC to industry varies substantially according to the mix of assumptions used relating to the key parameters, it is important to note that even under the most adverse scenario, the Beef CRC is still expected to generate a total benefit to the industry of $784 million, which is more than 50 per cent higher than the “without-CRC” scenario ($516 million). The most likely scenario delivers an expected industry benefit of $1,004 million, which is almost twice that of the “without-CRC” scenario, and provides a return on investment of more than $8 for every $1 invested into the Beef CRC. This level of return sits comfortably in the range of previous studies in the area (Mullen, 2007) and exceeds the level expected of CRC investments as detailed in the explanatory material related to use of the Impact Tool (Griffith and Burrow, 2013).

For those following behind, some lessons learnt about RD&E management and impact assessment are noted in the companion paper (Griffith and Burrow, 2013). However in terms of the particular level of analysis reported here, it is apparent in retrospect that not enough attention was paid in the original business case to the potential technological risks inherent in the proposal. Rather than simply reporting point estimates of the net benefits, it would have been preferable to report some formal sensitivity analyses. These could have ranged from best-case, most-likely and worst-case scenarios as reported in this paper, through to detailed probabilistic analyses such as Zhao *et al*. (2000) or what is now known as real options analyses (Guthrie, 2009). This is of course easier said than done – how do you anticipate the situation where the technology changes so radically that much of the R&D portfolio needed to head off in entirely new directions? and what would have been the probabilities of this occurring given the CRC's earlier successes with genomic technologies? Still, some attempt would have been better than no attempt.

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Appendix 1: The original business case (June 2004)

In this appendix a brief summary of the original business case is given to provide a baseline for the alternative ex post scenarios described in the body of the paper. More detail may be found in Griffith *et al.* (2005) and Griffith (2009).

Overall approach

A top-down modelling approach was followed, based on the same type of analysis in The Allen Consulting Group (2003). Given the nature of the proposed scientific programs in the CRC (i.e. many interlocking projects, resources applied across a number of projects and outputs from some projects becoming inputs into other projects), it was too difficult to allocate costs across individual project areas and to apportion benefits to individual project areas, as would be done in a more traditional bottom-up approach. Thus, the emphasis was on estimating the impact of the whole RD&E portfolio rather than the impacts of the individual project areas or programs. Overall rates of productivity improvement were examined and the role of technological change in generating this productivity growth was assessed. Expert opinion was used to disaggregate the shares of potential productivity growth due to the CRC across the various outcome areas and the benefits from the expected shifts in these various outcomes were then estimated.

A critical requirement was to define appropriate "with-CRC" and "without-CRC" scenarios: i.e. to estimate the marginal benefits from the proposed investment by the Commonwealth. This is a difficult requirement because evaluations of investments such as the CRC are concerned with on-going, rather than completely new research programs. For example, many of the broad areas of the proposed CRC research program had significant past and ongoing RD&E investments. There have been, and will be in the future, productivity improvements that result from these earlier RD&E programs. These will arise because the RD&E investments are being assessed in the beef cattle industry and there are very long biological lags involved in that industry. In addition, the nature of the technology under investigation (genetics) means the impacts of adopting such technologies are spread over a long time period, with the impacts accumulating over time. Benefits flowing from past investments, even though they formed the building blocks of some of the new proposals, cannot be claimed to be benefits of the proposed CRC research. Other issues to consider included the long history of collaboration achieved by researchers and agencies through their involvement since 1992 in the first and second term CRCs and the fact that research issues included in the renewed CRC program were the result of substantial consultation between industry and potential core partners.

Assumptions

Applying this broad approach in the context of the selected software package (the DREAM model, Wood *et al*., 2001) meant consideration of the following four key parameters.

Potential rates of total factor productivity improvement: Based on documented measured rates of total factor productivity (TFP) improvement of 1.0-1.5 per cent p.a. (ABARE data) and low rates of adoption of new technologies by the beef industry in the order of 25 per cent (MLA, pers. com. 2004), it was estimated the potential rate of productivity improvement available to the Australian beef industry in 2004 was approximately 5 per cent p.a. The adoption rate for genetic technologies was higher than 25 per cent, based on the proportion of the breeding herd mated to BREEDPLAN recorded bulls (around 30 per cent; Farquharson *et al*., 2003), so the adoption of non-genetic technologies was assumed to be less than 25 per cent.

It was estimated the aggregate impact of the third-term CRC on the Australian cattle and beef industry would be an additional 4 per cent in the potential annual rate of productivity improvement (i.e. 9 per cent in total). This would occur after maximum adoption of the research outcomes of the CRC. Such a figure reflected the expectation that the majority of benefits would be related to improvements in genetic merit, and so there would be a strong relationship between the level of explanation of genetic variance and potential productivity gains (see Table A3). This expectation was supported by: i) recent estimates of the benefits of specific genetic technologies (e.g. Burrow *et al*., 2003,a,b; Farquharson *et al*., 2003; Griffith *et al*., 2004); ii) the strong expectations by the scientists involved that CRC funding would provide the resources necessary to repeat these types of successes in the future (in particular that five-ten DNA markers could be discovered that would explain 50 per cent of the genetic variance in traits of interest); and iii) estimates by Manson and Black (2004) that the great majority of the measured rates of productivity improvement in the Australian beef industry are attributable to RD&E investment. Although a 9 per cent rate of potential productivity improvement seems large, when this rate is multiplied by an expected adoption level of 35 per cent (reflecting the additional ambition of the CRC to increase the industry adoption rate from 25 per cent in 2004 to 35 per cent by 2012), the implied actual or measured rate of productivity improvement is only just over 3 per cent. The Australian grains industry had exceeded 3 per cent annual productivity growth long before 2004 and according to the ABARE data available at the time, the northern Australian beef industry was close to 3 per cent already, indicating the 9 per cent potential productivity improvement was realistic.

The wide range of participants in the CRC application reached some consensus on the relative contributions of each of the seven major outcome areas to the success of the new CRC. These consensus estimates were used to allocate the selected overall potential rate of productivity improvement across different types of impacts and different regions, based on the RD&E activities in the various proposed programs of research. These allocations are listed in Table A1 and show that 20 per cent of the total productivity impact is predicted to come from the beef quality improvement outcome, 10 per cent from the reduced feed cost outcome, and so on. These overall allocations were assumed to relate to the whole Australian beef industry. Then, based on the material provided for each of the science programs in the prospectus (CRC for Cattle and Beef Quality, 2004), these impacts were allocated as either cost-saving (C), yield-increasing (Y) or demand-enhancing (D), and as applying to either the northern industry, the southern industry, or to both. These choices determined which regions the technologies applied to and how they were implemented in the software program.

Table A1. Original "with-CRC" scenario components of growth

Outcome area	Weighting	North C or Y		South C or Y		Demand D	
Increased beef quality	0.20	C	0.90	C	0.90	D	0.90
Reduced feed cost	0.10	C	0.45	C	1.35		
Reduced parasite input cost	0.10	C	1.80	C	0.00		
Increased market access	0.10					D	0.90
Increased meat yield	0.10	Y	0.90	Y	0.90		
Increased reproductive rate	0.30	Y	2.70	Y	2.70		
Misc. enhanced management	0.10	C	0.90	C	0.90		

Thus, in the first data row of Table A1, 20 per cent of the 9 per cent overall potential productivity figure, or 1.8 per cent, was estimated to be due to increased beef quality. Half of this 1.8 per cent was assumed to directly influence consumer demand in the domestic and major export markets; the other half was assumed to be reflected in reduced transaction costs throughout the marketing chain. These costs were further assumed to be split 50:50 between the northern and southern beef industries (since cattle numbers were assumed to be approximately 50:50 between the north and the south over the simulation period), so each region had the same cost saving of 0.9 per cent. In the second row, 10 per cent of the 9 per cent overall potential productivity figure, or 0.9 per cent, was estimated to be due to reduced feed cost. This was assumed to only influence cost of production, and to be split 25:75 between the northern and southern beef industries. Similar arguments were made to generate the other specific types of potential total factor productivity improvements applied to each region.

<u>R&D lags</u>: Even though funding was to be provided for seven years, there was a specific objective to achieve some industry outcomes before the CRC ceased in 2012. This meant speeding up the R&D process so the outputs would be available for industry use before 2011/2012. This was a reasonable expectation given the provision of more specific resources for the research and the assumption at the time that there would be only a small number of diagnostic tests that would explain approximately 50 per cent of the genetic variance in traits of interest and which could be delivered sequentially from 2006. Thus the assumption was a 5-year R&D lag, in contrast to the business-as-usual case of a 7-year R&D lag.

<u>Adoption lags and levels</u>: As a consequence of their biology, cattle genetic technologies have small initial impacts that slowly accumulate in the population over time. Thus the adoption process would

normally be expected to be spread over many years. However, in this case planned CRC commercialisation and adoption strategies were allowed to also contribute to the adoption of existing pipeline stocks of technologies produced from previous CRCs or elsewhere. There was an explicit focus on accelerated adoption methodologies and industry take-up of the outcomes generated (in particular, a continuous improvement and innovation cycle; Griffith, 2008) and the RD&E itself was planned to be more coordinated and intense. Thus it was expected there would be measurable change in adoption of new technologies, attributable to CRC activity in the short to medium term i.e., shorter lags in achieving results and in industry adopting them and an overall higher level of industry adoption than would otherwise be the case. This would be driven by higher accuracies for EBVs which would induce greater use of BREEDPLAN registered bulls and a significant improvement in the adoption of the non-genetic technologies generated by the CRC. Thus, assumptions were a maximum adoption level of 35 per cent and a 2-year lag till that level was reached. The maximum annual benefit was expected to be achieved in 2012/2013. This was in contrast to the business-as-usual case of a maximum adoption level of 25 per cent and a 5-year lag till that level was reached in 2017/2018.

Risk of failure: With the provision of more specific resources for equipment etc., it was also assumed the overall quality of the R&D would be slightly enhanced when the CRC was funded, with higher probabilities of successful outputs. The overall probability of success was assumed to be 80 per cent, instead of 70 per cent in the business-as-usual case.

Results

These key assumptions were used as inputs into separate scenarios for each of the demand and supply shifts using the DREAM modelling framework (Griffith *et al.*, 2005; Griffith, 2009). A consistent set of price and quantity data for a representative year (2001/2002) and a consistent set of producer and consumer responsiveness parameters were used to calibrate the model. The various scenarios were run over a 25-year time horizon and the return on investment criteria calculated using a 4 per cent real discount rate. Key results are shown in Table A2.

The total benefits from the demand-enhancing components of the portfolio had a present value of about $593 million when summed over the 25-year simulation period. More than half the benefits accrued to consumers in export markets because of the greater size of these markets and the higher prices that consumers in these markets are willing to pay for higher quality, compared to Australian consumers. Producers in export markets and in competing supply regions also gained from this investment, since the overall demand for beef is increased and they are large suppliers to these markets. Domestic producers and consumers gained about $125 million from these impact areas. The annual benefit of this set of impacts was around $55 million after reaching maximum adoption levels, with about $12 million accruing in Australia.

The total benefits from the cost-reducing and yield-increasing components of the portfolio had a present value of about $1.337 billion when summed over the 25-year simulation period. Most of these benefits accrued to cattle producers in Australia because they have direct access to the new technologies. Consumers in export markets were also beneficiaries as they have access to more beef at lower prices. However producers in competing supply regions lose from the research program as they suffer the consequence of an overall fall in prices but do not have the cost savings from the technologies to compensate. The annual benefit of this set of impacts is about $124 million after reaching maximum adoption levels, with almost all of the benefit accruing in Australia.

Table A2. Original results for the "with-CRC" scenarios (2006-2030; $ million Present Value over 25 years discounted at 4 per cent real)

Shift	Region	Producer Benefits	Consumer Benefits	Total Benefits	Total Cost	NPV	BCR
Demand	Northern Australia	5	21	26			
	Southern Australia	5	95	100			
	Export markets	152	315	467			
	All markets	162	431	593			
Supply	Northern Australia	691	1	692			
	Southern Australia	628	5	633			
	Export markets	-299	311	12			
	All markets	1020	317	1337			
TOTAL		**1182**	**748**	**1930**	**98**	**1832**	**20**

Total estimated benefits from the with-CRC scenarios therefore were around $1.930 billion. With the full costs of the CRC program (nominally expected to be $110m) having a present value of around $98 million when discounted at the same rate as the benefits, this results in a Net Present Value (NPV) of $1.831 billion ($1.930 billion - $98 million) and a Benefit: Cost Ratio (BCR) of 19.65:1 ($1.930 billion/$98 million). Thus, under the set of assumptions made in 2004, the proposed research portfolio of the CRC for Beef Genetic Technologies was expected to return around $20 to the Australian beef industry for every $1 invested from all sources.

Appendix 2: Re-assessing the original business case in June 2012

In this appendix the changes in the 2004 base assumptions are given. Some of these changes were introduced in the CRC mid-term review in 2007/08, while others reflect the new information available in mid 2012 as well as the changes required due to the error in the original analysis.

Based on the modelling philosophy adopted and the specific software chosen for the original analysis, any changes made to the initial assumptions have to be couched in terms of changes to one of the four key parameter values identified in Appendix 1 above. However, the major recognised uncertainty from the original "with-CRC" model related to the expected timeline and outputs stemming from the "gene discovery and gene expression" research program and the consequent use of DNA-based diagnostic tests by the seedstock sector and commercial beef producers to generate industry benefits. Issues documented in successive CRC annual reports related to the CRC's difficulty in achieving independent validation of DNA markers; the greatly increased numbers of DNA markers associated with each economically important trait; the lower levels of explanation of genetic variance for each set of DNA markers; and changes in the genomic technology that required significantly increased numbers of animal records than originally anticipated to validate results (e.g. Goddard and Hayes, 2009; Goddard, 2010; Bolormaa *et al*., 2011*a, b*; Pryce *et al.,* 2011; Van Eenennaam *et* al., 2011; Fortes *et al.,* 2012; Bolormaa *et al*., 2013; Zhang *et al*., 2013). It is this uncertainty which has driven most of the changes.

Changes made for the mid-term review

The Beef CRC underwent a mid-term review in 2007/2008. Some of the initial (2004) assumptions were changed for the mid-term review impact analysis (Griffith and Pollock, 2008). In particular, as the difficulty of the gene discovery task became clearer, expectations about the level of genetic variance that could reasonably be explained by DNA-based diagnostic tests or prediction equations were reduced from 50 per cent to "at least" 15 per cent, the sum of the R&D lag and adoption lag was lengthened from 7 years to at least 10 years, and the maximum level of industry adoption was reduced from 35 per cent to 30 per cent.

As shown in Table A3, there are strong positive relationships expected between the biophysical measures of level of genetic variance explained and EBV accuracy, and the economic measure of level of potential total factor productivity. Hence a decline in explained variance implies a decline in genomic EBV accuracy (i.e. accuracy of the predicted breeding value based on genomic data only), leading to a lower expected productivity gain following maximum adoption of research outcomes. Ten per cent of explained variance would imply 6 per cent potential productivity growth, 15 per cent would imply 6.5 per cent potential productivity growth, and so on.

Table A3. Level of genetic variance explained and overall rate of potential productivity improvement

Level of genetic variance explained (%)	Implied level of genomic EBV accuracy (%)	Overall rate of potential productivity improvement (%)
WITH CRC CASE		
50	70	9
30	55	8
20	45	7
10	30	6
WITHOUT CRC CASE 5	20	5

So based on the relationships shown in Table A3, for the mid-term review the implied potential TFP generated from the CRC's R&D portfolio was reduced from 9 per cent to around 7 per cent. The components of potential productivity (meat quality, feed savings, reproduction, etc) were also changed a little from those reported in Table A2 to reflect results to 2008/2009 in the different project areas.

Separating the genetic and non-genetic components of total factor productivity

Until recently, the genetic and non-genetic components of the CRC's RD&E portfolio were evaluated collectively and the same rates of productivity improvement and the same adoption lags and levels had been applied to the cost-saving and yield- and demand-enhancing areas. However, as evident in the implementation of the Impact Tool (Griffith and Burrow, 2013), there is now recognition of substantial differences between the genetic and non-genetic components of the portfolio in terms of these key parameters. To properly specify the DREAM model for the end-of-funding evaluation, it is necessary to separate out the initial assumptions into genetic and non-genetic components.

Using the business-as-usual baseline in the initial bid analysis (Table A3), it is now assumed the 5 per cent potential TFP annual gain was composed equally of genetic and non-genetic technologies i.e. 2.5 per cent genetics and 2.5 per cent non-genetics. Further, it is now assumed that the growth to 9 per cent potential TFP due to the CRC investment was entirely due to genetic progress i.e. genetics 2.5 per cent to 6.5 per cent, non-genetics stays at 2.5 per cent. Thus, for the changes foreshadowed during the mid-term review, growth in genetics was reduced from 6.5 per cent to 4.5 per cent, while growth in non-genetics remains at 2.5 per cent. This gives the aggregate potential TFP of 7 per cent as specified by Griffith and Pollock (2008).

Also, returning to the business-as-usual adoption baseline, the adoption of genetic technologies was around 30 per cent (i.e. proportion of cows mated to BREEDPLAN recorded bulls; Farquharson *et al.* 2003); hence if MLA assumed in 2004 that average adoption over all technologies was 25 per cent and genetic and non-genetic technologies were equally weighted, then adoption of non-genetics technologies would be 20 per cent.

As at June 2012, the accuracies of genomic EBVs for BREEDPLAN traits ranged between 0.16 per cent and 0.48 per cent for different traits, different cattle breeds and different methods of analysis, with lower accuracies achieved for traits such as retail beef yield that had fewer animals with measurements (Bolormaa *et al*., 2013; Zhang *et al*., 2013). For this assessment, a conservative average estimate of accuracy of 30 per cent was assumed. From Table A3, this implies explanation of genetic variance of around 10 per cent and an aggregate potential TFP of 6 per cent, if there is no change in the non-genetic components. Additionally, there is some enhanced accuracy (assumed to be an additional 0.5 per cent) from the extra collection and analysis of phenotypic data from several of the CRC projects and from ongoing analysis of past CRC databases. This gives an aggregate potential TFP of 6.5 per cent, and means that compared to the 2008 analysis, the growth in genetics should be reduced further to 4.0 per cent if there is no change in the non-genetic components.

However, based on the results from the Impact Tool analyses (Griffith and Burrow, 2013), it can now be shown that the value of the CRC's non-genetic technologies have at least partially compensated for the reduced impact of the genetic component. Growth in the non-genetic components is assumed to have increased from 2.5 per cent to 4.5 per cent. Non-genetic components impact both on-farm productivity and market access through improvements in meat quality and animal welfare attributes, so the total 4.5 per cent is split into supply side and demand side impacts. At the increased level of non-genetic growth, the aggregate potential TFP is 8.5 per cent.

As part of this separation of genetics and non-genetics, the original components of growth were also divided into genetics and non-genetics and reweighted so the weighted average matched the overall potential TFP figures. With slight differences in the impact of some of the components across northern and southern Australia, this gives slightly different productivity shifts for different states.

Adoption lags and levels

The final option involves varying levels of adoption lag (years) and adoption uptake (percentage). In the 2004 analysis, there was an explicit focus on accelerated adoption methodologies and industry usage of the outcomes generated (in particular, a continuous improvement and innovation cycle), and the RD&E itself was planned to be more coordinated and intense. Thus it was expected there would be some measurable change in adoption of new technologies, attributable to CRC activity, in the short to medium term i.e. shorter lags in achieving results and in industry adopting them and an overall higher level of industry adoption than would otherwise be the case.

In reality, the accelerated adoption project (Griffith, 2008) took longer to design and implement than originally anticipated and consequently, while the project ultimately progressed very well, actual evidence of the accelerated adoption of new genetic technologies was not as strong as initially expected (Parnell *et al*., 2008). Furthermore, the delayed discovery of DNA-based technologies associated with economically important traits delayed reaching those targeted levels of variance required to induce rapid and/or widespread adoption prior to the completion of the CRC's term.

All of the time sequences for the many individual products included in the Impact Tool were subsequently used to separately define average R&D lags, average adoption lags and average adoption levels across the genetic and non-genetic areas. These are shown in Table A4.

Probability of success

No changes were made to the figure of 80 per cent for the overall probability of successful outputs from the whole CRC portfolio. Of the 19 separate products identified in the original business case, only one related to gene expression for female reproduction was not delivered as planned. However there were several additional products delivered due to new, post-2004 funding opportunities.

Summary of new input parameters

The situation as at June 2012 was used to define the best, most likely and current or worst case scenarios (Table A4). Those scenarios were based on the most recent genomic EBV accuracies released in May 2012, together with feedback from project leaders and program managers responsible for the various CRC products.

On the supply side, the current/worst case potential TFP values were as described above (i.e. 4.0 per cent gross for genetics minus 2.5 per cent underlying growth, and 4.5 per cent for non-genetics, split up as 3.5 per cent for supply effects and 1.0 per cent for demand effects); a 7 year R&D lag for genetics (accuracies released recently, with enhanced EBVs to be used for cattle selection for the first time in 2012/2013) and a 5 year R&D lag for non-genetics (many of the products had already been released and were being used); a 5 year adoption lag for genetics (one generation interval) and slightly shorter for non-genetics; and adoption levels no better than the base case (35 per cent for genetics and 20 per cent for non-genetics). It could be argued that there may be different adoption lags for different "genetics" products, such as genomic tests versus more traditional phenotypic measurements, but this will depend greatly on the level of confidence breeders and commercial producers have in the products and at this level of aggregation it was decided to err on the conservative side and apply the same lag to all products.

On the demand side, the R&D lag was assumed to be the same as the supply side; the adoption lag was shorter as the two big drivers, meat quality programs and animal welfare, were already well entrenched in industry policies; and the adoption level was set at 5 per cent of the three major quality markets (Japan, Korea and the US) to reflect Australia's small share in total beef consumption in those markets.

The current/worst case scenario was then modelled over a 15 year time horizon and a 5 per cent discount rate to match as closely as possible the results from the Impact Tool. The models have quite different philosophies and different parameter inputs, but some small adjustments to the DREAM parameters were made to produce a similar balance in component areas as the fixed 15 year and 5 per cent scenario in the Impact Tool.

The most likely scenario (Table A4) reflects an improvement in the level of EBV accuracy to the targeted 40 per cent based on ongoing R&D and a consequent improvement in the use of EBVs and an improvement in the speed with which non-genetic technologies are adopted by industry.

The best case scenario (Table A4) reflects possible further improvements in potential TFP from the non-genetic portfolio and improvements in adoption levels.

Table A4. Assumptions for the DREAM analysis at the end of the funding period (given 2012 information)

Scenario and Component	Potential Total Factor Productivity (%)	R&D lag (years)	Adoption lag (years)	Maximum adoption level (%)
Current data/worst case				
Genetic Supply	4.0-2.5=1.5 (South=1.59; North=1.40)	7	5	35
Non-genetic Supply	3.50 (South=4.0; North=3.0)	5	4	20
Non-genetic Demand	1.00	5	2	5
Most likely case				
Genetic Supply	4.5-2.5=2.0 (South=2.12; North=1.88)	7	5	35
Non-genetic Supply	3.75 (South=4.28; North=3.24)	5	2	20
Non-genetic Demand	1.25	5	2	5
Best case				
Genetic Supply	4.5-2.5=2.0 (South=2.12; North=1.88)	7	5	40
Non-genetic Supply	4.00 (South=4.57; North=3.43)	5	2	25
Non-genetic Demand	1.50	5	2	5