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Abstract
The application of molecular genetics to improve meat yield in beef carcases has generated global interest in recent years. Myostatin has been identified as a negative regulator of skeletal muscle mass. Muscular hypertrophy or "double muscling" in cattle has been attributed to naturally occurring mutations in the bovine myostatin gene that result in "inactive" or "non-functional" myostatin. The objective of this study is to take the findings of some recent Beef CRC experimental results relating to selection for the non-functional myostatin mutation, and examine the profitability implications of possible commercial application in the Australian beef industry. A herd-level economic analysis was undertaken using Beef-N-Omics. Inputs included herd costs and returns for a representative self-replacing beef herd turning off young cattle, as published by the Industry & Investment NSW. Other inputs included pasture growth data for a representative good quality pasture system in the North-west of NSW, and herd production data based on the experimental results. Four scenarios were examined based on different combinations of herd structure and premiums available for muscle score. In a self-replacing system (with a $50 per female cost for the genetic screening test), the increase in gross margin over the base herd was 0.5 per cent ($3 per breeding cow or $2 per ha) when there was a 1 muscle score increase in the average muscle score of the heterozygous progeny. For an increase of 2 muscle scores in the progeny, the improvement in the gross margin was 4.9 per cent ($27 per breeding cow or $13 per ha). In the scenarios where a terminal sire system was applied to utilise the myostatin mutation, the economic benefits are potentially greater. In the case of a 1 unit increase in muscle score over the base herd, a 6.1 per cent increase in the gross margin was achieved ($34 per breeding cow or $17 per ha). If a 2 unit increase in muscle score was obtained a potential 17.7 per cent increase in the gross margin over the based herd was obtained ($96 per breeding cow or $48 per ha).

Keywords: beef; myostatin; muscle score; economic; evaluation; Australia
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Acronyms and Abbreviations Used in the Report

ABARE	Australian Bureau of Agricultural and Resource Economics
ADG	Average daily gain
BEEF CRC	Cooperative Research Centre for Cattle and Beef Quality
Beef-N-Omics	A software package (see Appendix B)
CFA	Cast-for-age
CW	Carcass weight
DM	Dry matter
EBV	Estimated breeding value
ME	Metabolisable energy
RBY	Retail beef yield
TGF	Transforming growth factor

Executive Summary

Meat yield is a key driver of profitability in beef production. Meat yield per animal can be increased by investing in particular breed types known to have higher meat yields or by selecting sires within breeds that have high Estimated Breeding Values (EBVs) for meat yield traits. Selection for the phenotypic trait known as “double muscling” or “muscular hypertrophy” is one avenue for increasing meat yield per animal. This trait is associated with higher meat yield, a higher proportion of preferred cuts of meat, leaner and more tender meat, higher birth weights and superior pre-weaning growth rates. However on the negative side, production problems have included reduced fertility, dystocia and lower rates of calf survival.

The application of molecular genetics to improve muscling in beef cattle, and hence meat yield in beef carcases, has generated global interest in recent years. Recent research has identified Myostatin as a potent negative regulator of skeletal muscle mass in cattle. Myostatin is a growth factor that limits muscle tissue growth, i.e. higher concentrations of myostatin in the body may cause the individual to have less developed muscles. Muscular hypertrophy in cattle has been attributed to naturally occurring mutations in the bovine myostatin gene that result in “inactive” or “non-functional” myostatin.

It is now possible to genotype individuals for the myostatin mutation and identify whether they are homozygous (+/+ or mh/mh) or heterozygous (mh/+). Thus it is now technically feasible for beef producers to incorporate selection for the myostatin mutation into their production system. Practically, the heterozygous form would be preferred to the homozygous form to avoid potential problems with fertility and calving difficulty.

The objective of the study reported in this bulletin is to take the findings of some recent experimental results relating to selection for the heterozygous myostatin mutation undertaken by the Beef CRC, and to examine the profitability implications of possible commercial application in the Australian beef industry.

A herd-level economic analysis of the heterozygous myostatin mutation was undertaken using the Beef-N-Omics software package. Inputs into the package included herd costs and returns for a representative self-replacing beef herd turning off young cattle of some 15 to 20 months of age, as published by the Industry & Investment NSW. Other inputs included pasture growth data for a representative good quality pasture system in the North-west of New South Wales, and herd production data based on the experimental results.

A base case herd was set up first. The gross margin of the base herd of 200 breeding cows was $108,105 or $540 per breeding cow or $270 per hectare. Then four scenarios were examined based on different combinations of herd structure and premiums available for muscle score. All scenarios showed that there is a potential economic benefit from incorporating the myostatin mutation gene in the heterozygous form in a commercial beef herd.

When the myostatin mutation was incorporated using the self-replacing system (where it is assumed that the genetic screening test for the myostatin mutation is $50 per female), the increase in gross margin over the base herd was 0.5 per cent or $3 per breeding cow ($2 per hectare) when there was a 1 muscle score increase in the average muscle score of heterozygous animals in the production system. If the outcome of the myostatin gene was an

increase of 2 muscle scores in the heterozygous animals, then the improvement in the gross margin is 4.9 per cent or $27 per breeding cow ($13 per hectare) over the base herd.

In the scenarios where a terminal sire system is applied to utilise the myostatin mutation then the economic benefits are potentially greater. In the case of a 1 unit increase in muscle score over the base herd, a 6.1 per cent increase in the gross margin is achieved over the base herd scenario ($27 per breeding cow or $13 per hectare). If a 2 unit increase in muscle score is obtained from the application of the myostatin gene then a potential 17.7 per cent increase in the gross margin over the based herd is obtained ($96 extra gross margin per breeding cow or $48 extra per hectare).

The relative profitability of a self-replacing herd production system compared to a terminal system, independent of the myostatin mutation, was tested by incorporating a terminal sire production system utilising a Limousin bull using published average bull prices. The use of a Limousin bull over British breed cows was assumed to increase muscle score of progeny by 1 unit, consistent with published results. It was found that the terminal sire system independent of the myostatin mutation achieved a 7.4 per cent higher gross margin, or $40 per breeding cow, than the self replacing herd modelled in this analysis. This terminal sire system using a Limousin bull also had a slightly higher gross margin ($580 per breeding cow) than the terminal sire system utilising the myostatin mutation ($574 per breeding cow), assuming a 1 muscle score increase in progeny for both scenarios.

Finally, the assumed premium for muscle score has a large impact on the potential profitability of introducing this trait into a breeding program. More recent data on muscle score premiums needs to be analysed to check the level of benefit the market is willing to pay for this extra yield of beef.

1. Introduction

Meat yield is a key driver of profitability in beef production. Under current selling and pricing systems, across the whole Australian beef industry it is estimated that meat yield contributes around 80 per cent to profit while meat quality contributes only 20 per cent on a per carcase basis. Aggregate meat yield produced by a beef business can be increased by lowering death rates or increasing weaning rates and growth rates. Meat yield per animal can be increased by investing in particular breed types known to have higher meat yields or by selecting sires within breeds that have high Estimated Breeding Values (EBVs) for meat yield traits.

Selection for the phenotypic trait known as "double muscling" or "muscular hypertrophy" is one avenue for increasing meat yield per animal. Some European breed types such as Pietmontese, Belgian Blue, Limousin and Charolais are well known to have a high proportion of double muscled progeny (see Figure 1 and Figure 2), but other breed types also exhibit this trait to varying degrees. Cattle exhibiting muscular hypertrophy incur both advantages and disadvantages from a beef production perspective. For example, the trait is associated with higher meat yield, a higher proportion of preferred cuts of meat, leaner and more tender meat, higher birth weights and superior pre-weaning growth rates (Arthur, 1995). However on the negative side, production problems have included reduced fertility, dystocia and lower rates of calf survival, while the impact of the trait on post-weaning growth rates appears uncertain (Arthur, 1995).

The application of molecular genetics to improve muscling in beef cattle, and hence meat yield in beef carcases, has generated global interest in recent years. Recent research has identified **Myostatin** as a key regulator of skeletal muscle mass in cattle (McPherron and Lee, 1997).

Figure 1. Belgian Blue bull exhibiting double muscling
(photo from http://en.wikipedia.org/wiki/Myostatin accessed 16 April 2008)

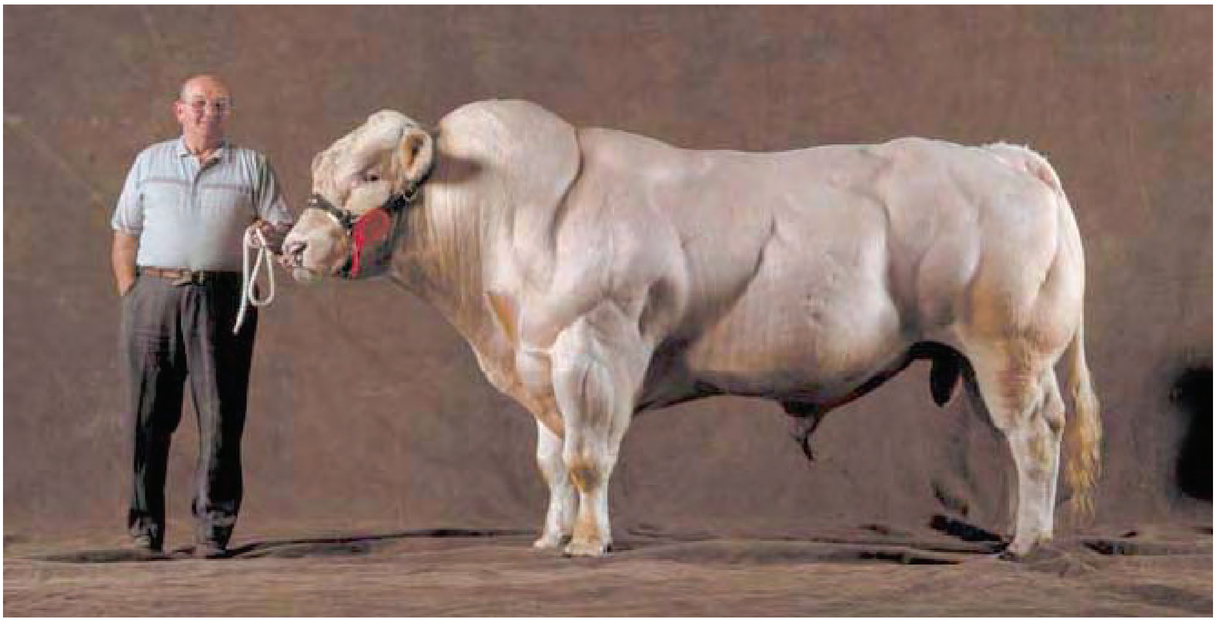

Figure 2. Limousin bull exhibiting double muscling
(photo by G.Griffith, Northern Ireland, August 2007).

Myostatin is a growth factor[1] that limits muscle tissue growth, i.e. higher concentrations of myostatin in the body may cause the individual to have less developed muscles. It is a member of the TGF- superfamily of transforming growth factors. The myostatin protein is produced primarily in skeletal muscle cells, circulates in the blood and lymph and acts on muscle tissue, apparently by slowing down the development of muscle stem cells.

In cattle with normal levels of muscling, the type of myostatin present is said to be "active" or "functional". This is represented as (+/+) and is known as homozygous normal. In cattle with abnormal levels of muscling, the type of myostatin present is said to be "inactive" or "non-functional" (Keele and Fahrenkrug, 2001). This is due to naturally occurring mutations in the myostatin gene (Grobert *et al.*, 1997). At least six different mutations in the bovine myostatin gene have been identified (O'Rourke *et al*., 2005, 2008). Non-functional myostatin can be of the form (mh/mh) which is known as homozygous mutation, or (mh/+) which is known as heterozygous.

Cattle with either the (mh/+) or the (mh/mh) non-functional forms of the gene have lower concentrations of myostatin and therefore more developed muscling. The action of myostatin in regulating muscle growth and development in meat animals is reviewed most recently by Dayton and White (2007).

[1] The term **growth factor** refers to a naturally occurring protein capable of stimulating (or inhibiting) cellular proliferation and cellular differentiation. Growth factors are important for regulating a variety of cellular processes. Growth factors typically act as signaling molecules between cells.

The muscular hypertrophy evident in the cattle in the two Figures is extreme and due to the (mh/mh) form of the gene. Up to a 20 per cent increase in muscle mass has been found in Belgian Blue cattle that are (mh/mh) (Grobert *et al.*, 1997). However there are serious potential production effects associated with this form of the gene, especially in relation to fertility and calving. Recent research has therefore examined the heterozygous form of the mutation. Cattle that are heterozygous (mh/+) for the myostatin mutation have been shown to have an advantage over homozygous normal cattle (+/+) with higher 200 day weaning weights and yearling weights as well as higher retail beef yields (Casas *et al*., 1999). Further, calving difficulties associated with heterozygous calves are less extreme than is the case for homozygous mutation calves (mh/mh) (Casas *et al*., 1998, 1999). Since it is now possible to genotype individuals for the myostatin mutation and identify whether they are homozygous (+/+ or mh/mh) or heterozygous (mh/+), it is now feasible for beef producers to incorporate selection for the myostatin mutation into their production system, producing heterozygous offspring (Casas *et al*., 1999; Keele and Fahrenkrug, 2001).

The heterozygous form has been found in breed types as divergent as Angus (O'Rourke *et al.*, 2008), Charolais (Levezial *et al*., 2006) and Santa Gertrudus (McKiernan *et al*., 2008). In two Angus crossbred herds in which increased musculature was the primary selection goal, a significant proportion of each herd (16 per cent and 23 per cent) was found to have the heterozygous form of the myostatin mutation (O'Rourke *et al*. 2009). A very much lower proportion (1 per cent of each herd) was found to have the homozygous form of the mutation.

The defining of causal DNA markers for double muscling has enabled diagnostic testing to be reliably undertaken to identify carriers of the known myostatin mutations, including the less phenotypically extreme heterozygous animals. This testing, including the identification of the number of copies of the mutation in individual animals, allows for the use and management of the trait in beef herds including the management of potential disadvantages associated with muscular hypertrophy (O'Rourke *et al*. 2009).

Prevalence of the myostatin mutations varies with breeds and this prevalence is related to the breeds' management and adaptability to the double muscling trait and associated negative association, particularly dystocia (Dunner *et al*. 2003). For example, an 11-base pair deletion found to be responsible for double muscling in Belgian Blue and Asturiana (de los Valles) cattle breeds (Grobet *et al*. 1997; Dunner *et al*. 1997) have a high frequency of the mutated gene in their populations (Dunner *et al*. 2003), while Gill *et al*. (2008) found that this same mutation occurred in Angus cattle in Scotland at a low frequency of 0.04. However, Smith *et al*. (2000) found that the deleted allele occurs at a frequency of 0.4 in the British South Devon breed, where muscular hypertrophy is generally selected against.

Keele and Fahrenkrug (2001) examined optimum mating systems for the myostatin mutation in beef cattle in the United States. They examined nine possible mating combinations and combined these in rotational systems so that female replacements are produced within the herd. Importantly Keele and Fahrenkrug (2001) highlighted the implicit assumption that the beef producer obtains a premium for the higher yielding carcase in the beef market. Apart from this study though, there are no economic evaluations of the usefulness of this selection process for improving profits from beef cattle production.

The objective of this study is take the findings of the experimental results relating to selection for the heterozygous myostatin mutation reported by Café *et al*. (2006) and (O'Rourke *et al*., 2008), and examine the profitability implications of possible commercial application in the Australian beef industry.

In this report, the experimental results are reviewed, a farm-level modelling system is described that allows an economic evaluation of the experimental results, and the economic outcomes of applying this system in a number of different ways are reported. Implications are then drawn for beef cattle producers.

2. The Experimental Results

The experimental study is reported in more detail in Café *et al.* (2006), McKiernan *et al.* (2008) and O'Rourke *et al.* (2008).

This study investigated carcase and yield characteristics after quantitative selection for high (H^{wt}) and low (L^{wt}) muscling Angus cattle that were homozygous normal for the functional myostatin gene (wild-type), and in cattle selected for high muscling that were heterozygous for a particular myostatin mutation (H^{Het}).

All cattle came from a research herd that comprised two distinct selection lines: a high and a low muscling line. Selection was based on muscle score (McKiernan 1990) assessed at weaning in heifers. The cows were crossbreds of predominantly Angus and Hereford origin, while Angus bulls were used, selected from industry herds, based on muscle score. The herd is located at the Industry & Investment NSW Centre for Perennial Grazing Systems at Glen Innes.

Following backgrounding on improved perennial pastures until approximately 25 months of age, 44 steers from this herd were transported to Yarranbrook Feedlot at Inglewood, Queensland, where following standard induction they were fed a grain-based diet for a period of 150 days. The steers included 14 high (H^{wt}) and 19 low (L^{wt}) muscling Angus steers that were tested homozygous for the functional myostatin gene, and 11 steers selected for high muscling that were tested heterozygous for one of the myostatin mutation genes (H^{het}).

The steers were slaughtered in November 2005 at John Dee Abattoir, Warwick, Queensland. Standard slaughter, chiller assessment and yield characteristics were determined. Additionally, one side of each carcass was commercially boned-out at the abattoir to determine the weight of retail beef yield, fat trim and bone. Later, measurement of ultimate pH, colour, texture, cooking loss, and intramuscular fat percentage was performed.

The results are reported in Table 1.

The H^{Het} steers had a statistically significant greater dressing percentage, eye muscle area and less fat trim than the H^{wt} steers which had significant higher dressing percentage, eye muscle area and less fat trim than the L^{wt} steers. The H^{Het} steers had significant less weight of bone and had greater retail yield and less fat trim and bone as a percentage of cold carcase weight than the H^{wt} and L^{wt} steers. The three groups did not differ significantly in liveweight, carcase weight, weight of retail beef, P8 and rib fat depths, AUS and MSA marbling scores, and ossification scores at 25 months of age.

Therefore the high muscling H^{wt} steers, the progeny of parents selected on the basis of muscle score, produced less fat, greater eye muscle area and a higher dressing percentage than the L^{wt} steers, but this did not translate into any significant difference in retail beef yield. However the high muscling H^{Het} steers, heterozygous for the myostatin mutation, produced less fat and bone and more beef at an equivalent carcase weight, and had greater eye muscle area, than either the H^{wt} or the L^{wt} cattle. This suggests that a breeding program that targets one non-functional myostatin mutant allele (heterozygotes) can increase retail beef yield by about 3.5 percentage points above that achieved from visual selection for muscle score alone. Further, the meat from the H^{Het} steers was significantly more tender than either the H^{wt} or the L^{wt} cattle.

Table 1. Least squares means for liveweight, carcase and yield characteristics of low and high muscling Angus steers at 25 months of age and equivalent carcase weight (358 kg) where appropriate

Variable	Muscling genotype			s.e.d.
	Low, wild-type (L^{wt})	High, wild-type (H^{wt})	High, heterozygote (H^{Het})	
Number of cattle	19	14	11	-
Liveweight (kg)	666	659	638	24.1
Carcass weight (kg)	359	360	357	13.5
Dressing %	53.9a	54.9b	56.0c	0.39
Ossification score	200	189	189	7.2
P8 fat	24.3	21.2	24.1	1.94
Rib fat (mm)	18.7	16.2	16.4	1.77
Eye muscle area (cm^2)	70.4a	76.9b	85.0c	3.05
AUS marble score (0-6)	1.32	1.13	0.92	0.20
MSA marble score (100-1100)	329	324	288	24.3
Shear force (kg)	4.70b	5.11b	3.98a	0.35
Retail yield (kg)	218	221	234	8.5
Fat trim (kg)	32.5c	30.0b	25.8a	1.20
Bone weight (kg)	33.0b	33.6b	31.7a	0.49
Retail yield (% CCW)	61.8a	63.0a	66.5b	0.68
Fat trim (% CCW)	18.3b	17.1b	14.5a	0.75
Bone (% CCW)	18.7b	19.0b	17.9a	0.26

Mean values followed by different letters differ at $P<0.05$. CCW, cold carcase weight.
Source: Café *et al*. (2006), O'Rourke *et al*. (2008).

3. Method of Analysis

The researchers associated with the experiments determined four possible ways of practically using the myostatin mutation trait within an Australian commercial beef production setting (Mckiernan *et al*., 2008). Each of the options has different advantages and disadvantages. These options included:

1. Using a heterozygous mutation bull (mh/+) over homozygous normal cows (+/+). This will result in 50 per cent heterozygous progeny and 50 per cent homozygous (+/+) normal progeny. All males would be sold. All females would be tested, with normal females (homozygous, +/+) retained as heifer replacements and heterozygous females (mh/+) sold. Alternatively, the heterozygous females could be retained and only mated with a homozygous normal bull (+/+) in future breeding.

2. Using a homozygous mutation bull (mh/mh) over homozygous normal cows (+/+). This will result in 100 per cent heterozygous (mh/+) progeny. This is a terminal system in which all progeny would be sold. Alternately two herds could be managed with females retained and mated to normal bulls. It should be noted that there would be difficulty in sourcing functional homozygous bulls (mh/mh) for use in this system.

3. Using a heterozygous mutation bull (mh/+) over heterozygous cows (mh/+). This will result in 25 per cent homozygous normal calves (+/+), 50 per cent heterozygous calves (mh/+) and 25 per cent homozygous mutation calves (mh/mh). Disadvantages of this system include that a market outlet for the proportion of calves that are homozygous for the myostatin mutation would need to be found and that detrimental effects would be expected from this proportion of the calf drop, for example calving difficulties.

4. Using a homozygous normal bull (+/+) over heterozygous cows (mh/+). This will result in 50 per cent heterozygous progeny (mh/+) and the remaining 50 per cent will be homozygous (+/+) normal, a similar result to option 1. In this instance all cows are heterozygous for the trait and thus would achieve higher cull values.

A real practical option in a self replacing herd would be to combine options 1 and 4. This would be simply treated like a rotational crossbreeding system whereby females produced from herd 1 replace females in herd 2 and vice versa. The result would be that 50 per cent of the progeny would always carry the mutation gene and consequent yield advantage.

3.1 Modelling tool

The Beef-N-Omics program (Dobos *et al*., 2006) has been selected as the model of choice for enterprise level modelling and economic evaluation of beef technologies relevant to the Southern Australian beef production systems within the Beef CRC. It has been used by beef extension officers in concert with commercial producers over a number of years enabling practical validation of the model and includes herd dynamic, pasture and feeding components. The feeding component is based upon metabolic energy demand algorithms derived from MAFF (1984) standards and matches feed demand and supply. The Beef-N-Omics program incorporates feed budgets and financial gross margin budgets for static herds. See Appendix B for more detail.

The program allows users to compare management options at a constant stocking rate. Therefore if one management option results in a change in feed demanded by the beef enterprise then stock numbers can be adjusted so that the total feed demand from the beef enterprise remains the same. That is, the same feed deficit or surplus is maintained on the assumed production area.

3.2 Production and economic assumptions

The herd-level economic analysis of the myostatin mutation trait is based upon herd costs and beef prices published by Industry & Investment NSW for a self-replacing beef herd turning off young cattle of some 15 to 20 months of age (NSW DPI, 2007a). The major difference between the gross margin budget used in this analysis and the published "Young Cattle" enterprise gross margin budget is that a higher growth rate of young stock was assumed - a sale weight for steers of 550 kg liveweight (heifers at 520 kg liveweight) at 16 months of age compared with the sale weight of 453 kg liveweight as used in the published budget (assuming a dressing percentage of 53 per cent). This increase in growth rate of the progeny is justified by the quality and quantity of pasture available and inputted into the model (see Appendix A). The weights are consistent with normal practice of the better producers in the higher producing areas of northern NSW, particularly the Hunter Valley and Liverpool Plains areas. They aim to capitalise on the generally more lucrative European beef trade market which requires carcases 300 to 400 kg dressed weight before 30 months of age.

A base herd of 200 breeding cows is assumed, and consistent with the published gross margin budget (NSW DPI, 2007a), an area of 80 hectares of improved pasture and 251 hectares of natural pastures is available for grazing per 100 cows or 662 hectares in total for the 200 cow herd. Herd dynamics are the same as that detailed in the NSW DPI (2007a) budget, with key herd parameters including a weaning rate of 82 per cent and a 88 per cent conception rate. A total of 46 heifers are retained as replacements for the 200 cow herd and cows are culled for age at 10 years. Age at first calving is 2 years. Bulls are joined at a rate of 3 per cent and adult mortality is assumed to be 2 per cent. Beef enterprise costs including health and marketing are taken directly from the NSWDPI (2007a) budget, while pasture maintenance costs are included in the budget as detailed in Appendix A. Table 2 illustrates a beef gross margin budget for this enterprise and Table 3 details production parameters for the assumed herd dynamics for the self replacing herd modelled in this study.

Cattle prices are the same as those detailed in NSW DPI (2007a) including cull cows at 250 c/kg (dw), cull bulls at 230 c/kg (dw), while young cattle are sold at 180 c/kg lw for steers at 16 months of age and 175 c/kg lw for heifers weighing 520 kg lw at 16 months. In this analysis a constant bull price of $4,169 is used and is based upon the average reported sale price of Hereford bulls in 2007 (Angus Australia 2008).

As shown in the experimental results outlined in Section 2 above, the phenotypic effect of the myostatin mutation trait is to increase the retail beef yield of the heterozygous carcase, which in the saleyard would appear as an increase in the muscle score of the animal. Therefore it was necessary to estimate a premium per unit of muscle score to attribute to the heterozygous animals over the price achieved by the base (normal) herd. McKiernan (2002) in an analysis of cattle sale yard prices found a 15 to 20 c/kg lw benefit per muscle score, and this premium was linear between scores. This is based upon the National Livestock Reporting Service visual assessment of muscle using 5 increments, from A (high muscle) to E (low muscle).

In adjusting the muscle score premium calculated for 2001 saleyard prices to 2007 prices for this analysis, it was found that the premium in nominal terms would be the same, since

Table 2. Young cattle 16 months (high growth) gross margin
Enterprise unit: 200 cows
Representative Year - 2007 dollar values

Income:				**$**
80	Steers 16-18 months[1]	550 kg l.w. \hd	@ 180 ¢/kg 1.w.	79 200.00
34	Heifers 16-18 months[1]	520 kg l.w. \hd	@ 175 ¢/kg l.w.	30 940.00
42	Cull cows[1, 2]	480 kg 1.w. \hd	@ 120 ¢/kg l.w.	24 192.00
2	Cull bulls[1]	820 kg 1.w. \hd	@ 127 ¢/kg l.w.	2 082.80
			Total Income	**136 414.80**

Variable Costs:						
Animal health -	vaccination, drenching and vet costs					**$**
	Cows	200	@	$6.83	\hd	1 366.00
	Replacement Heifers	46	@	$2.75	\hd	126.50
	Growing stock	114	@	$5.73	\hd	653.22
	Bulls	6	@	$86.00	\hd	516.00
	Calves	172	@	$0.46	\hd	79.12
Ear tags	Heifers	46	@	$2.00	\hd	92.00
Cartage	Sales/ Purchases	158	@	$8.00	\hd	1 264.00
Commission	Sales Revenue	$136 415	@	3.5%		4 774.53
Yard dues	No. of head	158	@	$3.00	\hd	474.00
MLA levy	No. of head	158	@	$5.00	\hd	790.00
NLIS + Tail tags	No. of head	158	@	$3.01	\hd	475.58
Replacements						
	Bull	2	@	$4 169.00	\hd	8 338.00
Pasture maintenance	(refer to Appendix A)					13 240.00
			Total Costs			**32 188.95**
			Gross margin			**$ 104 225.85**
		Gross margin per cow				**$ 521.13**

Livestock numbers provided to nearest integer may result in rounding errors.
[1] Prices for culled cattle taken from NSW DPI (2007) liveweights and c/kg lw prices based upon the following assumed dressing percentages for the base herd: 48% cows, 55% bulls. Price for young stock taken from ABARE (2007) average saleyard price in 2007 for yearlings of 330 c/kg dw, based on 54% dressed weight and 5 c/kg lw difference between steers and heifers.
[2]Apart from the culling of cows for age, all pregnancy tested empty cows are culled and 4 per cent of cows are culled for other reasons.

Table 3. Herd production parameters used in the budgets

Herd parameters:	
Calving date	August-September
Conception rate	88 %
Weaning rate	82 %
Adult mortality	2 %
Calf mortality	5 %
Bull requirement	3 %
Bull cull	Replaced after 4 years
Age at first calving	24 months
Cow cull age	10 years

nominal beef prices received by Australian producers for slaughtered cattle were almost the same between these two years. Specifically for yearling cattle the nominal price received was 331 c/kg dw in 2000/01 compared with a nominal price of 329 c/kg dw in 2006/07 (ABARE, 2007). This observation is further supported by examination of the ABARE index of prices for all slaughtered cattle (ABARE, 2007). In 2001/02 the index value was 167.7 and in 2006/07 the index value was 162.4, just a small (3 per cent) change in real slaughter prices between 2000/01 and 2006/07.

Since this study involves a single year budget then use of nominal prices is appropriate and the muscle score premium reported by McKiernan (2002) of 15-20 c/kg lw can be applied in the 2007 gross margin budgets. This assumes that the market premium for increased muscling has been maintained in relative terms over the period 2000/01 to 2006/07 (no more recent research was known to the authors at the time of writing). However, the lower value of 15 c/kg lw per muscle score is used as the premium in this study.

The results from the Beef CRC experiments reported in Table 1 show a consistent effect of the myostatin mutation gene in heterozygous cattle, however this effect is dependent upon the current level of muscularity in a herd. That is, the higher the level of muscularity in a normal herd (+/+), the less significant will be inclusion of the myostatin allele, compared with a herd that has had minimal or no prior selection pressure applied for muscling (Café *et al*., 2006).

Using the myostatin trait in a heterozygous form over cattle with a low level of muscling is an increase of two muscle scores or approximately 4.7 per cent increase in retail beef yield (RBY) (refer to Table 4). In the case of already higher muscling cattle, the introduction of the myostatin mutation trait results in an increase in muscling by one score or a 2.5 per cent increase in RBY in heterozygous progeny.

Given this impact of the myostatin mutant allele upon the carcase composition of heterozygote animals, the potential economic benefits can be captured by attaching an appropriate premium to the muscle score of the animal at the saleyards (15c/kg lw per additional muscle score). Alternately a premium might be attached on a carcase weight basis through its effect on RBY.

3.3 Scenarios tested

A conservative approach was taken in this study to examine the potential use of the myostatin mutation trait in Australian commercial beef herds so that no homozygous cows for the mutation (mh/mh) are produced, while homozygous bulls (mh/mh) for the mutation are assumed to be bought in from specialist breeders. In contrast, Keele and Fahrenkrug (2001) examined possible systems that include producing animals that are homozygous (mh/mh) for the myostatin mutation and they also included discussion of management strategies to minimise deleterious effects of particular strategies on production, such as dystocia in heifers.

Four scenarios were tested in this analysis. The first two are based on a self-replacing management system where two herds would be run. One herd would contain normal cows and heterozygous bulls and the other would contain heterozygous cows and normal bulls (like combining options 1 and 4 listed on page 7). In this case half the steers and heifers progeny

Table 4. Differences in muscle score, eye muscle area and retail beef yield, between groups of Angus steers at 25 months of age, selected for low or high muscling and a herd incorporating the myostatin mutation in heterozygote form

	Muscle Score (A to E scale)	Eye Muscle Area (cm^2)	Retail Beef Yield (% of CCW)
Low muscle herd	D	70.4	61.8
High muscle herd	C	76.9	63.0
Myostatin herd	B	85.0	66.5

Source: Cafe *et al*. (2006). CCW , cold carcase weight

sold would carry the myostatin mutation in heterozygous form. Further, half the cows and half the bulls would also be heterozygous for the myostatin mutation and consequently attract the muscle score premium. In this management system all female calves would need to be genotyped, incurring a $50/hd cost. The second scenario incorporates the higher premium of 30 c/kg for heterozygous stock within the previously described self-replacing herd, reflecting an improvement of two muscles scores in the progeny above the base herd from incorporation of the myostatin mutation gene.

The third and fourth scenarios model a terminal production system where a homozygous bull for the myostatin mutation is purchased and bred to homozygous normal cows (like option 2 on page 7). All progeny would be sold and replacement females would need to purchased in as one year olds. A 15 c/kg premium for all progeny from this terminal system is included. In the case of scenario four, a 30 c/kg lw premium is attached to all progeny from the terminal system, reflecting a potential two unit increase in muscle score over the base herd as a result of the use of the myostatin mutation.

4. Results

4.1 Base results

The results from the four scenarios are presented in Table 5. The budgets for the self-replacing scenarios assume that the genetic screening test for the myostatin mutation is $50 per head. The results show that there is a potential economic benefit from incorporating the myostatin mutation gene in the heterozygous form in a commercial beef herd. The gross margin of the base herd of 200 breeding cows is $108,105 or $540 per breeding cow or $270 per hectare. When the myostatin mutation trait was incorporated using the self-replacing system the increase in gross margin over the base herd was 0.5 per cent or $3 per breeding cow ($2 per hectare) when there was a 1 muscle score increase in the average muscle score of heterozygous animals in the production system. If the outcome of the myostatin gene was an increase of 2 muscle scores in the heterozygous animals, then the improvement in the gross margin is 4.9 per cent or $27 per breeding cow ($13 per hectare) over the base herd.

In the scenarios where a terminal sire system is applied to utilise the myostatin mutation then the economic benefits are potentially greater. In the case of a 1 unit increase in muscle score over the base herd, a 6.1 per cent increase in the gross margin is achieved over the base herd scenario ($34 per breeding cow or $17 per hectare). If a 2 unit increase in muscle score is obtained from the application of the myostatin gene then a potential 17.7 per cent increase in the gross margin over the based herd is obtained ($96 extra gross margin per breeding cow or $48 extra per hectare).

Table 5. Comparison of the economic outcomes for the four mating scenarios

Scenario	Cow herd hd	Enterprise Gross Margin, $	$GM/cow	$GM/ha	Change in GM over Base, %	Premium assumed c/kg lw
Base herd	200	108,105	540	270	-	-
Self replacing – scenario 1	200	108,670	543	272	0.5	15 (1 MS*)
Self replacing – scenario 2	200	113,364	567	283	4.9	30 (2 MS)
Terminal – scenario 3	200	114,701	574	287	6.1	15 (1 MS)
Terminal – scenario 4	200	127,234	636	318	17.7	30 (2 MS)

*MS refers to muscle score.

In the current analyses a constant bull price of $4,169 is applied, based upon the average reported sale price of Hereford bulls in 2007 (Angus Australia 2008). Therefore the additional gross margin between the base herd and the various scenarios tested effectively represents the maximum premium that could be paid for the myostatin bulls.

The maximum or break even premiums that could be paid for bulls carrying the myostatin mutation was determined by adjusting the bull purchase price for each scenario to identify the purchase price at which the enterprise gross margin was the same as the base herd. For the self replacing scenario, a producer could pay up 8.4 per cent more for a bull heterogeneous for the myostatin trait, if a 1 unit increase in muscle score was achieved. If the myostatin bull was anticipated to increase the muscle score of progeny by 2 units (over half the progeny), then the price paid for the bull could be up to $7,450 per bull or 79 per cent increase over the base bull price.

In the case of bulls homozygous for the myostatin mutation, the maximum price paid for the bull would almost double to $8,280/hd, a 98 per cent increase over the base bull price, in scenario 3, where all progeny would achieve a 1 unit increase in muscle score. The large increases in the maximum price that might be paid for myostatin bulls by a producer reflects the minor cost of bulls relative to total enterprise costs including pasture costs and livestock selling costs. Also bull costs are spread over the herd, a 3 per cent bull requirement, and remain in the herd for 4 years, therefore diluting their cost on a per cow basis. This premium can be viewed as a maximum, given that other management impacts such as increasing the complexity of managing a herd using the myostatin mutation have not been captured in the gross margin analysis.

It is also important to recognise the relative profitability of a self-replacing herd production system compared to a terminal system, independent of the myostatin mutation in comparing the results between the base self-replacing herd and terminal systems, scenarios 3 and 4. A terminal beef production system typically benefits from some combination of having a lower maintenance maternal line of cows, and a higher mature weight and or muscling terminal sires and obtaining further advantage in progeny growth rates from some degree of hybrid vigour. It requires different management practices and potential skills and different risks, such as sourcing acceptable replacement heifers. This alternative in using a terminal sire that does not include the myostatin mutation is given in Appendix C.

In the terminal sire case study applied in Appendix C, where a Limousin bull is joined over British breed type cows, that can increase progeny muscle score of the order of at least 1 unit (Wilkins *et al.* 2009), the lower average cost of Limousin bulls resulted in the non-myostatin terminal sire system achieving a 7.9 per cent higher gross margin than the base herd scenario or an extra $40 per cow. This is also a 1.1 per cent higher enterprise gross margin that that achieved by the myostatin terminal sire system (Scenario 3).

4.2 Sensitivity to genetic screening test cost

In the analyses presented above a genetic screening test of $50 per female progeny was assumed. If the test was used more widely by the beef industry then it is likely that the cost of testing for the trait would be reduced. To test the sensitivity of economic returns from the myostatin mutation to the cost of testing of animals in the commercial herd, budgets including a 50 and 80 per cent reduction in testing cost per head, or $25 and $10 per animal respectively, were constructed. These estimated testing costs were suggested by molecular geneticists.

The resulting gross margins incorporating the lower testing costs for the self-replacing production system (where testing of all female progeny is undertaken) are presented in Table 6. There is a $10 improvement in the gross margin per breeding cow when the testing cost is reduced by 50 per cent to $25 per animal tested, and there is a $16 improvement in gross margin per breeding cow when the testing cost is reduced to $10 per animal. A 20 per cent reduction in the genetic testing cost for screening of the myostatin mutation results in an approximate 0.8 per cent improvement in the beef enterprise gross margin for the self-replacing production system assuming a 1 muscle score improvement in the slaughter stock.

Table 6. Effect of lower genetic testing costs on the self-replacing mating systems

Scenario	Cow herd hd	Enterprise Gross Margin, $	$GM/cow (extra GM compared to $50 test[1])	Change in GM over Base %	Premium assumed c/kg lw
Base herd	200	108,105	540	-	-
$25/head myostatin test					
Self replacing – scenario 1	200	110,720	554 ($10/cow)	2.4	15 (1 MS[2])
Self replacing – scenario 2	200	115,413	577 ($10/cow)	6.8	30 (2 MS)
$10/head myostatin test					
Self replacing – scenario 1	200	111,950	560 ($16/cow)	3.6	15 (1 MS)
Self replacing – scenario 2	200	116,643	583 ($16/cow)	7.9	30 (2 MS)

[1]Difference is obtained from the corresponding scenario gross margins per cow presented in Table 5.
[2]MS refers to muscle score.

5. Conclusions

From this economic analysis it may be concluded that the use of the myostatin mutation gene in beef herds may be profitable. An improvement in the gross margin per breeding cow for a case study herd of 0.5 per cent (an extra $2 per cow) over a normal self-replacing herd was calculated if the introduction of the myostatin trait in heterozygous form results in a 1 unit increase in muscle score. This is based upon a premium of 15 ¢/kg liveweight paid per additional muscle score of the animal. The improvement in gross margin is further increased to a 4.9 per cent increase per breeding cow (or $13 per cow) over the base case scenario when an improvement of two muscle scores in heterozygous animals is obtained.

The use of the heterozygous mutation in a terminal breeding production system, that is where a bull homozygous for the trait (mh/mh) is used over normal cows (+/+) and all progeny are heterozygotes (mh/+) and thus attract the sale premium, was also found to be potentially more profitable. The improvement in the gross margin per breeding cow was 6.1 to 17.7 per cent over the self-replacing base case production system when an increase of one and two muscle scores for heterozygous progeny are achieved respectively.

In this study the relative profitability of a terminal beef production system compared to a self-replacing production system, independent of the myostatin mutation, was examined by including the average Limousin bull sale price in the terminal sire system. This resulted in an increase in the enterprise gross margin over the self-replacing base herd of 7.9 per cent or $40/ breeding cow, given the assumptions applied in this study. This was due to the typically lower commercial price paid for Limousin bulls compared with British breed bulls such as Herefords or Angus based on industry reported sale prices. Therefore where producers would consider the use of a terminal sire production system it would be appropriate to compare bull prices of suitable terminal sire breeds, normal for the myostatin mutation, with the premiums attributed to bulls homozygous for the myostatin mutation.

Further, the analysis undertaken does not take into account the extra management required to operate rotational breeding systems nor does it take account of additional risk that would be encountered by having to source and purchase the desired types of replacement females for the commercial herd following introduction of the terminal breeding system. Further the comparisons are made based upon steady state comparison of the enterprises and do not therefore account for costs that would be incurred by changing over enterprises and implications on farm business cashflow through a transition period.

Greater returns from using the myostatin mutation trait in terms of gross margin per breeding cow of the order of a further 2.4 per cent over the base case scenario are possible when the testing costs were halved from $50 to $25 per animal, in the self-replacing production system scenarios. Discussions with molecular geneticists during the course of this study suggested that such testing cost reductions or even greater, to possibly $10 per animal, as more testing was demanded by beef producers were feasible.

Additional information regarding the phenotypic outcome of the myostatin mutation in herds and the interaction of trait with the base level of muscling in the normal herd is required. Further this analysis assumes that there is no difference in the way heterozygous animals respond to various and variable nutritional regimes compared to normal cattle. Additional studies incorporating genetic by environment studies to test this assumption are necessary and important given the highly variable environments in which Australian commercial beef businesses operate. Further study is also warranted on the extent to which the myostatin mutation response varies at different ages and weights.

Finally, the assumed premium for muscle score has a large impact on the potential profitability of introducing this trait into a breeding program. Recent data on muscle score premiums needs to be analysed to check the level of benefit the market is willing to pay for this extra yield of beef.

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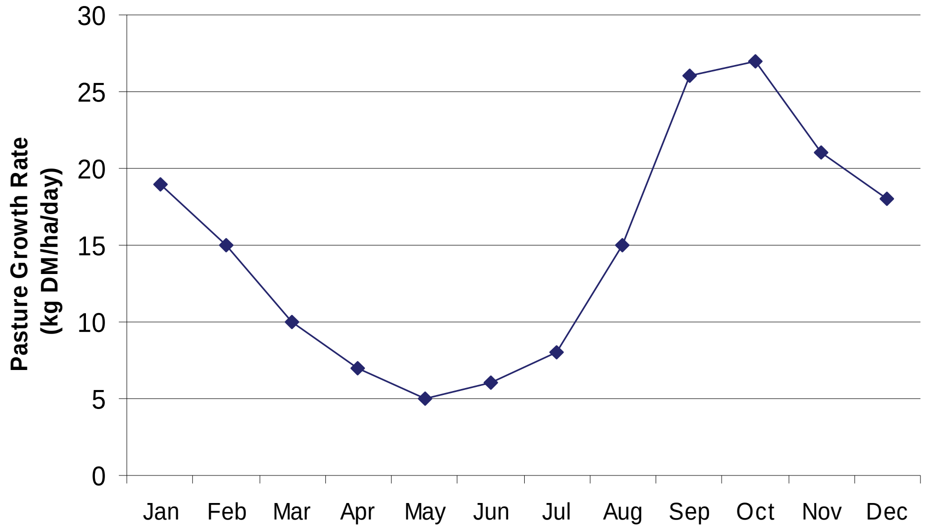
Appendix A: Selected Pasture for Beef-N-Omics Modelling and Associated Costs

The base pasture assumed in the Beef-O-Nomics model is a Danthonia – sub clover mix typical of the New South Wales north-west slopes and upper Hunter region. This pasture has as its main perennial grass native Wallaby grass (*Danthonia* spp.) while at least 20 per cent sub clover (*Trifolium subterraneum*) is present in the growing season. The soil is typically of moderate fertility, with maintenance levels of fertiliser applied (NSW Agriculture, 1996; McDonald, 1999). Figure A1 shows the average daily growth rate throughout the year of the selected pasture.

Figure 3. Estimated daily pasture growth rate (kg DM/ha/day) of the Danthonia/ subclover pasture



Source: NSW Agriculture (1996).

The More Beef from Pasture (MLA, 2004) manual provides various guidelines for estimating maintenance level of phosphorous (P) and sulfur fertiliser. This includes for soils with moderate buffering index of P of 1.0 kg of P per dse. Under the scenarios tested the carrying capacity of the pasture was approximately 18 dse per cow, with the NSW DPI (2007a) indicating a dse rating for the (slower growing) young cattle enterprise of 16.45 dse. Therefore with 200 cows over 400 ha this equates to a stocking rate of approximately 9 dse/ha. This would require a maintenance level of P of 9.0 kgP/ha or approximately 100 kg of superphosphate per hectare (at 8.8 % P).

At 30c/kg superphosphate ($300/t delivered) (NSW DPI 2007*b*) plus a further spreading cost of $3.10/ha (NSW DPI 2007*c*) then the total cost of $33.10/ha, or $13,240/yr for the 400 ha enterprise.

Appendix B: Beef-N-Omics

The Beef-N-Omics computer package (Dobos *et al.* 2006) is designed to analyse the effects that different management practices have on the profitability of a beef herd. The program integrates herd structures, feed budgets and financial gross margin budgets for beef cattle breeding herds.

User inputs are required on aspects of the beef enterprise such as herd size, live weight, calving times, age and weight at turn off, market prices, seasonal pasture growth, and variable costs. The package calculates gross margin per cow, per $100 capital, per hectare and per tonne dry matter (DM), as well as the monthly feed surplus or deficit.

Adjustments to herd size, monthly pasture growth, months of calving, age and weight of turn off, sale prices, variable costs, cow size, weaning percentage, or other aspects of herd management can be made to assess their impact on feed requirements and subsequently on herd gross margins. Adjustments to any of those parameters will be reflected in changes in monthly feed consumption and herd gross margin from which the principles of beef cattle management can be reinforced.

Beef-N-Omics is a static herd model designed so that all the inputs are used in the calculations. This assumes that these inputs have been the same for the entire history of the herd being analysed.

Because of this, Beef-N-Omics cannot be used accurately to assess the outcome of changes to aspects like sales policy, breeding or culling policy or calving patterns which will only be applied for a year or two, for example, during droughts.

Beef-N-Omics is not a FULL biological model. Local estimates can be used, but if accurate information is available, then more precise reports are generated. A disadvantage with this approach is that users must remember to input all the correlated consequences of any change to major inputs. A misleading output could result if this is not the case.

Examples are provided in the User’s Manual.

Appendix C: Alternative European Terminal Sire Production System

The myostatin study reported earlier highlighted the complexities of introducing the trait into most commercial herds, requiring specialised management to avoid homozygous animals due to associated negative traits. Given the weight gains achieved an alternative production system that would be relatively lower risk would be the use of a European terminal sire. Previous studies undertaken by Industry & Investment NSW found that the uses of Limousin and Charolais bulls over British breed cows could achieve improvements in the muscle score of progeny. For example, when pure-bred Hereford cows were crossed with Limousin and Charolais bulls the resulting steers had an average birth weight of 36.9kg and 37.6kg, and a weaning weight of 215 kg and 221kg at an average age of 235 days respectively. These cattle were then backgrounded to reach feedlot entry weight of 400kg and fed for 100 days, achieving a mean feedlot exit weight of 640 kg and 651kg, and a HSCW of 365.7 kg and 380.7kg for Limousin sired and Charolais sired steers respectively (Wilkins *et al*. 2009).

Commercial data from bull sales indicates that the average price paid for Limousin bulls was $3,360 in 2007 based on a survey of media reports and agents compiled by Angus Australia (2008). This is considerably less than the average reported bull sale prices for Hereford and Angus bulls in the same year which were $4,169 and $4,113 respectively (Angus Australia 2008).

The enterprise assumptions and associated costs and income were the same as those used in Scenario 3 in the myostatin study. This included bulls homozygous for the myostatin mutation and used as terminal sires, all offspring are sold and replacement heifers are purchased. If the Limousin bulls also achieved a 1 muscle score increase in the cross-bred progeny there would be a significant improvement in the gross margin of the beef enterprise over the base herd and also above the myostatin scenario.

Table 7. Comparison of enterprise gross margins of the base herd and a terminal sire production system incorporating the myostatin mutation, with a terminal sire system using a Limousin bull

Scenario	Cow herd hd	Enterprise Gross Margin, $	$GM/cow	$GM/ha	Change in GM over Base, %	Premium assumed c/kg lw
Base herd	200	108,105	540	270	-	-
Terminal – scenario 3	200	114,701	574	287	6.1	15 (1 MS)
Terminal – Limousin sire scenario	200	115,981	580	290	7.3	15 (1 MS)

*MS refers to muscle score.

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