The Benefits of Management Changes in Beef Enterprises on Pastoral Stations in Western Australia.

P. R. Tozer *
Department of Agriculture Western Australia, Geraldton, WA, 6531, Australia.

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Abstract

A set of simulations were run to estimate the impact on gross margins due to improvements in cattle breeding efficiency and other management factors in extensive pastoral systems in Western Australia. The output from the simulations was integrated into a statistical model of gross margin as a function of breeding and management variables. The simulations showed that gross margin was an increasing function of breeding rates, but age at first breeding and age at sale of offspring had variable effects on the gross margin of the enterprise. The statistical model illustrated that for a one per cent increase in breeding rates, an increase in gross income of $5274 was possible. The optimal ages at first breeding and sale of offspring were 20.6 months and 10.8 months respectively. Information generated by the simulation and the statistical model allows management to identify the breakeven value, or limit of expenditure, of changes to the system, beyond which the change will not increase enterprise gross margin.

Key words: Reproduction, economics, Australia, beef cattle, rangeland.

Introduction.

Reproductive efficiency can be measured in many ways, the number of cows pregnant as a percentage of cows bred or conception rate (O'Rourke et al., 1991), the number of live calves born (O'Rourke et al., 1992), or the number of calves weaned or branded (Bortolussi et al., 2005). Although these measures are somewhat different they all quantify how many animals a beef producer potentially has to sell or select replacements from and therefore affect the underlying economics of the system. The impact of reproductive losses to a production system varies with the goals of the system. For example, in a self-replacing breeding herd (i.e. cow-calf system), reproductive losses reduce the number of heifers available to enter the herd as replacements and decrease the number of saleable male offspring and excess heifers. A reduction in the number of replacements also reduces the ability of the producer to cull cows currently in the breeding herd or increase the genetics of the herd at a faster pace. In a terminal sire system, reproductive losses reduce the total number of animals for sale, thus reducing gross income.

In the extensive pastoral systems of north Western Australia reproduction rates, as measured by branding percentage, averaged 45% in the late 1970s (O'Rourke et al., 1991). Changes in management increased the branding rate to approximately 55% in 1990 and 65% in 1996-97 (Bortolussi et al., 2005). However, Burggraaf (2004) reported calving percentages in the pastoral regions of Western Australia in the range of 40-55%. Postweaning mortality losses and low growth rates reduce turnoff rates,

*Email ptozer@agric.wa.gov.au Tel., 08-9956-8524; Fax: 08-9921-8016

or sales as a percentage of total cattle carried, to about 20% (O'Rourke et al., 1991), although, in some years turnoff rates can approach 30% (Burggraaf, 2004). An optimal branding rate for systems in the pastoral regions should be around 70-75% (O'Rourke et al., 1991). At this branding percentage, turnoff rates would be approximately 40-50%.

Bos indicus[1] cattle and their derivatives, i.e. Brahman, Santa Gertrudis, Droughtmasters, Brangus or Brafords, while suited to the region have some inherent problems when managers attempt to increase reproductive efficiency and develop breeding strategies to improve efficiency. The first is that *Bos indicus* heifers reach puberty at an older age than do *Bos taurus* or British breed heifers (Randel 1994; NRC 1996). British breeds typically reach puberty at approximately 12-14 months of age, whereas *Bos indicus*-based heifers reach puberty at least 2 to 3 months older (Hearnshaw et al., 1994; Randel 1994). Secondly, the gestation length of *Bos indicus* females is longer than *Bos taurus* by approximately 5-10 days (Randel 1994). The final problem with *Bos indicus* breeds of cattle is that the females have a longer *post partum* anoestrus period than do British breed cows (Braden and Baker, 1973). The first problem means that it is extremely difficult to have heifers, in a pastoral system, calve at two years of age as in the temperate regions of Australia. The latter two show that it is problematic to ensure that the calving interval for cows in a pastoral system is 12 months, i.e. ensuring cows have a calf every year. Therefore, producers developing a breeding program to maximize efficiency will seek to find a compromise to satisfy the constraints imposed on their system by the physiological condition of the breeding herd.

Further exacerbating the reproduction management of a pastoral system is the area of most stations which are typically greater than 100,000 ha, with relatively low stocking rates, i.e. 15-25 ha per cow. Also, the animals are only mustered once a year. These conditions mean that producers, typically, do not remove the bulls from the herd leading to a year round calving pattern with some seasonal influences on reproduction (O'Rourke et al., 1991; Bortolussi et al., 2005). This type of management causes two problems in reproduction management. Firstly, cows that do not rear a calf or are not pregnant are not identified until mustering and are not culled until that time, which means non-productive cows are consuming feed that productive cows or their offspring could consume. Second, cows that may be pregnant at mustering but lose their foetus after mustering are again not identified until the next muster and again consume fodder that could otherwise be used productively (O'Rourke et al., 1991).

Another challenge for beef producers in extensive rangeland systems is determining when to sell animals to maximize returns (Burns et al., 1990). Typically, producers retain offspring until they are old enough to market into the live export trade or until the pasture quality diminishes and young stock must be sold. This means that producers reduce the number of breeding stock carried on the property to ensure that the offspring reach market weight. Otherwise, if the season is unfavourable producers must sell cattle not in ideal market condition. On the contrary if producers reduced the age at sale of offspring, they could increase the number of breeders and thereby increase the number of young stock sold. However, increasing the number of

[1] In the context of this paper when *Bos indicus* is referred to this includes *Bos indicus* breeds and their derivative cross-breds.

breeders increases the risk of the business when seasonal conditions are not ideal, as these animals require relatively high levels of nutrition compared to store animals (Bortolussi et al., 2005).

The primary objectives of this research were to: (i) estimate the benefits of improved reproductive efficiency in the pastoral region of Western Australia on the gross margin; and (ii) identify which factors, age at first breeding or reproductive rate, effect the gross margin of the beef breeding system most. A secondary focus of the research is to examine the impact that sale age of young stock has on gross margin, herd performance, and herd structure.

Methods and Material.

Simulation Model.

A problem with on-farm analysis of the type in this study is collecting data of sufficient quality and quantity to study the problem at hand. Collection of farm level data does not always provide the quality and quantity of data needed and identifying the effects of individual practices of each farm is difficult with small data sets. Also, as the proposed analysis has an economic component segregating out the different prices received by individual producers compounds the problem further (Trapp and Walker, 1986). For example, an unpublished benchmarking data set from six producers contains the data required. To undertake a simple statistical analysis of the data allowing for a constant term, price, farm, and reproduction effects leaves two degrees of freedom for statistical comparison. For these reasons a single hypothetical case study is used with constant prices, to remove farm and price effects from the analysis. This is not to say these are unimportant variables, it was done to identify the effects that the independent variables of interest have on the gross margin. Using this approach allows us to model the biological production process independently of the economic process, but in the statistical analysis described later, the two processes are merged to measure the effect of the biological processes on the economic outcomes of the system (Musser and Tew 1984).

To estimate the effects of herd management changes on the profitability of the beef enterprise a series of scenarios were analysed using the BREEDCOW herd software (Holmes, 2003). This program calculates the gross margin for a breeding herd based on inputs from the herd manager. The program is coupled with a herd dynamics component that calculates breeding herd structure based on the reproduction, sale, culling, and death parameters entered. Information regarding bull requirements and costs of bulls, variable costs, stocking rate and or herd size, and sale prices of different categories of animals are also required. Variable costs include health, vaccinations and drench costs, fodder and supplementary feed costs, and any other costs directly associated with the breeding enterprise. BREEDCOW allows the user to select either herd size or stocking rate as the basis of herd structure, in this study as mentioned before stocking rate is limited. Once the herd structure selection is made the program provides information regarding the number of weaner heifers to retain to maintain stocking rate or herd size at the desired level. In this study both stocking rate and herd size were changed in various scenarios.

A hypothetical farm was utilized in the research. Although hypothetical, the basic structure of the herd and herd size was derived from several unpublished benchmarking analyses in the north-western pastoral zone of Western Australia. The size of the property was 1368 sq km of which 50% was used for grazing giving a grazing area of 68,400 ha. The maximum stocking rate was 2,770 adult equivalents (AE), or approximately 25 ha/AE. An adult equivalent is the feed requirement to maintain a non-breeding, non-lactating 450 kg animal for 1 year (Anon, 2005).

In the case study herd the adult death rate is set at 3% for both females and males. Cows remain in the herd until 11 years of age if they are not culled or die. It is assumed that there is an optional annual cull rate of females of 10% of the breeding herd. Reasons for culling females include repeat non-breeders, injury or illness. The bull to cow ratio is set at 3.5 bulls per 100 cows, which typical for the type of system being studied (Rudder et al., 1992). Initially, male turnoff age and age at first breeding for females was set at 2 years old.

As one focus of this study is on reproductive performance and efficiency, parameters related to reproduction were varied. The parameters altered were branding or weaning rate and the age at first breeding (**BA**). The range of weaning rates, as a proxy for reproduction rate (**RR**), tested was from 55 to 80% in 5% increments with six increments in total. This range was chosen to represent the current situation and the ideal state, as defined by O'Rourke et al. (1991), and potential intermediate stages. The intermediate stages show how the herd's structure changes with variations in reproduction rates and the constraints imposed by the stocking rate limit. Age at first breeding of heifers was either 15 or 27 months of age. The typical sale age of male offspring is two years, the range for sale age (**SA**) in the scenarios tested was 0, i.e. weaners, 1, yearlings, or as two year olds[2].

Finally, two herd management strategies were used, either a constant number of females were kept in the herd and reproduction rates varied, therefore stocking rate varied with the reproduction rate. The second management strategy was that a constant stocking rate was maintained by adjusting female numbers to maintain the constant stocking rate. With the combination of variables tested there were potentially 72 different scenarios. However, in scenarios when the breeding herd was kept constant and the sale of age of offspring was set at two, the total stocking rate exceeded the upper limit of 2,770 AE. Because of this constraint the number of potential scenarios was limited to 56.

Variable costs were derived from benchmarking studies and were based on the costs per animal equivalent, which varies with animal age and sex. Income was based on the per kilogram price of beef at Karratha for live export animals. Cull cows and bulls are assumed to be sent for slaughter in the south of Western Australia. Bull purchase costs were the average purchase price, including transport costs, for *Bos indicus* herd bulls from Queensland.

The costs per animal class, in each scenario, were not changed to account for higher inputs that may be needed to achieve the reproduction levels for each respective scenario. This was done so that it was possible to estimate the difference in gross margin due simply to the change in reproduction or management variables. The difference between gross margins, before and after the change in reproduction rates,

[2] Age 0 implies the average age at sale was less than 1 year old, age 1 implies the age of sale is between 1 and 2 years old, and age 2 that average sale age is greater than 2, but less than 3 years old.

provides an indication to the manager regarding how much extra income is possible with higher reproduction rates or differences in sale or joining age. Management can then determine whether it would be profitable and or feasible for them to incur the extra costs to improve reproduction efficiency in their system.

Statistical Model.

A problem that arises from using simulation models, particularly in economic analyses, is that the simulation model by itself does not provide an optimal solution, unless by chance (Trapp and Walker, 1986). However, the information or data generated from simulation models can be used to estimate production or profit functions for use in economic analysis because of the number of potential scenarios that can be analysed with one simulation model (Musser and Tew, 1984; Dillon and Anderson, 1990). These functions can then be used to estimate optimal solutions.

Using the information generated from the simulation analysis a statistical evaluation of the effect of reproduction and management variables on gross margins was undertaken. Further analysis of the equations derived from this model determined the optimal reproduction strategy, age at first breeding, and sale age. The general model constructed was as follows:

$$GM = f(RR, BA, AE, SA) \quad (1)$$

Where RR = reproduction rate, BA = age at first breeding, AE = adult equivalents as a measure of stocking rate, and SA = age at sale of male offspring and surplus heifers. The model was estimated using the Gnu Regression, Econometrics and Time-series Library (GRETL) program (Cottrell, 2004). Initial examination of the model indicated heteroscedasticity, hence the final model was corrected for heteroscedasticity using weighted least squares.

Results and Discussion

Simulations

BREEDCOW provides extensive output with respect to the management and economic variables of the herd, many of which while useful are not relevant to the current study, hence only data pertinent to the study will be presented. Table 1 contains a summary of the data generated from the 56 scenarios simulated. The number of adult equivalents on the property, the number of females bred, and number of males sold varies widely depending on the scenario parameters. For example, the range in the number of adult equivalents is from 2287 to 2770 with an average of 2692, and females bred ranged from 1541 to 2375 and averaged 1813. The number of males sold ranges from 444 to 882 with an average of 525. When these values are compared to the unpublished benchmark values differences in management become immediately apparent. Using the same three variables as above, the benchmark data for adult equivalents ranges from 1351 to 5148 with an average of 2770; 553 to 2483 females bred; and 182 to 659 males sold. These values demonstrate the problems of using different farms and management systems to calculate the impact of management variables on the economics of the system.

The effects of changes in the various management parameters cannot be directly observed in Table 1, because of this three figures (Figures 1, 2, and 3) were constructed to present the data graphically. From Figure 1 it can be seen that total gross margin increases with reproduction rate, which would be expected in that more offspring are available for sale. Figure 2 shows that age at sale has, at first an increasing effect on total gross margin; however, this effect then diminishes as the animals get older. This occurs for two reasons, the increasing total gross margin from age 0 to age 1, shows the effect of the increasing value of the animals as they age and become heavier. The decreasing total gross margin after age 1 captures the effect of reductions in animals sold as fewer animals can be carried in total due to the number of older offspring and the demand on the system to provide feed for these older animals. Decreasing gross margins occur even though the older animals are heavier and worth more. This indicates that the marginal benefit of keeping animals longer is reduced by the opportunity cost of a reduction in the total number of saleable animals carried, even though they are worth less due to lighter weights.

The final figure of the three, Figure 3, illustrates the effect of age at first breeding on total gross margin, in this study, there were only two values for this variable 1 or 2 years of age. The data in Figure 3 implies that total gross margin decreases with an increase in age at first breeding; the reason for this effect is similar to that for age at sale. Breeding animals earlier implies that fewer non-productive females are required to maintain herd size; hence there are more surplus heifers that can be sold. Also costs are reduced as less money is invested in rearing heifers to calve at an earlier age (Tozer and Heinrichs, 2001). These costs include the variable and capital costs needed to rear heifers and the opportunity costs of keeping heifers that otherwise would have been sold to generate income.

Impact of Changes on Herd Structure.

As expected the changes in management variables affected the herd structure. Increasing reproduction rates reduced the number of cows and heifers mated and overall herd size, with a subsequent increase in weaner heifer sales. The reduction in females mated and herd size is a direct result of the constraint on herd size due to fixed stocking rate. The increase in weaner heifer sales is due to the reduction in the number of replacement females required to maintain herd size and the increase in the number of calves born. Also, an increase in reproduction rate reduced the capital investment in the herd, due to less cows being retained, but increased income due to more animals sold overall. As sale age and breeding age fell, breeding herd size increased as there is less demand on feed by older non-breeding animals. This lower feed demand allows the model to replace non-breeding animals with breeding females.

Statistical Model

The statistical model did not have a constant term as it is unrealistic to expect an animal breeding system to generate income without reproduction from the females within the system. Hence, the statistical model is as follows (values in parentheses are standard errors):

$$\underset{}{TGM} = \underset{(9533.22)}{527\,427 \cdot RR} - \underset{(15\,888)}{459\,195 \cdot BA} + \underset{(5296.7)}{133\,479 \cdot BA^2} + \underset{(2656.8)}{99\,066 \cdot SA} - \underset{(1469.5)}{54\,922 \cdot SA^2} + \underset{(4.094)}{152.56 \cdot AE}. \qquad (2)$$

As the model is linear in the parameters goodness of fit measures such as an adjusted R^2 can be used to measure fit. In this model the adjusted R^2, after correcting for heteroscedasticity is 0.9959. This value may appear somewhat surprising, suggesting that the model is a very good fit, however it must be remembered that the only variables changed in the model were those included in the statistical model, therefore a very good fit would be expected. Various models were tested that included higher level polynomial stocking rates, but these produced problems including collinearity and high degrees of heteroscedasticty. Also, there were no significant interactions between the variables studied.

The signs of the parameters also agree with the general shape of the curves shown in Figures 1, 2, and 3, i.e. increasing with reproduction rate, and inverse parabolic shapes for breeding age and sale age. Also, as stocking rate increases total gross margin increases. In the case of stocking rate there was no turning point, implying that increasing stocking rate will always increase total gross margin, this is true up to a critical point when increasing stocking rate leads to overstocking and a decrease in economic returns. However, with the stocking rates, stocking rate upper limit, and model variables studied here this turning point was not reached. Also, with the model construct used the turning point could not be identified as stocking rate was not an independent variable in the model.

One benefit of using a simpler model, other than ease of analysis and convergence, is that the parameters can be used directly to demonstrate the effects of changes in the independent variables on the dependent variable, in this case total gross margin. This is done by taking the first derivative of the model with respect to the variable of interest. For example, when analysing the effect of changes in reproduction rates on total gross margin, *ceteris paribus*, we have the first derivative of 527 427. This indicates that for every one per cent change in reproduction rates (i.e. from 68% to 69%) total gross margin increases by $5 274 (i.e. 527 427 * 0.01), as reproduction is measured in a scale of percentages.

Given that a one per cent increase in reproduction rates can increase total gross margin by $5 274, the producer can spend up to this level on techniques, technology or variable inputs, such as feed, health requisites, more bulls, or capital investments, and still increase total gross margin. However, it must be remembered that in the case of capital investments only the annual costs associated with capital investments, such as depreciation, interest and or principal repayments, are included, not the total capital costs. Similarly, for every extra adult equivalent that could be carried the total gross margin of the system will increase by $153.

Other benefits from estimating a mathematical expression for total gross margin is that it is possible to estimate the optimal value for variables of interest to provide further information for the manager. In the case of equation 2, we can calculate the optimal value of age at sale and age at first breeding using calculus. For age at first breeding the optimal age is approximately 20.6 months, which is less than the typical age of 24 months. Using the same method the optimal age at sale for male offspring and surplus heifers is approximately 10.8 months.

The benefits from improving reproduction rates and the values for age at first breeding and sale age of offspring provide information regarding the optimal system.

However, to achieve these optimal ages it may be necessary for the producer to make changes to management systems within the overall system. Such changes could include additional fencing and smaller paddocks to manage mating and calving, providing additional feed in the dry period when cows and calves begin to lose body condition, or culling non-pregnant cows or cows that do not rear a calf regularly, not necessarily annually, although that would be ideal, or moving from a year round breeding pattern to a seasonal breeding regime (O'Rourke et al., 1991). Also, it would be necessary to ensure that heifers and steers are at a weight suitable for breeding or market. This may require changes to the management of this group of animals or changes to the overall enterprise, farm management or structure.

Each of these changes will incur some expense to the system and it would be necessary for management to determine which, if any, of these options is most feasible given the constraints of the individual system. For example, research in the extensive pastoral region of Queensland concludes that providing urea-based supplements may increase the gross margin of the enterprise but only through a reduction in breeder mortality (Dixon, 1998). The economic effectiveness of this strategy depended mostly on the delivery system of the supplement. For some delivery systems the impact on gross margins was marginally positive or negative; hence the investment may not yield a benefit to the producer.

Moving from a year round breeding system to a seasonal calving pattern requires changes to the mustering schedule with a concurrent increase in costs. This management method allows for ease of introduction and removal of bulls from the breeding herd. Also identification of non-breeders or calves that could be weaned from their dams could be undertaken. This would reduce the nutritional requirements of the cow and allow the cow to build reserves for next the pregnancy and lactation (Webb-Smith 1996). The increased costs are more than offset by increased weaning rates and earlier sale of these weaners due to better management leading to heavier weights at sale.

Sensitivity Analysis

In the simulations and statistical models price was held constant to identify the effects of the variables of interest: reproduction rates, breeding and sale age, and stocking rate; on the enterprise gross margin. However, it would be reasonable to assume that price would also affect the gross margin of the system; hence a separate set of scenarios was run using prices that were 10 per cent lower than those used in the base scenarios to ascertain these effects. The new model is shown below in equation 3 (values in parentheses are standard errors):

$$TGM = 451\,845{*}RR - 413\,722{*}BA + 121\,146{*}BA^2 - 10847{*}SA + 138.62{*}AE \quad (3)$$
$$(7098.9) \qquad (13\,278) \qquad (4402.6) \qquad (1178.2) \qquad (3.865)$$

As expected with lower prices gross margin fell, but at a higher rate than the change in price. With a ten per cent reduction in prices the total gross margin of the system across all 56 scenarios fell by an average of 17 per cent, with a range of 14 per cent to 19 per cent. The highest impacts on total gross margin were on systems with relatively low reproductive rates. In general, the impact of the reduction in prices was to reduce the gross margins, but retain similar properties to those observed in Figures 1, 2, and 3.

One change that did occur, with lower prices, was that gross margin became less sensitive to the sale age of offspring. In figure 2 it is possible to see the quadratic nature of age of sale on total gross margin. In the situation where price was reduced it was not possible to identify this quadratic trend and indeed the fit of the sale age variable, while significant was much lower than in equation 2; hence the dropping of the sale age quadratic term in equation 3. As expected, lower prices reduced the amount of money available for improving reproduction rates or other management variables. In equation 2 the increase in total gross margin from a one per cent increase in reproduction rate was $5274, whilst in equation 3 this value has dropped to $4581, a reduction of 13 per cent.

With the decrease in prices the opportunity cost of keeping replacement heifers caused the optimal age at first breeding to fall from 20.6 months to 20.5 months. Because of the change in the function it was not possible to identify the optimal age at sale for surplus heifers and male offspring. However, it would be reasonable to assume that the age at sale would fall by a small amount, similar to the age at first breeding, due to the opportunity costs of keeping stock longer.

Conclusion

Reproductive inefficiency is costly to producers in any animal breeding system as it reduces the number of animals available for sale or for use as replacements in the breeding herd. The reduction in animals for sale reduces the income of producers. Further, changes in management variables, such as age at first breeding or age at sale can also impact on gross margins.

In this study a case study business is the basis of a statistical model to estimate the benefits of changing management variables in the pastoral region of Western Australia. The results of the models show that it is possible to increase the gross income of the enterprise through improving reproduction rates. With the assumptions used in the models constructed, a one per cent increase in reproductive rates would increase gross revenue by $5 274. This increase in gross income will come at some expense to the producer. However, the expense incurred will depend on the method chosen. Methods could include: changes in fencing to reduce paddock size; improve the nutritional status of certain groups within the breeding herd through strategic supplementation; or changing breeding strategies by converting to a seasonal breeding pattern from a year round breeding system.

Other changes to management variables also had positive impacts on enterprise gross margin. These changes included reducing age at sale and age at first calving. However, these changes, again must consider the quality of the animal. To simply say that producers need to reduce age at first breeding underestimates they complexities of the problem. It is essential that heifers be in ideal body condition at breeding, reducing the age at breeding without concurrent changes in nutritional strategies could reduce gross margin below the current margins, as the reproduction rate could be lower. Similarly, reducing the age at sale requires that the animals sold are in condition suited to the market. But, animals should not be sold at an age less than the optimal of 10.8 months. To achieve the optimal ages at breeding or sale, producers would more than likely incur some costs. The method used in this study can assist producers to identify the limit of these costs and potentially increase enterprise profitability.

The final choice of identifying and changing management must be made by the producer. However, if a change is made, the change must generate positive outcomes, whether they are economic or non-economic, such as changes in lifestyle. This modeling framework provides a useful method to assist in making these decisions.

References

Anon 2005, Estimating adult equivalents. Department of Primary Industries and Fisheries. http://www.dpi.qld.gov.au/beef/14699.html. Accessed May 20, 2005.

Braden AWH, Baker AA 1973, 'Reproduction in sheep and cattle' in G Alexander and OB Williams (eds.). *The Pastoral Industries of Australia: Practice and Technology of Sheep and Cattle Production*. Sydney University Press.

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, and Holmes CR 2005, 'The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management', *Australian Journal of Experimental Agriculture*, 45(9): 9-14.

Burggraaf, W 2004, *A Descriptive Analysis of the Beef Supply Chain in Western Australia*. Miscellaneous Publication 18/2004. Department of Agriculture Western Australia, South Perth,

Cottrell, A 2004, *Gretl Manual*: Gnu Regression, Econometrics and Time-series Library. http://gretl.sourceforge.net.

Dillon, JL, Anderson, JR 1990, *The Analysis of Response in Crop and Livestock Production*. Pergamon Press, Oxford.

Dixon, RM, 1998, *Improving cost effectiveness of supplementation systems for breeder herds in northern Australia*. Final Report, Project DAQ.098, Department of Primary Industries, Ayr, Queensland.

Hearnshaw, H., Arthur, PF, Barlow, R, Kohun, PJ, Darnell, RE 1994, Evaluation of Bos indicus and Bos taurus straightbreds and crosses. II. Post-weaning growth, puberty and pelvic size of heifers. *Australian Journal of Agricultural Research* 45, 795-805.

Holmes, WE 2003, BREEDCOW and DYNAMA. *Herd Budgeting Software Package*. Rural Industries Business Services, Department of Primary Industries, Townsville.

Musser, WN, Tew, BV 1984, Use of biophysical simulation in production economics. *Southern Journal of Agricultural Economics* 16, 77-86.

O'Rourke, PK, Doogan, VJ, Robertson, DJ, Cooke, D 1991, Prediction of conception rate in extensive beef herds in north-western Australia 2: Continuous mating and minimal management. *Australian Journal of Experimental Agriculture* 31, 9-14.

O'Rourke, PK, Esdale, CR, Howitt, CJ, Rudder, TH 1992, Productivity of Hereford, highgrade Simmental and Belmont Red beef herds in central Queensland; 3. Explanatory model for pregnancy rate. *Australian Journal of Experimental Agriculture* 32, 563-568.

Quin, A, Manners, A 1999, *Rising Above the Herd: An Analysis of the Western Australian Beef & Cattle Industry*. AGWEST Trade and Development, Perth.

Randel, RD 1994, Unique reproductive traits of Brahman and Brahman based cows, In: MJ Fields and RS Sand, (Eds.). *Factors Affecting Calf Crop*. CRC Press, Boca Raton.

Rudder, TH, Webber, RJ, Knights, PT, O'Rourke, PK, 1992. Productivity of Hereford, highgrade Simmentals and Belmont Red beef herds in central

Queeensland 6. Whole herd income and gross margins. *Australian Journal of Experimental Agriculture* 32, 1023-1029.
Tozer, PR, Heinrichs, AJ, 2001. What affects the costs of raising replacement dairy heifers: A multiple component analysis. *Journal of Dairy Science* 84, 1836-1844.
Trapp, JN, Walker, OL, 1986. Biological simulation and its role in economic analysis, in TH Spreen and DH Laughlin (Eds.). *Simulation of Beef Cattle Production Systems and Its Use in Economic Analysis*. Westview Press, Boulder.
Webb-Smith, ND, 1996. Cattle Management Strategies for the Northern Pastoral Industries of Australia. Department of Agricultural and Resource Economics, University of New England, Armidale, Australia.
Williams, OB, 1973. The environment. In: Alexander, G., Williams, O. B. (Eds). *The Pastoral Industries of Australia: Practice and Technology of Sheep and Cattle Production*. Sydney University Press.

Table 1

Summary of data from simulations of different breeding age, reproduction rates, sale age, and stocking rates, (n = 56).

Variable	Mean	Minimum	Maximum	Standard Deviation	Coefficient of variation
Adult equivalents	2679	2287	2773	153.2500	0.0572
Total number of cattle	2964	2376	3303	286.0400	0.0965
Number of heifers retained	404	329	482	36.0050	0.0892
Number of calves branded	1282	936	1765	180.7500	0.1410
Reproduction rate (%)	0.6839	0.5500	0.8000	0.0821	0.1200
Total number of cows retained	567	394	803	89.5910	0.1580
Heifer joining age (years)	1.50	1.00	2.00	0.5045	0.3364
Sale age of male offspring and surplus heifers (years).	0.82	0.00	2.00	0.7653	0.9317
Total cattle sold	1141	838	1451	152.7514	0.1339
Total gross margin (Base Price)	$426,590	$295,910	$572,720	$65,074	0.1526
Total gross margin less imputed interest	$285,470	$164,251	$429,387	$64,661	0.2265
Gross margin per adult equivalent	$159.14	$116.00	$207.00	$22.38	0.1406
Total gross margin (Low Price)	$352,675	$255,640	$464,770	$49,031	0.1390
Total gross margin less imputed interest	$228,069	$138,479	$345,288	$49,450	0.2168
Gross margin per adult equivalent	$131.75	$99.10	$167.91	$17.39	0.1320

Figure 1: Effect of reproduction rate on total gross margin.

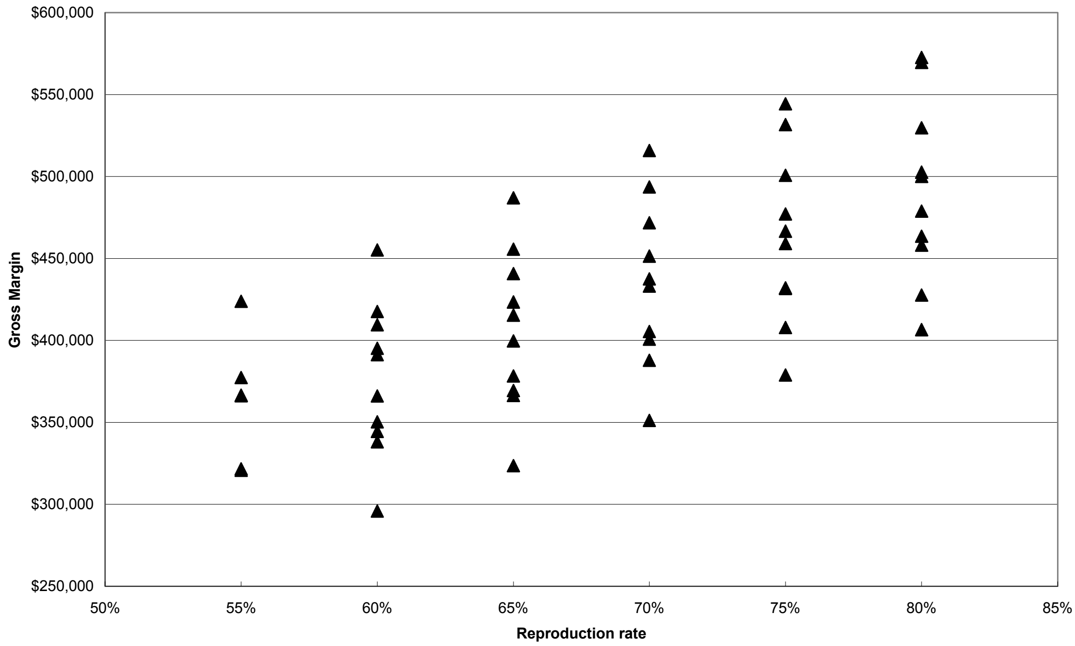

Figure 2: Effect of average age at sale of male offspring and surplus heifers on total gross margin, age 0 implies the average age at sale was less than 1 year old, age 1 implies the age of sale is between 1 and 2 years old, and age 2 that average sale age is greater than 2, but less than 3 years old.

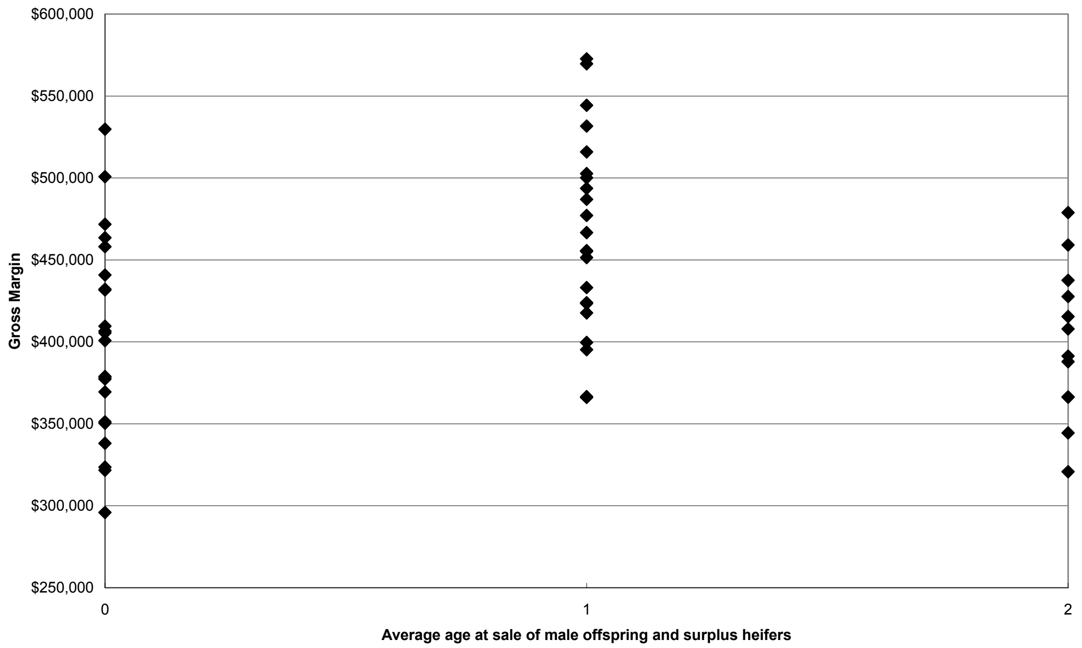

Figure 3: Effect of age at first breeding on total gross margin.