CSIRO PUBLISHING

Animal Production Science, 2015, **55**, 133–144
http://dx.doi.org/10.1071/AN13351

Perspectives on Animal Biosciences

The value of research: using the *Impact Tool* to evaluate realised and anticipated benefits of the Cooperative Research Centre for Beef Genetic Technologies

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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 developed 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. In this paper we assess how well the third-term Beef CRC met its objectives, at the end of its funding period, using the *Impact Tool* software package developed by the CRC Program of the Commonwealth Government. The *Impact Tool* generates two commonly used measures of return on investment: the net present value (NPV) and the benefit : cost ratio (BCR). The NPV, the sum of discounted benefits minus the sum of discounted costs, was $233.2 m, when evaluated over the period 2005/06–2020/21. The BCR, the sum of discounted benefits divided by the sum of discounted costs, was 2.94, over the same period. Thus on both measures, investing in the Beef CRC is expected to have been profitable. We conclude by noting that the value of the *Impact Tool* is not only for ex-ante and ex-post evaluation of the impacts of particular technologies, but it also provides a very effective tool for RD&E project planning.

Keywords: Beef CRC, impact assessment, Impact Tool, return on investment.

Received 23 August 2013, accepted 27 May 2014, published online 23 September 2014

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 aimed to achieve an additional 1.5% p.a. in gross revenue of the Australian beef industry over 25 years to 2030 by developing new genetic and genomic technologies and non-genetic ‘products’ (practices, processes, tools and technologies) based on a combination of genetics and cattle management 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 (CRC for Cattle and Beef Quality 2004) were published in Griffith *et al*. (2006) and Griffith (2009*a*). Those analyses were based on a broad ‘top-down’ modelling approach, supported by detailed ‘bottom-up’ analyses of specific project areas. Subsequently, 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* (CRC 2013) 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 collates 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 *et al.* 2013) is to determine how well the third-term Beef CRC met its objectives at the end of its funding period. As 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 by the Beef CRC to evaluate its impact (CRC for Beef Genetic Technologies 2012).

First, several 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. The analyses were detailed investigations of how the individual products would be used in beef farming systems or in beef value chains. They could be termed 'on-the-ground' analyses.

Second, the Beef CRC used these product analyses as inputs into the *Impact Tool*, where they were aggregated and used to generate return on investment values. The Commonwealth Government requires the *Impact Tool* to be used as an overview of the outputs and outcomes from the CRC at the program level, and asks analysts to take a 'helicopter' view.

Third, after the winding up of the Beef CRC, 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 underpinning it, replacing the 2004 estimates. By its nature, it is an industry-wide view of the outcome of the whole CRC, and could be termed an 'airliner' view.

The second 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 measured by application of the *Impact Tool*. This analysis is then used as an input into the third level of evaluation, reported in Griffith *et al*. (2013). The paper concludes with some lessons learnt from working with the *Impact Tool*.

The Cooperative Research Centre (CRC) for Beef Genetic Technologies (2005–2012)

The CRC for Beef Genetic Technologies was a collaborative effort between 21 partner institutions from Australia, United States, Canada, New Zealand, Korea, Brazil, Ireland, France and South Africa. It commenced in 2005 and focussed on development of new genetic and genomic technologies to address beef industry priority issues to improve profitability, productivity, animal welfare and responsible resource use of Australian beef businesses (CRC for Cattle and Beef Quality 2004).

The Beef CRC employed emerging genetic technologies based on DNA sequence information to develop new tools and technologies to enable the Australian beef industry to:

- Improve the capacity to deliver high quality beef to Australia's 110 global markets using cattle of known genetic merit for exacting specifications, without compromising animal welfare or the environment;
- Enhance beef yield and herd reproductive efficiency, improve efficiency of resource use, reduce production costs, minimise methane emissions and avoid chemical and antibiotic residues through precise application of knowledge about the genes controlling these attributes in cattle, their rumen microorganisms and in parasites that affect cattle productivity; and
- Ensure Australia is the number one supplier of beef to meet the growing demand by neighbouring Asian countries to 2020.

Operationally, the Beef CRC was organised into the seven program areas listed in Table 1, together with the designated sets of activities undertaken to achieve the CRC's overall objectives. The research program areas were used as the basis for budget allocations, project reporting and operational planning. The cash inputs to each of these seven programs were used as inputs to the *Impact Tool*.

CRC products

To meet the additional input needs of the *Impact Tool*, which has a focus on the use of specific outputs to create outcomes and hence impacts, another way of reporting on CRC achievements was needed. Thus all of the individual planned outputs from the RD&E were grouped into 17 'products' summarised in Table 2. Some of these products were closely related to a very specific set of activities in a particular research program. For example, one of the products is a DNA test for the polled gene in Australian beef cattle breeds, while another is a set of candidate antigens for a vaccine to control cattle ticks. Both of these products were derived from specific project areas. Other products however are an aggregation of outputs from a range of activities across several research programs. For example, one of the products is a set of genomic prediction equations for growth, feed efficiency, carcass and beef quality and reproductive performance. This product encompasses 12 separate outputs across four different research programs.

The *Impact Tool*

The *Impact Tool* aims to identify the potential impact of a funding proposal, or the realised and anticipated impacts from existing funding, by articulating the process by which research leads to impacts on the end-user and/or the broader community. The Cooperative Research Centres Association developed the initial version of the tool in 2007 and published a comprehensive discussion paper on the rationale behind impact evaluation modelling, together with some worked examples (CRC Association 2007). Recently, the CRC Program assumed responsibility and upgraded the tool (CRC 2013). One of the objectives of mandating the use of the *Impact Tool* is that a common framework is available to enable direct comparisons of multiple CRCs across diverse industries and discipline areas.

The *Impact Tool* uses an input-to-impact chain model involving a systematic grouping of different types of information. Fig. 1 is derived from the *Impact Tool User Guide* of the CRC Program Guidelines (CRC 2013) and sets out a schematic of the input to impact chain model. Several alternative documents have been made available, by a range of state government agencies, to provide guidance on how the *Impact Tool* should be used (e.g. Government of Victoria 2013).

The *Impact Tool* software is written in Excel format and when first downloaded comes as a generic template. The user is required to specify the form of the template that suits their particular CRC. Embedded macros then format the *Impact Tool* to that specification. Thus, specifying seven research programs as in the Beef CRC results in seven sets of input, activity, output, usage and impact tables. For each of the seven programs the user is required to populate the relevant tables with the financial value of the resources used, the activities undertaken, the various outputs produced and so on. There is also an overview tab generated at the front that has seven tables like Fig. 1 which summarises the information for each program. The model requires costs and outputs to be specified annually over a 10-year period, usage to be specified over a 12-year period

Table 1. Beef CRC programs and designated activities

Research Program 1 High Quality Beef for Global Consumers	Research Program 2 Feed Efficiency, Maternal Productivity and Responsible Resource Use	Research Program 3 Adaptation and Cattle Welfare	Research Program 4 Female Reproductive Performance	Research Program 5 Education and Training	Research Program 6 Administration, Commercialisation and Business Development	Research Program 7 Underpinning Science
Design, execute and analyse experiments aimed at increased biological understanding of aspects of beef quality such as tenderness, retail yield, muscling and marbling, or of the mechanisms by which genes associated with these traits are expressed or inhibited through environmental interventions. Develop, validate and field test accurate and commercially useful models and tools to enable an increased rate of compliance with market specifications and associated improvements in profitability. Work in partnership with several value chains to create value by analysing existing slaughter and production data, and testing and verifying the phenotypic prediction models in commercial situations.	Design, execute and analyse experiments aimed at increased biological understanding of the determinants of improved feed efficiency and its relationships with various aspects of beef quality and animal growth, and of the mechanisms by which genes associated with efficiency traits are expressed or inhibited through environmental interventions. Design, execute and analyse experiments aimed at increased understanding of the relationships between selection for feed efficiency and end-product traits, such as retail yield, fatness and breeder herd productivity. Develop strategies to simultaneously increase the capture of dietary energy and reduce methane emissions by cattle.	Design, execute and analyse experiments to better understand the host mechanisms associated with resistance of cattle to the cattle tick and susceptibility in divergent breeds of cattle; screen available tick genome sequences to identify immunogenic vaccine candidates; and conduct 'proof of concept' cattle trials of the most promising candidates. Design, execute and analyse experiments to better understand the mechanisms by which genes associated with stress responses are expressed or inhibited through environmental interventions and assess whether there is any additional value in using gene expression with the traditional measures of cattle welfare. Develop genetic marker tests for the polled gene in tropical beef cattle.	Design, execute and analyse experiments aimed at increased biological understanding of the genes and gene networks associated with lactating cows resuming reproductive activity after calving that may be expressed or inhibited through environmental interventions. Design, execute and analyse experiments aimed at identifying pre- or post-pubertal male traits that are early-life predictors of the male's own fertility and the reproductive performance of the bull's progeny. Design, execute and analyse experiments aimed at identifying female traits that are early-life predictors of lifetime reproductive performance of breeding cows in northern Australian beef herds.	Deliver a more skilled beef industry workforce through postgraduate, undergraduate and vocational training in the sciences underpinning beef genetic improvement and effective innovation, commercialisation and adoption of outputs to generate beef industry outcomes. Develop and deliver a set of information packages related to new research results, tools and technologies to facilitate implementation and make beef businesses aware of these packages, tools and technologies so that they lead to positive impacts on productivity and profitability of beef businesses. Design, execute and analyse a pilot of an accelerated adoption process to speed up implementation of new research results, tools and technologies by industry.	Efficiently and effectively administer the resources at the disposal of the CRC to achieve the stated objectives. Establish an identified brand for the CRC and a set of strong internal and external networks through which the CRC can disseminate its messages to improve the productivity and profitability of the Australian beef industry and its stakeholders. Establish processes for the identification, protection and management of Intellectual Property generated by the CRC and its partners where appropriate. Establish and implement a framework or 'path to adoption' for the commercialisation of new research results, tools and technologies developed by the CRC.	Coordinate all gene discovery and gene expression research activities across Programs 1–4 to develop DNA-based tests that predict the breeding values of cattle for economically important traits. Provide support for the experiments being conducted by other research programs, including maintaining the CRC's database of phenotypic animal records and DNA collection; designing and analysing gene discovery and gene expression experiments; and coordinating bioinformatics support across all programs.

Table 2. Product use and key end-users of Beef CRC products
P1, probability that all required outputs are produced to enable this usage. P2, probability of usage given required outputs have been generated

Product	Product use	Key end-users and probabilities of delivery and use occurring as planned
Genomic prediction equations for growth, feed efficiency, carcass and beef quality and reproductive performance.	DNA-based (genomic) prediction equations for economically important traits provide beef businesses with a simple and cost-effective method of identifying animals best suited for breeding purposes. In the near future, it is likely the predictions will also be used to best manage commercial cattle to meet market specifications and improve reproductive performance of commercial cattle herds.	35% of commercial beef producers start purchasing BREEDPLAN registered superior bulls with gEBVs of greater than 30% accuracy in 2013/14. Their progeny are available for sale in 2016/17. P1 = 95; P2 = 92 (average across several traits).
DNA markers in Meat Standards Australia.	Costs of DNA testing individual animals are still too expensive for commercial use. However CRC results provide 'proof of concept' that DNA markers can improve MSA compliance rates as soon as testing becomes cost-effective.	DNA markers will be incorporated into the existing MSA model and will be used in the same way as other new or improved input data. Usage and impact are measured through ongoing evaluations of the MSA program.
Marker-enhanced EBVs for economically important traits.	Genetic parameters for traits associated with beef tenderness and DNA markers for tenderness were estimated and included in a new method to calculate marker-enhanced BREEDPLAN EBVs in 2008. The method has subsequently been adapted for other traits to increase the rates of genetic gain in seedstock herds.	DNA markers will be incorporated into the existing EBV model and will be used in the same way as other new or improved input data. Usage and impact are measured through ongoing evaluations of BREEDPLAN.
Poll gene marker.	Beef CRC commercialised a diagnostic DNA test to differentiate polled animals used for breeding that carry one (heterozygous) or two (homozygous) copies of the favourable polled marker to enable industry to more rapidly transition to a genetically polled herd.	10 000 bulls will be tested annually within 5 years of release in 2010/11. P1 = 100; P2 = 100 (already adopted).
SNP discovery from sequencing.	Beef CRC sequenced the genomes of Brahman, Africander and Tuli bulls to discover novel SNPs for use in high-density SNP panels released by Illumina and Affymetrix in 2011. These breeds were selected to ensure the new commercial panels included SNPs from tropically adapted cattle relevant to northern Australia.	Any DNA markers found from the SNP discovery will be incorporated into the existing EBV model and will be used in the same way as other new or improved input data. Usage and impact are measured through ongoing evaluations of BREEDPLAN.
Genetic parameters for use in BREEDPLAN.	The CRC's genetic parameters for carcass and beef quality, feed efficiency and male and female reproductive traits are being used to directly improve these traits through selection on BREEDPLAN EBVs to significantly increase genetic gains and improve productivity in seedstock and commercial herds across Australia.	35% of commercial beef producers start purchasing BREEDPLAN registered superior bulls with higher accuracy due to more trait measurement in 2013/14. Their progeny are available for sale in 2016/17. P1 = 93; P2 = 90 (average across several traits).
Genetic and management tools to improve compliance rates and reproductive performance.	CRC results have been packaged to enable: (i) beef producers and feedlotters to balance growth rates of animals against costs to maximise compliance with market specifications; (ii) southern Australian beef producers to best target markets using combinations of genetics and management strategies; and (iii) beef producers across Australia to improve the reproductive performance of their herds.	250 000 breeding cows in the South, and 250 000 steers in the South, 5 years after release of packages in 2009/10. P1 = 100; P2 = 90 (average across several packages).
'*BeefSpecs*' calculator to increase compliance rates for grass- and grain-finished animals and to predict breeding cow herd performance.	'*BeefSpecs*' helps commercial beef producers predict weight and fat specifications of animals for store and premium markets to increase compliance rates for fatness and weight targets. The *BeefSpecs* optimisation model is customised for the feedlot sector and optimises feed and resource use relative to market specifications and return on investment across the supply chain to most profitably meet market specifications. The maternal model predicts cow herd performance and the trade-offs needed in steer performance to optimise profitability and productivity of cow-calf herds in temperate production environments. Ongoing research beyond the Beef CRC term will extend the maternal model for use in (sub) tropical systems.	1 million steers assessed annually 5 years after release of simple model in 2008/09; 400 000 steers and heifers from large producers assessed annually 5 years after release of on-farm drafting model in 2013/13; 400 000 animals in feedlots assessed annually 5 years after release of the optimisation model in 2012/13; and 30% of southern breeding herd assessed 5 years after release of the maternal model in 2013/14. P1 = 87; P2 = 85 (average across all models).

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Table 2. (*continued*)

Product	Product use	Key end-users and probabilities of delivery and use occurring as planned
Tick vaccine candidates.	Beef CRC has discovered and evaluated 14 tick vaccine candidates (antigens/peptides) for potential use in developing a commercial vaccine to control cattle ticks in Australia and internationally. Ongoing research beyond June 2012 is required to evaluate the candidates in different combinations and to deliver a commercial cattle tick vaccine.	It is expected that the potential candidate vaccines will be licenced to a commercial animal health company, who will then develop and market a vaccine. It is expected that the licence agreement will be signed in 2013/14. P1 = 95; P2 = 100.
Test for acaricide resistance.	The Beef CRC developed a simple diagnostic tool that is being used to identify ticks that are resistant to synthetic pyrethroids (a class of chemicals used to control cattle ticks).	Primary users are tick regulatory authorities in Northern Australia.
Candidates for pro-biotic drenches and management strategies to reduce methane emissions in cattle.	The CRC has discovered candidate protein targets and microbes for potential use in live microbial and/or bio-active products that restrict methane emissions by rumen microbes and maintain desirable levels of feed digestion. Once developed through further research, these candidates could be administered to cattle as a drench or a feed additive.	It is considered likely that the candidate products would be licenced to a commercial animal health company, who will then develop and market the products. However due to the uncertainty of this path to market, no usage or impacts were calculated.
Objective measures of cattle welfare.	The CRC's cattle welfare results underpin new voluntary or mandatory animal welfare protocols, standards and guidelines.	The Beef CRC's objective measures of cattle welfare are being used by beef producers across Australia.P1 = 90; P2 = 90.
Understanding and managing the welfare impacts of dehorning.	Ultimately beef producers will breed polled cattle to eliminate the need for dehorning. However some dehorning is required during the transition to a polled herd. The Beef CRC developed recommendations to minimise the impact of dehorning on cattle and they have been incorporated in new draft national welfare standards and guidelines for cattle.	600 000 calves dehorned in 2012/13 and thereafter in Northern Australia. P1 = 90; P2 = 90.
Beef Profit Partnerships.	A system of partnerships between beef businesses, value chains and the broader beef industry designed to accelerate improvements, innovations and adoption for sustainable and quantifiable impact on business profit.	5% of the beef producers in Qld, NSW, VIC and WA by 2016/17. P1 = 100; P2 = 100.
Training materials and resources to create a more skilled beef industry workforce (including *Livestock Library* and publications).	Beef CRC's educational and training materials are freely available online and have been widely distributed to extension specialists and consultants across Australia to underpin ongoing industry delivery activities to improve profitability and productivity of Australian beef enterprises.	No attempt was made to calculate usage or impact.
38 PhD and 4 MSc graduates across a very broad range of sciences impacting on the Australian beef industry.	More skilled beef industry workforce across all sectors of the Australian beef industry. More than 70% of these graduates have been retained directly in the Australian beef industry and more than 80% have been retained in the agricultural sector more broadly.	No attempt was made to calculate usage or impact.
Comprehensive beef cattle databases.	These databases play a critical role in Australia's BREEPDLAN and Meat Standards Australia schemes and are also essential for ongoing bovine genomics research.	No attempt was made to calculate usage or impact.

and impacts to be specified over a 15-year period. So starting at 2005/06, costs and outputs can be measured up to 2015/16, usage to 2017/18 and impacts to 2020/21. Wherever monetary values are inserted, the program automatically adds them over the relevant time frame and then discounts them at a standard rate (5%).

From the output and subsequent tabs, more specific detail is required on what is produced, how it is used and how it is valued. So the 17 separate CRC products described in Table 2 are allocated across the seven research programs. However as some products are combinations of outputs from several programs, and some products have different versions for different purposes, 28 separate outputs were specified (5, 3, 3, 2, 9, 1, 5 across programs 1–7 respectively). In this analysis each of these products had a separate usage and a separate impact to ensure nothing was missed. However, when specifying the *Impact Tool* it is possible for particular products to have multiple uses and multiple impacts, and vice versa.

For each product, the usage tab requires a description and justification of the expected annual adoption over a 12-year period, an estimate of any additional annual costs that users would have to incur for further refinement or application of the

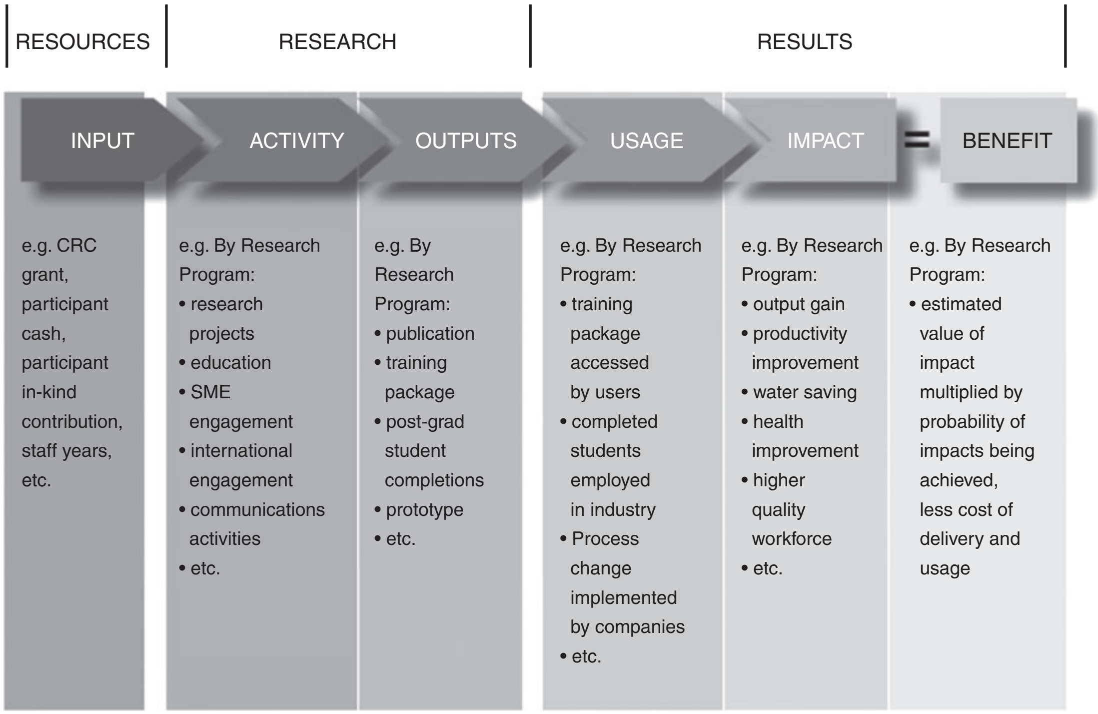

Fig. 1. The inputs to impact chain (Source: CRC Program 2013).

output, and estimates of the probability that the output would in fact be produced as planned and of the probability that usage will occur as anticipated. This is where knowledge of industry systems and institutions is important and where detailed studies of the new tools and technologies in the farm or value chain business are crucial.

Next, and again for each product, the impact tab requires a description and justification of the expected annual monetary benefit over a 15-year period, usually a per unit benefit multiplied by the usage numbers estimated earlier, and estimates of the probability that the usage and monetary impacts would occur as planned. Again, access to detailed studies of the implementation of new tools and technologies in the farm or value chain business are crucial. At the end of each program section in the impact tab, non-monetary impacts also can be specified.

A further section requires that the key risks which might prevent the outputs, usage and impacts occurring as anticipated are described. This is followed by the benefit: cost analysis tab where for each program the sum of the discounted benefit stream for all of the products specified in that program are set against the sum of the discounted R&D and usage costs for that program to generate a program specific benefit : cost ratio (BCR). Benefits and costs across all programs are then added to generate a whole of CRC BCR.

There is one final section called ‘additional information’ where detailed calculations for a specific product or products can be shown, and where relevant references can be cited.

Therefore what is being measured (and the type of data required) will depend on the life-cycle stage at which it is used. When it is used as part of an exit report at the end of the funding period, real data that have accrued over the life of the CRC will be used, together with projected data for the remainder of the 15-year period.

Many of the expected economic benefits from the Beef CRC’s third term were generally still to be realised at the end of the funding period (2011/12) as many of the products were still being delivered. These anticipated impacts were therefore assessed using estimates of production levels and costs and prices (at regional level where appropriate) derived from published analyses relating to each CRC product, with projections of future usage levels. The *User Guide* stresses the notion that the process is more important than the results: ‘The intent of the *Impact Tool* is not to generate precise estimates of all CRC costs and benefits, but rather to assist the consideration of the potential costs and benefits in a systematic way and to enable key issues that impact upon the potential projected value to be consistently addressed.’ (CRC 2013, p. 4).

Economic benefits of the Beef CRC outputs

That said, the best estimates of the usage and key endusers of each of the CRC’s products are reported in Table 2, and the best estimates of the per unit and aggregate monetary impacts of each of the CRC’s products are reported in Table 3. A listing of potential non-monetary impacts is given later.

A summary of the economic benefits of the Beef CRC, as measured by application of the *Impact Tool*, is provided in Table 4. The estimates come from the benefit: cost analysis tab where for each program, the sum of the discounted benefit stream for all of the products specified in that program is set against the sum of the discounted R&D and usage costs for that program to generate a program-specific BCR. Benefits

Table 3. Economic impacts of Beef CRC products

Product	Per unit impacts, and probabilities of impact occurring as planned	Economic impact
Genomic prediction equations for growth, feed efficiency, carcass and beef quality and reproductive performance.	Value of increased rates of genetic progress in the commercial beef herd due to incorporation of genomics information into EBVs. Raw data from Banks (2012). Specific assumptions in Griffith (2012*b*). Additional benefits estimated as $0.39/cow.year from 2016/17. P3 = 87.5; P4 = 90.	Only 4 years of benefits with an expected NPV of $12.4 m can be counted in the *Impact Tool*. Most genetic benefits derived from the CRC's genomic prediction equations will accrue beyond 2020, with the *non-discounted* sum of genetic improvement set in train by the Beef CRC accruing between 2020 and 2030 being $251 m.
DNA markers in Meat Standards Australia.	No separate impact measured.	The economic impact of use of DNA markers in MSA will accrue through improved compliance with MSA standards (and hence be measured through ongoing evaluations of MSA).
Marker-enhanced EBVs for economically important traits.	No separate impact measured.	The economic impact of the CRC's new method to integrate DNA marker information and BREEDPLAN EBVs accrues through use of DNA markers associated with complex traits. No attempt was made to independently quantify the impact of this new method.
Poll gene marker.	Use of the poll gene marker test on 10 000 bulls 5 years after industry release will reduce the number of horned calves by ~30 0000 head, saving $560 000 p.a. in dehorning costs, based on an estimate of $1.85 per head from Prayaga (2005). P3 = 100; P4 = 95.	Expected NPV is $2.2 m. However the greatest benefit of this test accrues through improved animal welfare and maintaining market access threatened by animal welfare concerns.
SNP discovery from sequencing.	No separate impact measured.	The economic impact of the SNP discovery from sequencing accrues through use of DNA markers associated with complex traits.
Genetic parameters for use in BREEDPLAN.	Value of increased rates of genetic progress in the commercial beef herd due to more trait measurement. Raw data from Banks (2012). Specific assumptions in Griffith (2012*b*). Additional benefits estimated as $0.33/cow.year from 2016/17, and $7/AE for Northern reproductive traits (Fordyce *et al*. 2012). P3 = 90; P4 = 92.	Only 4 years of benefits (independent of those derived from genomic selection) with an expected NPV of $16.2 m can be counted in the *Impact Tool*. Most genetic benefits derived from the CRC's more accurate trait measurement will accrue beyond 2020, with the *non-discounted* sum of genetic improvement set in train by the Beef CRC accruing between 2020 and 2030 being $101.5 m
Genetic and management tools to improve compliance rates and reproductive performance.	20% improved compliance with MSA specifications (Griffith and Thompson 2012); $10/cow increased profit due to improved reproduction rate in the north (Alford *et al*. 2007); $20/cow and $20/steer increased profit from improved maternal and nutritional management (Griffith 2009*b*; Deland 2011). P3 = 90; P4 = 87.	• Increased compliance with MSA specifications: expected NPV $15.8 m• Improved maternal management in southern Australia: expected NPV $14.1 m.• Improved weaning rates in commercial northern herds: expected NPV $20.3 m.• New genetic and management tools to make better breeding and management decisions, excluding the *BeefSpecs* models: expected NPV $46.2 m.
'*BeefSpecs*' calculator to increase compliance rates for grass- and grain-finished animals and to predict breeding cow herd performance.	Estimated saving in the cost of non-compliance calculated as a net $10/head for pasture fed cattle (Slack-Smith *et al*. 2009) and $35/head for feedlot cattle (McKiernan 2011). P3 = 74; P4 = 92.	The different versions of the '*BeefSpecs*' tool will significantly reduce non-compliance rates in commercial herds across Australia and improve weaning rates in commercial herds in southern Australia. Total expected NPV is $74.8 m.
Tick vaccine candidates.	The payment for the licence will be a lump sum up front and then a royalty stream based on wholesale sales revenue. P3 = 95; P4 = 90.	The impact measured is the royalty stream that a commercial company will pay to the CRC partners based on a proportion of future wholesale sales revenue. The expected NPV is $1.3 m.
Test for acaricide resistance.	Benefits accrue through reduced costs of more effective chemical treatments, improved regulatory control and maintaining market access under threat due to inappropriate acaricide use in tick-endemic areas.	No attempt was made to quantify the economic impact of the test.

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Table 3. (*continued*)

Product	Per unit impacts, and probabilities of impact occurring as planned	Economic impact
Candidates for pro-biotic drenches and management strategies to reduce methane emissions in cattle.	No economic benefits were calculated for the candidate protein targets and microbes. However there is an additional benefit from reductions in methane emissions due to breeding more efficient cattle. This is calculated from Alford *et al*. (2006) being a value of $4.75/cow.year over 10% of the southern breeding herd 5 years after release of the new EBVs in 2013/14. P3 = 85; P4 = 90.	There is an additional expected NPV of $4.8 m from reductions in methane emissions.
Objective measures of cattle welfare.	The use of the new animal welfare guidelines will improve access to high value export markets. This is assumed to be a 1% increase in willingness to pay by consumers in these markets for Australian product. P3 = 81; P4 = 90.	It has an expected NPV of $79.6 m.
Understanding and managing the welfare impacts of dehorning.	The cost of labour for de-horning calves is $0.17–$0.33 per head. The value from reduced mortalities due to de-horning is $1.70 per weaner (Prayaga 2005) It is assumed that 20% of Northern calf producers will save half the cost of mortality from adopting these improved practices. P3 = 81; P4 = 90.	The total value to Queensland alone from not having to de-horn calves is ~$3.5 m per annum. The use of better management practices for de-horning procedures on 600 000 calves p.a. has an expected NPV of $2.1 m.
Beef Profit Partnerships.	The benefit from being a member of a BPP is calculated as the difference in farm business profit/head between BPP members and specialist beef producers in the same region as measured from ABARES farm survey data. Analysis is reported in Griffith (2012*a*). P3 = 100; P4 = 95	The aggregate value to November 2011 flowing from the BPP network in Australia (i.e. excluding the BPPs in New Zealand and South Africa) is $28.76 m. The NPV estimated through to 2020 is $63.5 m.
Training materials and resources to create a more skilled beef industry workforce (including *Livestock Library* and publications).	No attempt was made to calculate usage or impact.	No attempt was made to quantify the aggregate economic benefits derived from a more skilled beef industry workforce.
38 PhD and 4 MSc graduates across a very broad range of sciences impacting on the Australian beef industry.	No attempt was made to calculate usage or impact.	No attempt was made to derive the aggregate economic impact of these additional graduates, many of whom won prestigious national and international awards during their CRC training periods.
Comprehensive beef cattle databases.	No attempt was made to calculate usage or impact.	Benefits from these comprehensive beef cattle databases are mainly for ongoing research.

Table 4. Return on investment metrics by program and whole-of-CRC as determined by the *Impact Tool*, 2005/06–2020/21

Program	Discounted costs $m	Discounted benefits $m	NPV $m	BCR
1	28.5	106.8	78.3	3.74
2	30.0	18.9	−11.1	0.63
3	15.1	85.1	70.0	5.64
4	22.6	20.3	−2.3	0.90
5	9.8	109.6	99.8	11.21
6	14.1	0	−14.1	0.00
7	0.0	12.4	12.4	0.00
Whole CRC	**119.9**	**353.1**	**233.2**	**2.94**

and costs across all programs are then added to generate a whole-of-CRC BCR over 15 years, starting at the first year of RD&E investment.

Behind these aggregate numbers lie detailed calculations that rely on the information provided in Tables 2 and 3. Let us take as an example the first product listed in Tables 2 and 3, the development of genomic prediction equations.

What we have to measure is the value of increased rates of genetic progress in the commercial beef herd due to incorporation of the new genomics information into EBVs. The base model comes from Banks (2012). This is a spreadsheet that maps historical and expected future rates of genetic progress in the Australian beef herd, weighted by breed types and markets, as valued by BreedObject (Barwick and Henzell 1998). Account is taken of the proportion of cows mated to BREEDPLAN registered bulls and the generation interval for cattle. Specific assumptions are then made about the influence of the genomic prediction equations on EBV accuracy and therefore on the nature and timing of changes in the rate of genetic progress. Given the information available in June 2012, we estimated that the rate of genetic progress would increase by \$0.39/cow/year from 2016/17 to 2030/31 (Griffith 2012*b*). The relevant annual benefits were then transferred to the *Impact Tool*, where they are discounted, summed up to 2020/21 to give present values, and finally multiplied by the relevant probabilities (P3 = 87.5; P4 = 90). The net result is a net present value (NPV) of \$12.4 million for the 4 years 2016/17–2020/21. This is the figure which appears in the right hand column of the first row of Table 3 and in the second last row of Table 4 against Program 7 benefits.

Thus, across all of the program areas, some \$120 m (in 2005/06 dollars) was expected to be spent, either on the RD&E over the 7 years to 2011/12, or on extra costs expected to be incurred by users of the CRC products up until 2020/21. User costs might include the costs of DNA tests by individual producers or the costs of software packages such as the expanded versions of *BeefSpecs* (McKiernan 2011). Some \$353 m of economic benefits (in 2005/06 dollars) were expected to be generated by using the CRC products up until 2020/21. These benefits included better compliance to market specifications, better rates of genetic gain, better nutrition, better management, etc, as detailed for each product in Tables 2 and 3.

Two commonly used measures of return on investment are the NPV and the BCR. The NPV is defined as the sum of discounted benefits minus the sum of discounted costs, or \$353.1 m–\$119.9 m = \$233.2 m, evaluated over the period 2005/06–2020/21. Thus this investment, as measured by the *Impact Tool*, is expected to return a surplus of \$233 m to the Australian beef industry over this period. The BCR is the sum of discounted benefits divided by the sum of discounted costs, or \$353.1 m/\$119.9 m = 2.94. Thus this investment is expected to return almost \$3 for every \$1 invested over the period 2005/06–2020/21. On both measures, investing in the Beef CRC is expected to have been profitable, and according to the *User Guide*, the calculated BCR fits very comfortably with the expectations of the Commonwealth Government for the net returns from CRCs.

The pattern of NPV and BCR across the seven programs is quite varied. This partly reflects the way the programs were initially set up and funded compared with the way the individual products were subsequently allocated to program areas. For example, program 6 (administration) incurred \$14.1 m in discounted costs over the period 2005/06–2011/12 but had no outputs set against it. Conversely, program 7 (underpinning science) was set up mid-way through the CRC when the genomics technology that was the cornerstone of our RD&E strategy changed radically following the availability of the bovine genome sequence in 2005/06. It had no costs explicitly set against it but it was the home for most of the genomic products, valued at \$12.4 m over the period 2005/06–2020/21. Further, programs 1 and 5 captured the benefits of some of the expenditure undertaken in programs 2 and 4 in relation to new and improved genetic parameters (program 1) and improved management tools and practices (program 5). Finally, the fact that program 5 generated a relatively large proportion of the benefits reflects the types of tools and technologies developed there compared with other programs. Most of the management tools and practices sitting in program 5 were already adopted by the cessation of funding, or were expected to be adopted in the near future, so there were quite a few years of realised or anticipated benefits able to be counted in the *Impact Tool*. However genetic technologies residing in programs 1 and 7 are slower to become available and accumulate gradually over time, so there are only a few years of realised or anticipated benefits able to be counted and the change in genetic gain is very small in those early years.

Non-economic benefits of Beef CRC outputs

It was not possible to calculate a financial value of many of the Beef CRC's outputs. For example, the value of an outcome such as 'improved animal welfare', depends on the preferences of both Australian and foreign consumers in a wide range of export markets who demand that animals be treated with utmost care, that their production environments remain 'natural', and that livestock remain 'clean and green'. Little research in these areas has been done in Australia, so these types of benefits were classified as non-economic when completing the *Impact Tool*.

Similarly, the value of animal science education to the Australian economy is not readily quantifiable, although clear evidence exists that ongoing improvements in productivity are affected by levels of basic education and levels of continuous employee development. Over 40 post-graduate students were trained over the time period of the Beef CRC, with the majority being retained in Australia and in the livestock sector. As well, the CRC's undergraduate and vocational training programs have provided enhanced technical and human capacity in industry and the wider economy.

Hence, in addition to the direct economic benefits accruing from the use of Beef CRC products, significant additional social, environmental and animal welfare benefits have accrued as a result of research outputs from the Beef CRC, including:

Social benefits

- Unique ability to guarantee the eating quality and food safety of beef, thereby increasing consumer confidence in Australian beef products;
- Improved on-farm and abattoir best practice to reduce pathogen loads on beef carcasses, increasing consumer confidence in beef safety;
- More skilled beef industry workforce across rural and regional Australia; and
- Increased commitment, loyalty and trust across beef value chain sectors arising from the collaborations forged through all three Beef CRC terms.

Environmental benefits

- Reduced methane emissions per kg of beef product arising from improved productivity of beef businesses and reduced feed requirements through improved feed efficiency;
- Confidence by consumers that Beef CRC products have been extensively developed and validated under Australian beef production systems and are therefore sustainable for Australian environments;

- Improved use of the pasture resource base through improved feed efficiency and reproduction; and
- Reduced chemical use in cattle production systems, reducing the risk of environmental contamination.

Animal welfare benefits

- New cattle welfare standards and guidelines underpinned by cattle welfare studies;
- Improved production, transport and pre-slaughter lairage systems designed to improve cattle welfare; and
- More resilient cattle through reduced stress and improved behaviour.

The outcomes and impacts achieved by the Beef CRC also resulted in several prestigious national and international awards, including (i) three separate Eureka Awards for Bioinformatics, Animal Welfare and Interdisciplinary Research; (ii) two CRC Association national Awards for Excellence in Innovation; and (iii) the International Meat Secretariat Millenium Prize for Meat Science and Technology.

Conclusions

The Beef CRC operated for its third successive 7-year term from July 2005 to June 2012. Some $120 m (in 2005/06 dollars) was spent in trying to achieve its objectives. Now that the funding period has ceased this analysis aims to determine whether this money was well spent.

It does this using the *Impact Tool*, which evaluates the impact of all the outputs relative to the input costs (cash and staff and non-staff in-kind contributions over the 7-year term of the CRC plus industry implementation costs), to estimate an overall BCR of the CRC over a 15-year time horizon. Based on several detailed economic analyses, estimates were made of economic benefits for most of the CRC's 17 separate 'products', as summarised in Table 2 above. Some of these benefits have already been realised, however most of the benefits are those anticipated to accumulate over the next 7–8 years. The NPV, the sum of discounted benefits minus the sum of discounted costs, was estimated to be $233.2 m, while the BCR, the sum of discounted benefits divided by the sum of discounted costs, was estimated to be 2.94, both measures evaluated over the period 2005/06–2020/21. Thus on both measures, investing in the Beef CRC has been profitable.

In using the *Impact Tool*, several lessons have been learnt. First, the *Impact Tool* is an excellent vehicle for forcing the applicants for CRC funding, and then the managers of the expenditure if funding is secured, to have an explicit focus on achieving outcomes and impacts. While such a focus is mandatory within CRCs, and was always a priority within the Beef CRC, it is not a widely held view externally (Griffith 2008). We argue that the *Impact Tool* could have a wider role in RD&E funding and management more generally, such as in state and other federal government agencies, universities and other research organisations and in the rural industries' RD&E corporations.

Second, using the *Impact Tool* for annual monitoring of progress against planned milestones provides an objective and effective mechanism for realigning the RD&E portfolio if that is required due to changing circumstances. The Beef CRC set very ambitious targets from the outset and we were very serious about managing the RD&E portfolio to try to achieve those targets. When the genomics technology that was the cornerstone of our RD&E strategy changed radically with the availability of the bovine genome sequence and associated new technologies in 2005/06 (see Goddard and Hayes 2009; Goddard 2010), the focus on achieving outcomes and impacts that is embedded in the *Impact Tool* allowed a rapid and effective realignment of the portfolio.

Third, the detail on per unit net benefits and on user numbers over time required to populate the *Impact Tool* provides explicit guidance on the variables that have to be measured and monitored over the life of the CRC and beyond, on the type of detailed economic evaluations that have to be done at the product level, and on the modelling frameworks that have to be used to support the targets and the measures of success.

However, using the *Impact Tool* is not always straightforward. First, one of the objectives of the CRC program in mandating the use of the *Impact Tool* is that a common framework was available to enable direct comparisons of multiple CRCs across diverse industries and discipline areas. Thus, 'one size fits all'. However many of the agricultural CRCs are disadvantaged by this, especially those where investment in genetic improvement is a key aspect of the RD&E portfolio. The primary focus of the Beef CRC was new genetics and genomics technologies in beef cattle. Genetic improvement is a long and slow process, gradually accumulating over time. Due to the long generation intervals in cattle (~5 years), most genetic benefits accrue beyond a 15-year timeframe.

Second, the *Impact Tool* is essentially an accounting framework rather than an economic framework. Costs and benefits are described and quantified where possible, and discounting is used to bring all monetary values to a common point in time, but there is no mechanism in the *Impact Tool* for economic incentives to trigger responses by producers or consumers. Depending on the industry and the time frame under consideration, this may mean a significant set of benefits are not counted in the *Impact Tool.* If the user wishes to properly account for these extra benefits, additional analyses have to be done either before data are entered, or preferably, afterwards. Additional analyses also have to be done if the analyst is interested in the distribution of benefits across segments of the value chain, including consumers domestically and in export markets, or across different production regions.

Finally, the *Impact Tool* makes no attempt to examine the 'with-CRC' scenario relative to a 'without-CRC' scenario: what would have the investment been and what would have the outcomes and impacts been if the CRC had not been funded? This is especially relevant to this CRC as much of the new and improved genetic information available from the CRC's RD&E would be implemented via existing industry schemes such as BREEDPLAN to ensure easier use and greater understanding by industry about how best to apply the new technologies to achieve value. While this makes adoption easier, it creates potential difficulties in properly attributing changes in rates of genetic progress to CRC investment or to other past or new investments outside of the CRC.

However, if a multi-pronged approach to impact assessment is envisaged, these disadvantages can be overcome. In particular, the *Impact Tool* provides many of the inputs and assumptions on each of the CRC's products necessary for a third, more aggregate but more economic, level of evaluation. That third level uses the DREAM benefit: cost analysis program (Wood *et al.* 2001) to provide a direct assessment of progress towards the CRC's overall targeted outcome as recorded in the Commonwealth Agreement. It evaluates the CRC's realised and potential impacts over a 25-year timeframe, which is more appropriate for beef genetic technologies. In addition to domestic industry benefits, it also includes wider benefits such as those achieved by export markets and consumers and enables a 'with-CRC' and 'without-CRC' comparison to be made. Application of this framework is reported in Griffith *et al*. (2013).

In summary, in our experience, the value of the *Impact Tool* is not only for ex-ante and ex-post-evaluation of the impacts of particular technologies, but it also provides a very effective tool for RD&E project planning. By way of example, we have found that investing in learning and using the *Impact Tool*:

- Ensures the products or outputs of the proposed research are clearly identified and targeted in all planning from the outset;
- Enables development of a clear 'path to adoption' for every product on a customised product-by-product basis, including clearly defined end-users and an understanding of how those users will use or adapt the product for use in their own businesses;
- Provides guidance and a 'reality check' on the effectiveness of the proposed and alternative commercialisation models for each product;
- Ensures the costs of implementation of research results in commercial businesses are not overlooked or inadvertently ignored;
- Provides a mechanism so that the probabilities of success and adoption are challenged and cross-checked for accuracy, providing an additional 'reality check' on individual components of the entire commercialisation and adoption processes for each product; and
- Allows effective evaluation of alternative research strategies when developing new RD&E project proposals, in both developed and developing countries.

References

Alford AR, Hegarty RS, Parnell PF, Cacho OJ, Herd RM, Griffith GR (2006) The impact of breeding to reduce residual feed intake on enteric methane emissions from the Australian beef industry *Australian Journal of Experimental Agriculture – ASAP Special Edition* **46**, 1–9.

Alford A, Cafe L, Greenwood P, Griffith GR (2007) The economic effects of early-life nutritional constraints in crossbred cattle bred on the NSW North Coast. Economic Research Report No. 33. NSW Department of Primary Industries, Armidale, NSW. Available at: http://www.dpic.nsw.gov.au/research/economics-research/reports/err33

Banks R (2012) MLA spreadsheet of genetic gain by breed and market segment. Unpublished data, March.

Barwick SA, Henzell AL (1998) BreedObject: breeding objective and indexing software for beef breeding. *Proceedings of the 6th World Congress on Genetics Applied to Livestock Production* **27**, 445–446.

Cooperative Research Centre (2013) Impact Tool user guide: instructions for the completion of the Impact Tool for use in applications and performance reviews. CRC Program, Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Canberra, ACT. Available at: https://www.crc.gov.au/Selection-Rounds/Documents/CRC%20Impact%20Tool%20User%20Guide%20%28Feb%202012%29.pdf

Cooperative Research Centres Association (2007) Economic impact guide. Available at: http://crca.asn.au/wp-content/uploads/2012/05/EconomicImpactAnalysisGuide2007.pdf

Cooperative Research Centre for Beef Genetic Technologies (2012) Exit Report. Beef CRC, Armidale, NSW. Available at: http://www.beefcrc.com/products/outcomes-of-past-investments-in-beef-crc.html

Cooperative Research Centre for Cattle and Beef Quality (2004) CRC for beef genetic technologies prospectus: economic growth, genomics revolution, livestock revolution, Beef CRC, Armidale, NSW.

Deland M (2011) Rates of non-compliance over time, South East South Australia. Unpublished data, March.

Fordyce G, Barwick S, Corbet N, Burns B, Holmes WE (2012) Potential economic impact of Beef CRC Program 4 outputs when applied in north Australian cow herds. Appendix 13 to CRC for Beef Genetic Technologies (2012).

Goddard ME (2010) Genomic selection in farm animal species: lessons learnt and future perspectives. In 'Proceedings of the 9th World Congress on Genetics Applied to Livestock Production, Leipzig, Germany', paper 0701.

Goddard ME, Hayes BJ (2009) Mapping genes for complex traits in domestic animals and their use in breeding programmes. *Nature Reviews Genetics* **10**, 381–391. doi:10.1038/nrg2575

Government of Victoria (2013). 'What is involved in developing a CRC bid? A few pointers to guide you on your way.' Available at http://www.business.vic.gov.au/grants-and-assistance/programs/victorian-crc-bid-support-program-vcbsp/crc-development-resources/example-program [Verified 12 September 2014].

Griffith GR (Ed.) (2008) Accelerated adoption through sustainable beef profit partnerships. *Australian Farm and Business Management Journal* **5**(1–2), i–iv, 1–129.

Griffith GR (2009*a*) Economic impact of a major beef industry research and development investment: the renewal of the Cooperative Research Centre for Beef Genetic Technologies. Australasian Agribusiness Review **17**, Paper 13, 235–265. Available at: http://www.agrifood.info/review/2009/Griffith.pdf

Griffith GR (2009*b*) Economic effects of alternate growth path, time of calving and breed type combinations across southern Australian beef cattle environments: industry-wide effects. *Animal Production Science* **49**(6), 542–547. doi:10.1071/EA08264

Griffith GR (2012*a*) Have beef profit partnerships made a difference? Appendix 15 to CRC for Beef Genetic Technologies (2012).

Griffith GR (2012*b*) The value of genetic progress in Australian beef cattle due to Beef CRC R&D. Unpublished paper, Beef CRC, Armidale, NSW. See also Appendices 10 and 11 to CRC for Beef Genetic Technologies (2012).

Griffith GR, Thompson JM (2012) The aggregate economic benefits to the Australian beef industry from the adoption of Meat Standards Australia: updated to 2010/11. *Australasian Agribusiness Review* **20**(2), 11–38.

Griffith GR, Parnell PF, McKiernan W (2006) The Economic, Environmental and Social Benefits to NSW from Investment in the CRC for Beef Genetic Technologies. Economic Research Report No. 30, NSW Department of Primary Industries, Armidale, NSW.

Griffith GR, Pollock KS, Burrow HM (2013) How did we go? Revisiting the ex ante economic impact assessment of the CRC for Beef Genetic

Technologies, as at the cessation of funding. *Australasian Agribusiness Review* **21**(5), 83–100.

McKiernan B (2011) Solutions to feedback: Livestock Data Link. Final Report to Meat and Livestock Australia, Project V.LDL.1004, NSW Department of Primary Industry, Armidale, NSW.

Prayaga K (2005) Replacing the practice of dehorning in tropical beef cattle through the development of genetic markers for polled, African horn and scurs genes. Innovative Projects Fund Application, National and International Research Alliances Program 2005/06, CSIRO, Rockhampton, Qld.

Slack-Smith A, Griffith G, Thompson J (2009) The cost of non-compliance to beef market specifications. *Australasian Agribusiness Review* **17**(9), 178–190. Available at: http://www.agrifood.info/review/2009/Slack-Smith_Griffith_Thompson.pdf

Wood S, You L, Baitx W (2001) 'DREAM Version 3 User Manual.' (International Food Policy Research Institute: Washington, DC.)