
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

Gross margin analyses of using cloned embryos in cattle

D. C. SMEATON, S. J. R WOODWARD, D. N. WELLS, J. F. SMITH

AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand
Woodward Research Limited, PO Box 21160, Hamilton, New Zealand

ABSTRACT

A spreadsheet model was developed that evaluated the gross margin (GM) profitability of clone embryos placed by embryo transfer into recipient cows compared to Hereford x Friesian cows naturally mated to a high growth rate finishing sire. Biological parameters in the model included variables of performance such as losses at various points through pregnancy, calving and rearing and cow losses and calving difficulty. Variance (SD) and correlation information associated with gestation length, birth weight and calf liveweight gain were included. Allowance was made for the extra costs associated with clone ET and the possibility of lower pregnancy rates. To provide a stable result, the model was based on a 1000-cow herd. Assuming 50% of clone ET cows are diagnosed pregnant at 28 days after ET (35 days of gestation) we determined that clone embryos must sell for NZ$84 each to break even with the natural mating system, assuming *80%* of clones surviving to weaning would sell in niche markets at 3 times the price/kg liveweight of their cohorts. When *all* clones attracted the premium, the breakeven price was $142/embryo. The coefficient of variation (CV) of GM profit was 6% for the clone herd vs. 2% for the naturally mated herd. For smaller herds (say 100 cows), with a proportionately lower herd GM, the CV of GM and therefore risk, was higher, at 17%. At weaner clone premiums ranging from 2.25 to 4 times the normal weaner price/kg, the breakeven price ranged from $0 to $195/embryo respectively if 80% of the clones received the premium and $10 to $280 when all weaned clones received the premium.

Keywords: beef; cow; embryo transfer; clone; profitability.

INTRODUCTION

Beef markets are increasingly demanding greater consistency, or predictability, of product safety, quality, size, and timing of delivery. New reproductive technologies for cattle, described by Thompson *et al.* (1998), have the potential to accelerate genetic gain and increase the rate of propagation of superior genotypes compared with systems using artificial insemination (AI) or natural mating. In addition, production of cattle via fertilisation of egg with sperm results in the random re-mixing of genes with subsequent genetic and phenotypic variation in the offspring. Improvement in the average expression of desired traits through breeding programmes is possible (and is a major industry) but guaranteed retention and rapid propagation of a superior genetic mix is only possible with cloning. However, although propagation through cloning is straightforward and widespread in the world of horticulture it is a much more challenging matter in mammals such as sheep and cattle.

Domestic farm animals do produce identical offspring or clones naturally but at a very low incidence (Thompson *et al.*, 1998). An enormous amount of research continues to be focused on cloning cattle with the technique of nuclear transfer, using cells either obtained from early embryos or somatic tissues from elite adults (Thompson *et al.*, 1998; Galli et al., 2003; Oback and Wells, 2003). Although there are numerous technical difficulties still to be resolved, especially with somatic cell nuclear transfer, it is a rapidly developing area and also a potentially very valuable means of copying rare and superior genotypes and/or producing or copying transgenic animals (Brophy et al., 2003; Galli *et al.*, 2003). A by-product of the technologies includes the additional benefits of calving to synchronised matings (Pleasants *et al.*, 1999).

In anticipation that the technical problems in producing clone cattle will be solved and that the procedure is eventually accepted by regulatory authorities and the community at large, we carried out the present modelling project to establish the likely premiums that cloned animals will have to achieve to compete with existing reproductive technologies based on natural mating or AI.

MATERIALS AND METHODS

Description of systems simulated

A biological and gross-margin model was developed on a spreadsheet to simulate a system using cloned cattle embryos and synchronised embryo transfer (ET). This model allowed tests to be carried out for price sensitivity and break-even results for a range of applications using cloned embryos. Breakeven was assumed to occur when the clone system ran at the same level of profit as the designated natural mating system. Biological assumptions were included in the model and financial parameters, including enterprise costs, associated mostly with mating and calving, and returns from the sale of weaner calves and cull cows were added. The cost of the farmer's labour at mating time was not included. The weaner calf was used as the end point of sale.

In the model, a "status quo" beef production system was simulated for use as a base line comparison. This system involved the use of Hereford x Friesian (HxF) breeding cows naturally mated over 9 weeks to a large high growth rate finishing sire with all progeny sold as weaners to be finished for slaughter. Cows that were diagnosed empty after mating were replaced by purchasing in-calf HxF cows assumed to be 4 to 5 months pregnant to natural mating. Cows dying around calving time were replaced prior to the following mating. Herd size therefore remained constant from year to year.

A clone system was also simulated. Here, the oestrous cycles of HxF cows or similar were synchronised and then on day 7 each received a cloned embryo transferred to the reproductive tract. Those cows that failed to hold were resynchronised for another round of embryo transfer before using natural mating, for a third potential cycle, to a bull as above. Conception rates were assumed for each mating cycle of 21 days. Cow losses were treated as in the natural mating model above.

Assumptions were made about conception rates, dates, subsequent embryo losses, losses at and after calving and calf liveweight gains to weaning. Variance values for calf birth weight and growth rate from birth to weaning were incorporated into the model on the grounds that animals with essentially identical nuclear genetics would have lower liveweight-gain variance than unrelated animals. Correlation coefficients for gestation length with birth weight and subsequent liveweight gain were also included. Biological assumptions, described by Smeaton (2001) were based on published data, observed values in a field project concurrently running at Whatawhata Research Centre, and from the Reproduction Laboratory at Ruakura Research Centre.

Financial data (excluding GST), based on prices in New Zealand in 2003, were then incorporated including the costs of mating by either system, costs of replacing dead or empty cows, extra costs associated with calving cows carrying clones and the returns that could be expected from the calves at weaning. Provision was made for the possibility that clone calves that met required weight criteria at weaning would have one value and those that did not meet the criteria (below an assumed cut-off weight) might be worth less (a split premium system) than naturally mated calves per kg of liveweight. This feature was included in the model based on comments provided by a potential end user (Phil Tither pers. comm.). The results are presented with and without this feature incorporated.

Where values were assumed to be the same across the different systems, they were generally not included in the model. Break-even was defined to have occurred when the gross margin (GM) returns from the clone-based system were equal to those from the natural mating system.

Table 1 shows a copy of the user input screen. It provides a full list of assumptions or input data used and which the model user could alter. The values shown in the table are those used to provide the breakeven results described in Table 2 (split premium) and Figure 1 and are our best assessment of realistic figures as of the year 2003 although the clone embryo survival figures are optimistic. In Table 1, C1, C2 and C3 refer to mating or oestrous cycles 1, 2, and 3 respectively after the start of mating, NM = naturally mated, Prob. = probability, MT = empty or non-pregnant cow, PD = pregnancy diagnosis result, BWt = calf birth weight, LWG = calf liveweight gain (kg/day) from birth to weaning and LWt = calf liveweight.

Important assumptions which differed between the clone and natural mating systems, included the value of the weaner calves per kg liveweight (with or without split premium), the standard deviations (SDs) applied to calf birth weight and liveweight gain, the differences in conception rates, embryo and calf and cow survival and the additional costs of calving cows which were carrying clones.

The model operated in a step-wise fashion so that each event (e.g. ET) with its associated probability was applied to each animal present in the model at that point. The probability result was calculated using a random number and the answer was then applied to the next event and so on. As a result, at weaning time, a number of surviving calves were present, each with their own designated birth date, sex, weaning weight and clone (or not) status from which mean weaning weights and SDs were calculated.

Output of interest was presented in tabular form for each class of calves (somewhat consolidated in Table 2 below). The model was run to establish GM profit values compared with the natural mating system. Initially, the model was run with 1000 cows to provide a statistically stable output. The following results provide information on our tests on breakeven values for embryo price, pregnancy and/or embryo loss rates, and lastly, the impacts of herd size on risk. Tests of statistical significance were not appropriate because, with a simulation model, it is easy to keep running additional simulations until even small differences become statistically significant. Instead, coefficients of variation (CVs) and SDs are presented to indicate the variation in each mean prediction.

TABLE 1: List of assumptions used in the model: a very small proportion of the values shown are calculated, based on assumptions in the lines above.

Assumptions and input data

Synchronised clone mating system:	
Day of first oestrous used for ET	1
Oestrous cycle length	21
Prob of conception to ET C1	0.5
Prob of ET C1 failure in C2	0.1
Prob of ET C2 failure in C3	0.1
Prob of conception to ET C2	0.5
Prob of ET cycle 2 failure in C3	0.1
Prob of conception to ET C3 (NM)	0.6
Cycle 1 calf type or breed	Clone
Cycle 2 calf type or breed	Clone
Cycle 3 calf type or breed	Natural
Prob % of male sex embryos C1	100
Prob % of male sex embryos C2	100
Prob % of male sex embryos C3	52
Cost of C1 ET mating:	
CIDR $/cow	10
Other scynchronising drugs $/cow	10
Farmer's labour $/cow	10
Cloned embryo $/embryo = $/cow	**84.33**
ET technician $/cow	20
Rompun $/cow	10
Other costs $/cow	40
Total cost C1 synch mating $/cow	184.33
Cost of C2 ET mating:	
Costs of C1 failed ET mating	184.33
CIDR $/cow	0
Other scynchronising drugs $/cow	0
Farmer's labour $/cow	10
Cloned embryo $/embryo = $/cow	84.33
ET technician $/cow	20
Rompun $/cow	10
Other costs $/cow	40
Total cost C2 synch mating $/cow	348.66
Costs of C3 natural synch mating:	
Average cost of failed C1 or C2 ET mating	321
Assessed cost of bull $/cow	50
Total cost C3 synch mating $/cow	371
Costs of ultimately empty cow	
Average cost of failed ET mating	324

Dates and cow numbers	
Start mating date (=day 1)	30/11/2001
Weaning date	30/03/2003
Mating synch or not: True/False	TRUE

Natural mating system -unsynchronised	
Oestrous cycle length	21
Prob. of conception to cycle 1	0.6
Prob. of conception to cycle 2	0.6
Prob. of conception to cycle 3	0.6
Prob % of male sex embryos C1	52
Prob % of male sex embryos C2	52
Prob % of male sex embryos C3	52
Cycle 1 calf type or breed	Natural
Cycle 2 calf type or breed	Natural
Cycle 3 calf type or breed	Natural
Accumulated cost of cycle 1 mating $	50
Accumulated cost of cycle 2 mating $	50
Accumulated cost of cycle 3 mating $	50

Both systems -extra IC cows	
These make up for MTs at May PD	
Oestrous cycle length	21
Prob. of conception to ET cycle 1	0.6
Prob. of conception to cycle 2	0.6
Prob. of conception to cycle 3	0.6
Prob % of male sex embryos C1	52
Prob % of male sex embryos C2	52
Prob % of male sex embryos C3	52
Cycle 1 calf type or breed	Natural
Cycle 2 calf type or breed	Natural
Cycle 3 calf type or breed	Natural
Net cost of buying an IC cow	200
Accumulated cost of cycle 1 mating $	524
Accumulated cost of cycle 2 mating $	524
Accumulated cost of cycle 3 mating $	524

Foetal and calf survival, weights, calf income	Female Clone	Female Nat mate	Male Clone	Male Nat mate
Mean gestation length days	282	282	282	282
Gestation length SD days	3	3	3	3
Prob of foetal mortality	0.1	0.05	0.1	0.05
Prob of calf mortality at calving	0.1	0.05	0.1	0.05
Mean birth weight kg	30	30	30	30
Birth weight SD kg	1	4	1	4
Correlation BWt with Gest length	0.36	0.36	0.36	0.36
Calf mortality birth to weaning	0.1	0.03	0.1	0.03
LWG birth to weaning kg/day	1	1	1	1
LWG SD kg	0.03	0.13	0.03	0.13
Correlation LWG with BWt	0.34	0.34	0.34	0.34
Calf value at weaning $/kg LWt	6	2	6	2
Calf value $/kg LWt low weight	1.8		1.8	
Cut-off high vs. low weight: deviation from avg wean wt kg	-5		-5	

Costs of calving cows Applied to calves born	clones Calf	Nat mate Calf
Vet costs per cow	20	5
Managed calving costs per cow	20	0
Cow loss rate	0.05	0.02
Cost of dead cow	500	500
Total cow costs per calf born	65	15

TABLE 2: Typical single replicate results from the model set to simulate a clone split premium system and natural–mating system respectively. Note that the two systems show a similar level of profit.

System simulated	Clone	Natural mating
No. of cows present at start of mating	1000	1000
No. of cows present at weaning	958	983
No. of calves weaned	786	880
All calves average weaning weight (kg)	216	212
All calves weaning weight SD (kg)	23	30
Clone calves weaning weight SD (kg)	6	N/A
Average income/cow mated ($)	660	373
Average costs/cow mated ($)	366	76
Average profit/cow mated ($)	294	298
No. of high value clones weaned	356	0
No. of low value clones weaned	104	0
Cut-off wean weight* deviation (kg)	-5	N/A
No. of embryos transferred**	1592	N/A

* The user input weight deviation below the average at which the cloned calf value changed from high to low price/kg wean weight.
** One embryo transferred per cow per ET mating

RESULTS

Calf weaning weight and survival

Table 2 shows the results from a typical simulation run for both a clone (split premium) and a natural calf production system. Based on the assumptions used (Table 1), average weaning weight of the calves for the 2 systems was similar, although the SD of weaning weight of *all* the calves from the clone system was 23% less than that of the calves from the natural mating system. Note that the clone system SD included a component of calves produced by natural mating in cycle 3 or from cows purchased as replacements to replace empty cows (Table 2). The clone calves in this system had a SD that was only 20 % of that of the calves from the natural mating system. The clone system produced 11% less calves and 3% less cows surviving to weaning than the natural mating system because of assumed higher cow and calf losses in late pregnancy and at calving (Table 2). In this particular run, 1592 embryos were required for ET (1000 in cycle 1 and 592 in cycle 2) to produce 460 clone calves at weaning. The table also shows that, for the cut off weight assumption used of 1 SD unit deviation (6kg) below the average clone weaning weight (split premium system), just over 20% of all clone calves failed to achieve the clone premium and were therefore deemed worth less per kg liveweight than if they had been calves produced by natural mating.

Breakeven embryo price

Figure 1 shows gross margin results for both the clone systems at a range of embryo prices with all other assumptions held constant at the values in Table 1. The results were compared with those for the natural mating system to establish breakeven values for the clone embryos that would enable these systems to run at the same level of profit as the natural mating system. Using the regression functions in Figure 1, this value was found to be $84/embryo (split premium) and $143 when all clone calves received a premium.

FIGURE 1: Simulated gross margin returns to clone versus natural mating systems at a range of clone embryo prices (the price of the embryo in the inseminating straw ready for ET). The trendlines show that breakeven with the natural mating system occurs at $84 and $142/embryo for the split premium and "all-clones" premium systems respectively. Other assumptions were set as described in Table 1.

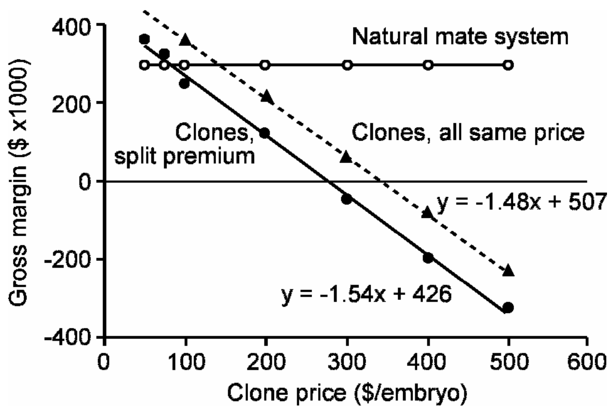
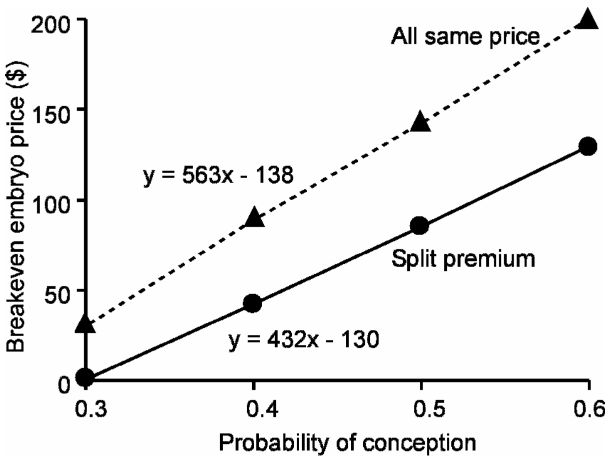


Figure 2 illustrates how early conception rate can affect the breakeven clone embryo price for both clone premium systems. This result was obtained by altering the two assumptions called "Prob of conception to ET C1 and ET C2" in Table 1. Both were varied together so that for any run, they had the same value. The fitted regression lines indicate that clone embryo price can rise by $43 (split premium system) with every 0.1 probability increase in conception rate and still break even. When conception rate probability was 0.3, the clone embryos had to be supplied for free for this system to break even with the natural mating system!

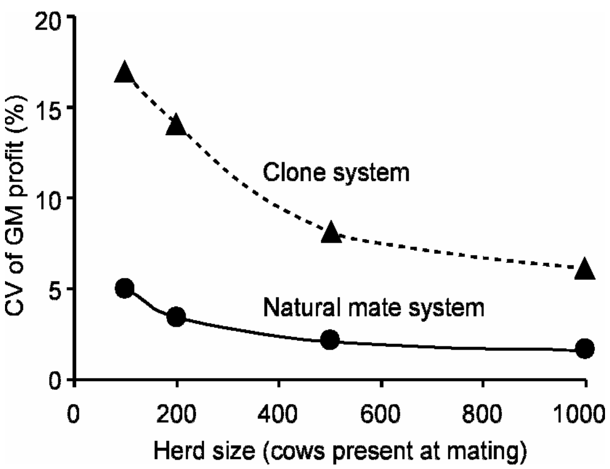
FIGURE 2: The price of a clone embryo for both premium systems, at a given conception rate to ET in either cycle 1 or 2, that is required to breakeven with the natural mating system, using the assumptions in Table 1.



Herd size, clone weaner price and risk

For a 1000 cow herd and at the weaner price assumptions shown in Table 1, repeated runs (n=100) of the model showed a coefficient of variation (CV) between runs for whole-herd GM profit of 6.1% for the clone herd compared with 1.6% for the naturally mated herd. For smaller herds (100 cows) with a proportionately lower herd GM, the SD also declined but not in proportion to the herd size so that the CV, and therefore risk, was higher, at 16.9% (Figure 3, split premium system). Below herd sizes of 200 to 300 cows, risk (CV %) increased rapidly.

FIGURE 3: Effect of herd size (cows present at mating) on the CV (%) of GM profit for both the natural mating and clone mating systems (split premium system only).



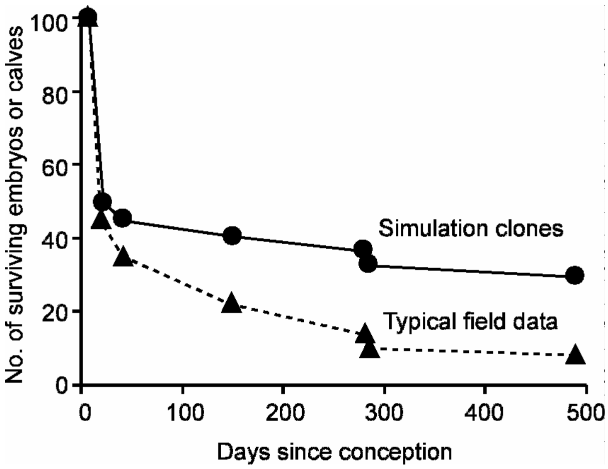
At weaner clone returns ranging from 2.25 to 5 times the natural-mate weaner price of $2 per kg, the breakeven embryo price for the split premium system ranged from $0 to $300 in a linear response ($10 to $420 when all clones received the premium). For every unit increase in the ratio of clone weaner price/kg wean weight to that of calves from natural mating systems, the breakeven price of clone embryos increased by $109/embryo for the split premium system and $145/embryo for the other clone system.

DISCUSSION

When compared with survey data cited by Anon (2002), the model accurately simulated the number of calves weaned over cows joined for the natural mating or 'status quo' beef production system. Weaning weights and variances also compared favourably with field data described by Baker *et al.* (1990) and Smeaton *et al.* (1999). The model with its biological assumptions as in Table 1 faithfully produced weaned calves of the correct numbers per cow mated and at the expected average age, weight and SD. Assumptions for survival of cloned embryos through pregnancy, calving and rearing were more difficult to set because of (1) the relatively few cattle clones that have been produced worldwide to date (Oback and Wells, 2003) and (2) the developing and therefore changing nature of the technology. In situations like this, does the model user set assumptions appropriate to the technology as it is now or rather, choose values that might be more appropriate in five years' time as the technology advances, or both? The range of options available is virtually limitless. In fact, the model was designed as a tool to enable reproduction scientists and others to determine the minimum performance specifications and prices that cloning technology must meet if it is to be a viable alternative to currently available systems of producing cattle. In this project, we made assumptions on the optimistic side of current performance. Figure 4 shows embryonic and calf losses based on the assumptions used in the model from Table 1 compared with current performance levels achieved in the field (Oback and Wells, 2003; Wells et al., 2004).

Our simulation results indicated that for GM profit to breakeven with natural mating systems, clone embryos must sell for $84.33 assuming the clone calves can be sold at a niche market premium of three times the 'normal' weaner price of $2/kg weaning weight. This split premium system assumed 20% of the cloned calves would not achieve the premium, due in our case, to an unacceptably low weight. This was deemed to be a likely outcome based on observations that buyers of animals always reject a portion of those offered for sale. The proportion of animals failing to achieve the clone premium price, the size of the premium itself and the proportion of cloned calves weaned per cows mated to ET were all important additional drivers of GM profitability. Calf weaning percentage altered the breakeven price of the clone embryos over a huge range of $0 to about $400/embryo. Clearly it is most unlikely that clone embryos could be produced at prices near the bottom end of this range.

FIGURE 4: Comparison of embryo, foetal and calf survival as described by the model assumptions in Table 1 vs. typical field data described by Oback and Wells, (2003) and Wells et al (2004). Note that at day 490, the calves are 7 months old and are weaned on that day.



Herd size impacted on the risk of a "bad-luck" adverse outcome. Use of larger herds, equivalent to a more committed adoption of the technology, reduced the variability of profit outcome but would require a greater initial capital investment. Most innovators prefer to try new technologies on a small scale initially (Rogers, 1995), but as was demonstrated by the results of Figure 3, the risk of a demoralising poor outcome for this technology was greater, especially below 200 cows selected for ET. This indicates that large-scale farmers are likely to be the first adopters of cloning technology.

Breakeven, whereby the profitability of the clone system equalled that of the natural mating system, was used as the criteria for comparing the two systems described in this paper. Innovators considering adopting new, potentially risky technologies are most unlikely to proceed unless they can expect to do much better than breakeven. The premium they might require (split system or otherwise) over breakeven will depend on their interest in the new technology, their perception of its complexity, how they will use it, its "trialability" and their attitude to risk (Rogers, 1995). Our model enables potential users and developers of cattle cloning technologies to input their own assumptions and to make their own informed decisions about what the performance and profit criteria have to be to warrant adoption in various applications.

ACKNOWLEDGEMENTS

This project was funded by FRST (Contract C10X0018). The authors also wish to thank all science peers who provided critical commentary. Specific thanks also goes to Dr Neil Cox for assistance with spreadsheet construction.

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