AN EX ANTE ECONOMIC ASSESSMENT AT THE FARM LEVEL OF A NEW BEEF PRODUCTION TECHNOLOGY

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ABSTRACT

The objective in this study was to review methods of economic assessment of new technologies at the farm level and to apply some of these methods to a particular technology. The process of technology assessment was discussed in the context of project evaluation and selection. The project cycle approach was used as a basis for determining the purpose of economic assessment - whether for the research allocation/project selection question or in further refining a technology during the development stage prior to commercial release or implementation.

The methods of assessment at the farm level included budgeting approaches and whole farm analysis (including Linear Programming). A review of methods of comparing stochastic gross margin results was included. The justification for the preferred analytical approaches was given in terms of suitability, ease of use and applicability for the specific task at hand.

A particular new technology - twinning in beef cattle - was assessed using a case study farm approach. This assessment will contribute to an actual research project on twinning in beef cattle. A Linear Programming analysis based on activity budgets was undertaken to assess the potential impact of twinning on the case study farm. A risk analysis was also conducted in which key factors were varied stochastically and the resulting distributions of gross margins were compared. The analysis showed that twinning could potentially improve the returns to intensive beef production systems, depending importantly on the level and variability in weaning percentage.

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1. INTRODUCTION

There are a number of research and development (R & D) institutions in Australia which are conducting and/or funding agricultural projects and programs. These institutions are interested in maximising the extent of uptake or eventual use of technologies by a target group or audience. There are a number of strategies which can be used to achieve this aim. One of these is to determine the potential payoffs from alternative R & D projects and programs as an aid in the project planning process and in making resource allocation decisions. Is the new technology likely to be profitable at the farm level and what are the aggregate industry impacts?

Some industry R & D funding bodies are using a project cycle approach (of identification, preparation, appraisal, implementation, monitoring and evaluation) for planning and managing projects. Economic assessments within this cycle can be undertaken while the project is being prepared based on hypothetical results (i.e. an *ex ante* analysis) or after it has been implemented (i.e. an *ex post* approach) for evaluation purposes.

Ex ante evaluations can be further distinguished according to purpose - whether for the research resource allocation decision or for refining new technologies. The first of these purposes can be helpful in the process of setting and assessing research priorities as a basis for decision-making by R & D managers (Bureau of Rural Resources 1989, Richardson 1988a, b, 1989). Anderson and Parton (1983) list a range of techniques available for this purpose (rules of thumb, scoring models, production function/systems/mathematical programming models, benefit-cost approaches). Parton, Anderson and Makeham (1984) consider technology assessment to be an extension of the net social benefit approach of Edwards and Freebairn (1981, 1984) and Davis, Oram and Ryan (1987).

The second purpose of economic appraisal involves evaluating the notional and preliminary new technologies defined by Anderson and Hardaker (1979). The assessment is aimed at establishing whether a new technology really will "improve the farmer's lot" and whether the anticipated improvements are reasonably substantial. This assessment can be undertaken while the technology is still being developed as an aid to the scientists involved in the development project. It was for this latter purpose that the present study was undertaken.

2. TWINNING TECHNOLOGIES FOR BEEF CATTLE

New technologies are being developed with the potential to revolutio[illegible]e cattle breeding in Australia. These technologies include:

(a) *in vitro* fertilisation;
(b) cloning of individual cells from early embryos;
(c) embryo splitting;
(d) embryo transfer; and
(e) fertility vaccines.

The objective of the research into these techniques is to develop methods which allow multiple pregnancies with the objective, through twinning, of raising the annual reproductive rate of cows (Anon 1990). The success of such programs will depend largely on appropriate levels of management and on catering adequately fo[illegible]e increased nutritional requirements of the herd.

Three methods of non-genetically improving reproductive technology are currently being investigated (Piper and Bindon 1990). One involves the embryo transfer of eggs that have been fertilised *in vitro*, the second involves vaccination of the cow against the hormone Inhibin (which injection to increase ovulation rate. It is assumed that either the anti-Inhibin vaccine approach or the *in vitro* fertilisation/embryo transfer twinning method will be available commercially by the end of 1992 (Piper and Bindon 1990). The embryo transfer method has the benefit of allowing control over features such as day of conception and therefore date of birth, genotype and, perhaps eventually, sex of calf. However, the anti-Inhibin vaccination method is simpler and probably cheaper as it only requires the annual injection of cows prior to mating. Therefore, despite the fact that this method provides control over nothing more than the shedding of an extra egg, it may be more appealing to beef producers.

Twinning in beef cattle through anti-Inhibin vaccination would require all breeding cows in the target herd to be injected prior to mating. After mating all cows would be scanned to identify those with twins, and the diagnosed twin-bearing cows would then be subjected to more attention. It is only in the more productive agricultural areas with intensive management that twinning is considered to be potentially successful. Important management factors for successful twinning might include use of restricted mating seasons, supplementary feeding, pregnancy testing and culling strategies for infertile and aged cows. It is considered that country capable of producing prime lambs is likely to be suitable for twinning in beef cattle (Dr B. Bindon, CSIRO, personal communication).

The twinning technology could also potentially be used in the dairy industry. With more intensive feeding and management, dairy herds may be particularly suited to twinning. However, no assessment of twinning in the dairy industry has been included in this analysis.

Research studies are being conducted by the NSW and Victorian Departments of Agriculture in a coordinated program into various aspects of nutrition and management required for successful use of twinning at the farm level (Drs D.W. Hennessy, J.F. Wilkins and L.J. Cummins, personal communication). These studies will determine the extra feed demand of twin-bearing beef cows and investigate alternative farm management strategies for accommodating twin-[illegible]ng herds.

3. PROBLEM DEFINITION AND HYPOTHESIS TO BE TESTED

The problem addressed in this analysis is the *ex ante* evaluation of potential economic gains from twinning by vaccination at the farm level. This type of assessment can be used either as an input to aggregate industry-level assessments or to identify areas where the technology needs fine tuning prior to commercial release. If aspects of a technology are identified as constraining its use in normal farm operation, or if the potential financial benefits are not large enough, then the technology can be reviewed and changed if necessary to improve it for the target group.

Important aspects of the appeal a twinning enterprise may have at the farm level include:

(a) whether a twinning enterprise is complementary or competitive with existing enterprise in terms of resource requirements;
(b) the expected level of financial return from twinning compared to that of other enterprises; and
(c) the impact of a twinning enterprise on beef production risk, including the variability in return from twinning as well as the covariability in return between twinning and other enterprises.

The assessment will need to be conducted in a manner that will account for these questions. The [illegible]ll and alternative hypotheses to be tested are:

Ho: Twinning is not economically appealing to beef producers in the target group;
Ha: Twinning provides an economically appealing alternative enterprise to beef producers.

The null hypothesis will be rejected if twinning is among the group of activities selected as optimal in a farm plan where twinning is an option. The power of the test of the null hypothesis depends on using the best possible information and the most useful methods of *ex ante* assessment.

4. REPRESENTING THE TARGET GROUP

The aim of this type of analysis is to undertake an assessment for a "representative farm" from which can be drawn general conclusions for the target group. Three main approaches to this problem were outlined by Anderson and Hardaker (1979) - a case study approach, a representative farm approach and a sample survey. In this study a case study approach was used, but the farm chosen was fairly representative of the likely target population.

A mixed-enterprise (sheep-beef) property situated between Glen Innes and Inverell was used as the case study farm. It was located on fertile soils with improved pastures and was subject to relatively intensive management. Because of this it was considered to be representative of the group of farms that might be suitable for twinning in beef cattle. Furthermore, the farmer kept good records and was willing to talk freely. Information was collected by personal interview on the property.

5. METHODS OF ASSESSMENT

5.1 Budgeting methods

At the farm level different activities (technologies) can be initially compared using budgeting methods (Longworth and Menz 1980). Gross margins, cash flow and partial budgets can be used for comparative analysis of activities and to examine the effects of changes over a number of years (Makeham and Malcolm 1988, Dillon and Hardaker 1984). A partial budget for the introduction of twinning to a beef store/vealer activity is shown in Table 1. The impacts of increased weaning percentage and reduced weaning weight are that a net benefit of $33 to $55 per herd cow is seen.

Budgeting methods are a useful first step in comparing farm activities, but they do have a number of disadvantages. One of these is that in a whole-farm context, with other competing activities, the limited availability of resources means that the choice of farm plan can be more complex. In this respect the methods of whole-farm analysis discussed in Section 5.3 are more appropriate for major changes to farm plans.

Another disadvantage with budgeting approaches is that they generally do not account for risk. Here risk is conceptualised as variability in outcome with consequences for human choice (Anderson 1988). The inclusion of aspects of risk in a gross margin results in a stochastic gross margin (Anderson 1976). If a stochastic variable is to be introduced to a budget, information is required on the type and parameters of the distribution of that variable. This implies that the probability of different outcomes can be estimated. This type of information may be available from historical records or experimental data but often it may not be available. The introduction of risk into a gross margin budget requires that stochastic distributions for the most important variables be known or capable of estimation and that the covariability of those distributions be included. If it is possible to estimate the probability of the risky outcome (e.g. gross margin per hectare) being less than a range of values then the comparison of risky gross margins is possible.

5.2 Stochastic efficiency rules

If risk is incorporated into a gross margin, the result can be expressed as a probability density function (PDF) or as a (less than) cumulative distribution function (CDF) - see Figure 1. In comparing technologies the problem then becomes one of comparing PDFs or CDFs. However, the comparison of PDFs with different measures of central tendancy and dispersion is difficult when the decision-maker's utility function is unknown. The utility or preference function shows the willingness to trade off extra expected income against increased variability in income. The rules of stochastic efficiency have been devised to assist choice in this situation.

Table 1

Partial budget of twinning in a 100 cow beef activity

	$ per cow	$ per 100 cows
Returns foregone Single calf	360 (300 kg vealer at $1.20) (a)	32400
Extra returns Twin Calves	610-660 (2 x 255 kg (b) at $1.20 at $1.30(c))	43650 45900
NET CHANGE IN REVENUE	250-300 per twin-bearing cow	11250-13500
Extra costs		
Induction (d)	20	2000
Diagnosis (d)	15	1500
Supervision at Calving (e,f)	30	1350
Extra feed: (e,g)		
- pregnancy	38	1710
- lactation	32	1440
TOTAL EXTRA COSTS		8000
NET BENEFITS : - without feed costs		6400-8650
- with feed costs		3250-5500

(a) Normal weaning = 90%
(b) Assumes 10 cows dry, 45 with single calves, 45 with twins and 15% lower liveweight per twin weaner
(c) Beef advisory officers indicate that liveweight price ($/kg) is often greater for lighter animals
(d) All cows
(e) Twin-bearing cows only
(f) Includes veterinary costs at calving
(g) Grain at $200/tonne fed

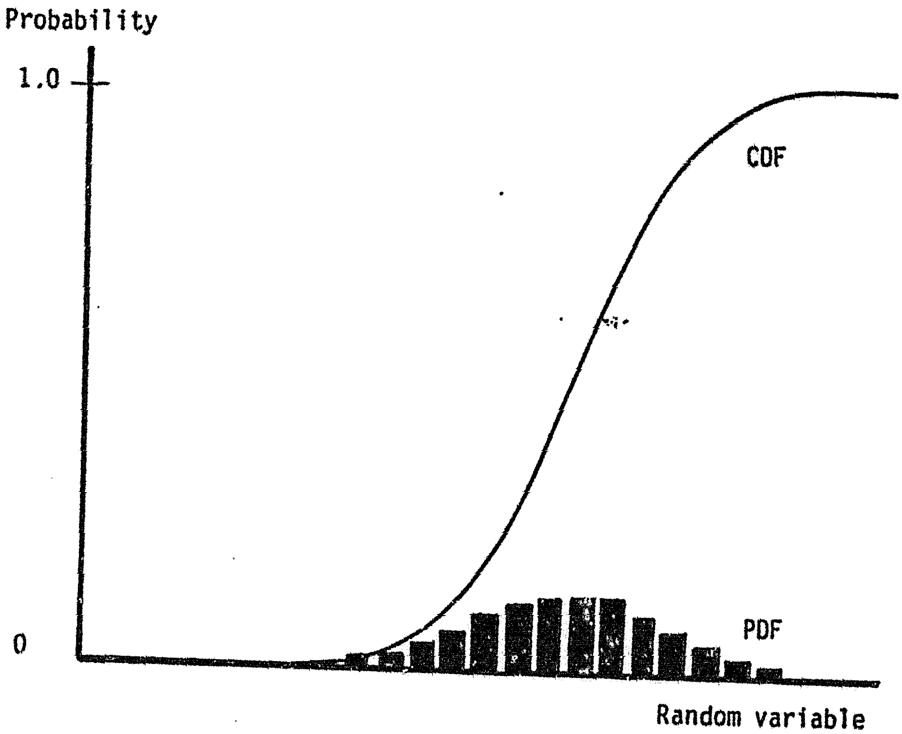

Figure 1 An equivalent Probability Density Function (PDF) and Cumulative Distribution Function (CDF)

Some attempts have been made to measure in aggregate the risk attitudes of Australian farmers. Bond and Wonder (1980) measured risk attitudes using a risk attitude questionnaire and Bardsley and Harris (1987) measured risk aversion coefficients by observing the actual behaviour of farmers in a realistic economic environment. Both studies concluded that Australian farmers were generally risk averse.

However, the utility functions for individual farmers or smaller groups are unknown and the formal specification of such functions is a difficult and costly process. Stochastic dominance rules are very useful in practical comparisons of activities or technologies when utility functions are unknown. Anderson (1974) and Anderson, Dillon and Hardaker (1977, Ch. 9) have reviewed these rules which search for efficient sets of distributions that are not dominated given certain assumptions about the behaviour or preferences of decision-makers.

The comparisons require the pairwise comparison of CDFs. If f(x) and g(x) are two PDFs for risky gross margins of technologies F and G, then the corresponding CDFs are defined as

$$F_1(R) = \int_a^R f(x)dx$$

$$G_1(R) = \int_a^R g(x)dx$$

where x is the gross margin which varies in the range [a,b] (Anderson, Dillon and Hardaker 1977, p. 282).

The concept of first-degree stochastic efficiency is based on the assumption that the decision-maker's utility function is monotonically increasing ($U'(x)>0$). Second- and third-degree stochastic efficiency are based on the assumptions that the function is also concave ($U''(x)<0$) and always positive ($U'''(x)>0$). F is said to dominate G in the sense of first-degree stochastic dominance if $F_1(R) \leq G_1(R)$ for all possible R with at least one strict inequality. Graphically this implies that a FSD dominant CDF must lie nowhere to the left of a dominated curve.

In the same way F is said to dominate G in a sense of second-degree stochastic dominance if $F_2(R) \leq G_2(R)$ where:

$$F_2(R) = \int_a^R F_1(x)dx$$

$$G_2(R) = \int_a^R G_1(x)dx$$

Similarly, F dominates G in the sense of third-degree stochastic dominance if $F_3(R) \leq G_3(R)$ and if $F_2(b) \leq G_2(b)$, where b is the upper range, where

$$F_3(R) = \int_a^R F_2(x)dx$$

$$G_3(R) = \int_a^R F_2(x)dx$$

The distributions not dominated in each division are the efficient sets of risky actions that would always be preferred by those decision-makers whose utility functions satisfy the various criteria.

The concept of stochastic dominance with respect to a function (SDWRF) enhances the stochastic efficiency rules above. It was developed by Meyer (1977a, b) based on Pratt's (1964) coefficient of absolute risk aversion which relates to the curvature of the utility function

$$r(x) = -U'(x)/U'(x)$$

The use of SDWRF requires specifying a preference interval bounded by upper and lower values of r(x). Once the preference interval is narrowed the SDWRF criteria become more powerful in distinguishing between distributions. This approach allows different sets of decision-makers to be distinguished for different bounds (values of r(x)).

Pandey (1990) identified risk-efficient irrigation strategies for wheat in India using four ranges for risk aversion coefficients between 0 and 0.04. Australian farmers might be expected to be less risk averse because of their greater wealth (including human capital). Recent research on Australian farmers attitudes to risk has been conducted by Bardsley and Harris (1987). They listed three measures of risk aversion. If U is the utility of wealth function, W is wealth and x is income then the absolute, partial and relative risk aversion coefficients are given respectively by (their lettering)

$$\alpha = -U''(W)/U'(W)$$

$$\beta = -U''(W+x)x/U'(W)$$

$$r = -U''(W)W/U'(W)$$

It is easy to convert between these measures because

$$\alpha = r/W \text{ and}$$
$$\alpha = \beta/x$$

Bardsley and Harris (1987) estimated values for median income and partial risk aversion coefficient for the Pastoral, Wheat-Sheep and High Rainfall Zones of Australia. From their results the value of absolute risk aversion for Australian farmers was 1×10^{-5}, 6×10^{-5} and 1×10^{-6} for the High Rainfall, Wheat-Sheep and Pastoral Zones respectively. These figures are at the lower end of the range of values used by Pandey (1990). A microcomputer program developed by Goh, Raskin and Cochrane (1987) was used to conduct the stochastic efficiency comparisons using SDWRF. The distributions in this analysis were compared pairwise over a range of values for absolute risk aversion intervals including the absolute risk aversion levels estimated from the Bardsley and Harris (1987) results.

5.3 Whole-farm approach

To overcome the disadvantages of partial budgeting, the whole-farm approach allows a more holistic or systematic view of technology testing and adoption (Dillon 1976). It requires the setting up of a model of a farm that is representative in some sense of the population of farms (see Section 5.1). The model can be used to test the effect of including the new technology as an alternative activity. In effect the model results are compared with and without the new technology to show how successful it might be and to indicate the 'size' of the effects of the new activity. This information can be used to make estimates of the wider socio-economic impact of the technology.

Gross Margins Analysis and Simplified Programming are methods of whole-farm planning based on activity gross margins that do not require a computer to solve. These methods are not widely used and have a number of weaknesses compared to Linear Programming (LP) when solved using a computer.

LP for farm planning involves determining the level of farming activities (x_j) under a set of m linear constraints

(5.1) $$\sum_j a_{ij}x_j \; (\leq = \geq) \; b_i \quad i=1 \ldots m$$

where only one sign in the brackets holds and the b_i are either accounting identities or resource constraints. The a_{ij} are technical input-output coefficients showing the level of the ith resource required for the jth activity. Also required is that the x_j be non-negative. An optimal farm plan is found by maximising the objective function

(5.2) $$z = \sum_j c_j x_j - F$$

where z is farm income, c_j is the net revenue per unit of the jth activity and F is fixed costs (Anderson, Dillon and Hardaker 1977, p.196).

In the LP method it is assumed that the a_{ij}, b_i and c_j are all known with certainty and do not vary. The assumption of linearity between inputs and outputs implies a linear production function - to decide between different levels of input for any activity a separate activity for each different input level must be specified. Also, since the objective function is linear, the model excludes the option of accounting for the decision-maker's non-neutral attitudes to risk (Anderson, Dillon and Hardaker 1977, p. 197).

There are a number of methods that extend the LP approach to incorporate risk. Ghodake and Hardaker (1981) list linear risk programming, quadratic risk programming, stochastic programming and Monte Carlo programming in this category, as well as systems simulation.

Quadratic risk programming (QRP) is a procedure for accounting for risk in mathematical programming models. The assumption is made that risk is considered only in relation to the activity net revenues, c_j, and that these c_j follow a multivariate normal distribution (Anderson, Dillon and Hardaker 1977, p.197). Therefore the means, variances and covariances of the c_j are required and can be obtained from trend-corrected historical data. This implies that utility is specified in terms of the mean (E) and variance (V) of z. The efficient mean-variance (or E-V) set of activities is determined as the locus of vectors with minimum variance for each mean, or with maximum mean for each given variance. Once this set of efficient mean-variance vectors is derived, the subsequent task is to choose the vector that maximises utility.

From Anderson, Dillon and Hardaker (1977, p.198), if σ_{ij} is the covariance of activities i and j, the objective is to minimise

(5.3) $$V(z) = \Sigma_i \Sigma_j \sigma_{ij} x_i x_j$$

subject to a parametric expected profit constraint

(5.4) $$\Sigma_j E(c_j)x_j - F = \beta \quad \beta = -F \rightarrow E_{max}$$

and

(5.5) $$\Sigma_j a_{ij}x_j \leq b_i$$
$$x_j \geq 0$$

In (5.3) the objective is to minimise the variance V(z) of profit in the current plan. In (5.4) $E(c_j)$ is the expected net revenue of activity j, F is fixed costs and β measures the expected profit E(z) of the farm plan and is varied over the range of possible values.

Using this parametric procedure the efficient set of solutions in (E-V) terms can be derived. Identification of the utility-maximising solution for any risk-averse decision maker can be made by individual choice of the decision-maker or determined by imposing a uniquely determined utility function on the (E-V)-efficient set (Anderson, Dillon and Hardaker 1977, p. 199).

QRP is consistent with decision theory and it has been tested empirically and found to predict better the actual behaviour of a group of farmers than other alternative formulations (Lin, Deane and Moore 1974).

5.4 Alternative Analytical Approaches

The discussion in the preceding section has indicated the desirability of using a whole-farm approach and of accounting for risk in comparing alternative farm activities. LP was considered the most useful method of undertaking the basic whole-farm analysis because it provides good information as a basis for comparing technologies, it is relatively straight-forward to use and computer programs are available and user friendly.

For the risk analysis a spreadsheet-based program, @RISK (Palisade Corporation 1989), was available which enabled the definition of uncertain spreadsheet cell values as probability distributions. A considerable number of distribution types can be specified and a cell within the spreadsheet can be designated as the output cell which contains the distribution of possible results.

A number of alternative approaches to conducting a risk analysis as an extension of LP are possible. Two particular approaches were considered for this analysis. The first was to use a QRP model which accounts for variability and covariability in farm activity net revenues. The alternative was to place the LP results for key activities back into a spreadsheet format and use @RISK to generate CDFs for comparison using the stochastic efficiency concepts outlined in this Section 5.2.

The latter approach was preferred in this analysis for a number of reasons. The main advantages are that @RISK allows the incorporation of stochastic variability to a number of parameters within the beef activity rather than just net revenue, as in QRP. In terms of technology assessments in conjunction with scientific R&D projects, @RISK allows physical parameters to be varied which the scientists can directly relate to and which are important for the analysis. Also @RISK has a great deal of flexibility in specifying types of distributions and accounting for different types of distributional information.

The main disadvantage of this latter approach is that the selection of the optimal farm plan in the whole-farm analysis only allows for risk in some activities and does not account for the influence of that variability in the whole-farm plan. However, an analysis using QRP would require much more information on the net revenue variability and covariability of all potential farm activities which might be very difficult to determine. For the purposes of the particular technology assessment in this analysis the use of LP and @RISK was considered the best approach.

6. RESULTS

6.1 Linear programming model

In constructing an LP model of the case study farm a set of gross margin budgets for the existing and proposed activities was constructed. First the energy requirements for livestock were derived on a herd or flock basis (Rickards and Passmore 1977, Agricultural Research Council 1980, Ministry of Agriculture, Fisheries and Food 1984, Animal Production Committee 1990). The estimated metabolisable energy (ME) requirements per breeding female (including followers) throughout the year in units of megajoules of metabolisable energy per female per day are shown in Table 2.

Then the energy supplied by pastures throughout the year wa specified in the same units. Published estimates of improved pasture production from basaltic (self-mulching) soils at the Glen Innes Agricultural Research and Advisory Station were used (Hennessy and Robinson 1974, 1979). Carryover of pasture from one time period (season) to the next was incorporated in the model. The amounts of energy in feed carried over between seasons were estimated to be 33% from Summer to Autumn, 20% from Autumn to Winter, zero from Winter to Spring and 28% from Spring to Summer (Dr P. Mears, NSW Agriculture & Fisheries, personal communication).

Because of the winter feed gap, supplementary feeding of breeding stock through winter is often undertaken in the tablelands areas of NSW. Oddy (1983) set out the basis for use of the ME system for drought feeding of sheep and cattle. He presented average ME and DM content of feeds. The relationship between animal liveweight and ME content of feed can be used to determine the quantity of feed required per day for sheep and cattle. This relationship can be

Table 2

Estimated ME Requirements per Breeding Female (including followers) throughout the year

	Quarter			
	Spring	Summer	Autumn	Winter
	MJ of ME/female/day			
Cows				
- single	153	146	166	161
- twin	170	166	186	282
Ewes				
- Merino	13	13	15	10
- First-cross	23	26	11	14

adjusted for the lec s of pregnancy and lactation. It allows the amount of different types of feed to be estimated fo. specific types of animals, and was used in developing the supplementary feeding activities of the LP model.

Gross margin budgets were drawn up for the beef (store/vealer production) and sheep (Merino wool growing, first- and second-cross lamb production) activities of the case study farm. The beef twinning activity budgets were set up based on three alternative scenarios: - cows first calve at 2 years, cast-for-age (cfa) at 10 years (the same as the normal beef activity); cows first twin calve at 4 years (after 2 years of singles), cfa at 10 years; and cows first twin calve at 4 years, cfa at 9 years. The implications of these alternative assumptions for herd structure and turnoff were derived from use of a herd model (Holmes 1988) as shown in Table 3.

Table 3

Herd Structures for Single- and Twin-Bearing Herds Producing Vealers and Store Weaners

Cattle type	Singles	Twins(a) (2-10)	Twins(b) (4-10)	Twins(c) (4-9)
Calves born start of year	92	138	125	124
Heifers aged 1 start of year (heifers retained)	17	15	15	16
Heifers aged 2 start year	15	14	14	15
Cows aged 3 years plus	68	71	71	69
Bulls	3	3	3	3
Total	195	241	229	229
Cows and heifers mated	100	100	100	100
Calves branded	92	138	125	124
Breeder deaths	1	3	3	3
Sales - cull cows	8	6	6	7
- Cfa cows	7	7	8	9
- surplus heifers	29	53	47	45
- steers	45	68	[illegible]2	61

(a) First calving at 2, last calving at 10, 9 opportunities to calve as twins.
(b) 2 opportunities to calve as singles, 7 opportunities to calve as twins.
(c) 2 opportunities to calve as singles, 6 opportunities to calve as twins.

Labour budgets were also constructed for each activity. In discussions about labour requirements for farm activities, the case study farmer indicated that he considered the labour budgets in Turvey (1988) to be adequate. Consequently the labour requirements for activities were based on Turvey (1988), with the labour requirements for twinning activities being pro-rata increases over the normal beef herd according to the increased calf weaning rates.

In discussing supplementary feeding the case study farmer indicated that breeding stock carried through winter are fed supplements due to the shortage of pasture rather than winter fodder crops or conserved fodder (hay or silage). For breeding ewes grain is fed and cows are fed molasses and cottonseed meal. The ME content and average daily requirements, given liveweight and pregnancy status, were estimated (Oddy 1983) and the costs per feed unit determined. This information was used in the development of winter supplementary feeding activities for both cattle and sheep in the LP model.

A summary of the gross margin budgets is shown in Table 4. The sheep activities were more profitable than the cattle activities and the twinning activities were more profitable than the normal beef activities. The profitability of sheep was partly due to the buoyant wool prices in the early part of 1990. Since the lowering of the floor price for wool the relative advantage of wool activities has probably been reduced, but no investigation of this outcome was undertaken here. However, the relative profitability of sheep over cattle activities had implications for construction of the LP model.

Table 4

Gross Margin Comparisons for Livestock Activities

Activity	GM/cow	GM/ewe	GM/ME unit (a)	GM/labour unit (b)
Beef				
- normal	279	-	1397	140
- twins (2-10)	373	-	1863	186
- twins (4-10)	343	-	1716	172
- twins (4-9)	345	-	1724	172
Sheep				
- Merino wool	-	67	3354	335
- First-cross lamb	-	66	3321	332
- Second-cross lamb	-	52	2613	261

(a) 20 MJ/day
(b) 200 hours/season

The LP model was based on the land, labour and feed resources on the case study farm. The treatment of resource constraints was considered in line with comments by Dent, Harrison and Woodford (1986). In particular the personal attitudes and longer term goals of the case study farmer were important determinants of the balance of livestock activities on the farm and in the LP model. The LP matrix for the livestock activities was based on the model structure of Muir and Vere (1987).

In setting up the original or "base" model the relatively greater profitability of Merino woolgrowing meant that it was the only activity selected. This result was considered to be unrealistic in light of the management strategy of diversifying activities undertaken by the case study farmer. To overcome this problem the land resource was separated into two categories (one for cattle and one for sheep) based on the case study farm area and each land category was provided with a feed supply. This structure reduced the potential value of the objective function and partly determined the outcome of the model. The approach was justified on the grounds that it was a more realistic outcome in comparison with the actual case study farm plan. That plan means that beef cattle are retained even when wool prices are very high. Another advantage of having a mix of livestock types and ages is that worm control is facilitated by a rotation of livestock types over pastures.

The main results of the base LP model are shown in Table 5. The Merino wool growing activity was the major contributor to the objective function. Merino cast-for-age ewes were transferred to the first-cross activity rather than being sold. However, the second-cross activity did not enter the final optimal solution. The beef herd consisted of 239 breeding cows.

The names and amounts of slack resources for this base solution are shown in Table 6. Excess labour was available in all four quarters. Pasture supply for sheep in winter was limiting the objective function.

Table 5

Base results of Linear Programming Model

Variable	Unit	Value
Merino ewes (to Merino rams)	no.	4622
Merino ewe replacements	no.	1294
Sell Merino ewe hoggets	no.	893
Sell Merino wether lambs	no.	2265
Transfer old Merino ewes	no.	1063
Sell Merino wool	kg	37355
Merino ewes (to Border Leicester rams)	no.	1063
Sell first-cross ewe hoggets	no.	592
Sell first-cross wether lambs	no.	627
Sell old Merino ewe culls	no.	999
Sell first-cross wool	kg	1183
Sell Border Leicester wool	kg	191
Breeding cows	no.	239
Cow replacements	no.	41
Surplus heifers	no.	68
Steer vealers	no.	55
Steer stores	no.	55
Sell veal	kg live	15931
Sell store	kg live	13733
Sell heifer	kg live	17129
Pasture for cattle	ha	650
Pasture for sheep	ha	1500
Purchase molasses	kg	0
Purchase grain	kg	230
Livestock selling costs	$	15019
Wool selling costs	$	42014
Sheep production costs	$	64484
Beef production costs	$	1890
Cattle pasture carryover Summer to Autumn	MJ/ha/day	158639
Cattle pasture carryover Autumn to Winter	MJ/ha/day	76683
Cattle pasture carryover Spring to Summer	MJ/ha/day	55308
Sheep pasture carryover Summer to Autumn	MJ/ha/day	324442
Sheep pasture carryover Autumn to Winter	MJ/ha/day	150162
Sheep pasture carryover Spring to Summer	MJ/ha/day	109120
Objective Function Value	$	383 666

Also shown in Table 6 is the shadow price of the binding constraint. The shadow price is the marginal value of this resource - the objective function would increase by $63.75 if one further unit of grain for sheep could be supplied (Lee, Moore and Taylor 1985, p.146). The shadow price of grain ($63.75) is greater than the cost of purchase ($11.70). From this it would be profitable to increase the supplementary feed supply fro sheep, and hence the stocking rate, but this would be at the expense of increased risk in a bad season.

When the beef twinning activity was included in the matrix the optimal solution was as shown in Table 7. Since the sheep activities were unchanged only the beef results are presented. When the twinning activity was included in the model it replaced the single-breeding cow activity completely. There were fewer cows, increased progeny (numbers and weight), higher costs and an increase of $4015 in the value of the objective function.

The main resource constraints under twinning are shown in Table 8. In comparison with Table 7, inclusion of the twinning activity resulted in more labour being used in each quarter. Cattle winter feed supply was now limiting and the shadow price of an extra unit (MJ/day) of molasses in winter was $16.23.

Two further analyses with this twinning model were undertaken. To determine the impact of reducing labour availability the use of only 3.5 full time labour units (compared to 4 people) was

Table 6

Key Binding and Slack Constraints in Base Solution

Resource	Unit	Binding or Slack	Amount	Shadow Price
Labour spring	hr	S	117	-
Labour summer	hr	S	658	-
Labour autumn	hr	S	740	-
Labour winter	hr	S	1264	-
Grain	kg	B	0	63.75

tested. The amount of labour available in each quarter was reduced from 1920 to 1680 hours. When this change was made the twinning activity did not enter the optimal solution - the normal single vealer/store activity was selected and the objective function value was reduced to $363 716. Labour in spring was a binding constraint and the shadow price of spring labour was $170 per hour.

To determine the impact of changed feed supplies on twinning the supplementary feeding of molasses and cottonseed meal to breeding cows in winter was deleted from the model by setting the amount of molasses available for feeding to zero. The resulting solution was that 197 twinning cows were selected and the objective function value was $373 005.

The twinning activity added to the base model was for cows first calving at 2 years and being culled at 10 years. The two additional twinning scenarios (identified in Table 3) were added individually to the base model (no twinning) and to the twinning (join year 2, cull year 10) model. In no case were these other twinning activities selected in the optimal farm plan. Therefore the normal beef activity appears to be profitable in the whole-farm context but the second and third twinning activities are not.

Table 7

Results of Introducing Beef Twinning Activity

Variable	Unit	Base solution	Twinning included
Breeding cows	no.	239	216
Replacement cows	no.	41	32
Surplus heifers	no.	68	116
Steer vealers	no.	55	-
Steer stores	no.	55	149
Sell veal	kg live	15931	-
Sell store	kg live	13733	36028
Sell heifer	kg live	17129	24748
Cattle pasture	ha	650	650
Purchase molasses	kg	0	450
Selling costs(a)	$	15019	15714
Beef production costs	$	1890	6007
Objective Function(a)	$	383 666	387 681

(a) Includes sheep activities

Table 8

Key Binding and Slack Constraints under Twinning

Resource	Unit	Binding or Slack	Amount of Slack	Shadow Price
Labour spring	hr	S	17	-
Labour summer	hr	S	591	-
Labour autumn	hr	S	628	-
Labour winter	hr	S	1127	-
Molasses	kg	B	-	16.23

The LP model results presented in this section have shown that the twinning technology (given various assumptions) is superior to the conventional beef activity in some circumstances. If cows are joined and culled for age at the normal ages, twinning is more profitable. Under twinning the number of cows is lower than normal for the same given land area or feed supply. Although the quality of the progeny is lower (lighter weights and no vealers) and costs are higher, the greater turnoff increases the value of the total gross margin (TGM) for twinning.

The increase in value of the objective function is $4015. Whether this is sufficient to convince beef producers to adopt the twinning technology depends on the minimum rate of return they would require on their investment in breeding stock. Under twinning the number of breeders is reduced from 239 to 216 (Table 7) and it is highly likely that the funds invested in breeding stock would be reduced.

The results also indicate that the herd dynamics involved in either a later joining or an earlier culling age for twinning cows would not improve the financial return compared to the normal beef activity. This is an important implication for the developers of the twinning technology.

In setting up the twinning model, the availability of labour and feed seemed to be two important factors. When labour supply was reduced the spring labour constraint became binding and the normal beef activity was selected rather than twinning. When the feed supply (from supplements) in winter was removed twinning was still selected over normal beef production, although at a lower level. The implication of these last two results is that labour required for twinning may be more important than the feed requirements.

6.2 Risk analysis

In this section the LP results are extended through a risk analysis. In the LP model all variables were represented by 'point' estimates which provided a single predicted result. The implicit assumption was that these values were known with certainty. Apart from the fact that estimates based on biological processes or economic forces over time will be subject to variability, estimates of future outcomes will also be subject to uncertainty. If one scenario is more uncertain than another then this may be an important consideration. Because we are unable to see into the future, risk can be important if the degree of risk is significant enough to affect our current economic decisions.

A more realistic model will include some of this variability in at least some of the key factors. The method of analysis in this section allows more information about key variables to be incorporated - including the range of possible values for a variable and a measure of the likelihood of occurence of each one considered. The resulting analysis is a simulation in which a large number of 'what if' scenarios are presented together. 'Simulation' can be defined as 'the use of an analogue to study the properties of a system' where an analogue 'pertains to any device which represents a variable by a continuously moving or varying entity' (The Macquarie Dictionary 1985). The output of the simulation can be presented graphically and comparisons made between beef production with and without the new technology. Some methods of comparison of distributions have been discussed in Section 5.2.

The risk analysis was conducted using the @RISK program. The distribution types used in this analysis were normal (@NORMAL), triangular (@TRIANG) and truncated normal (@TNORMAL). The arguments for these functions in the @RISK program are (mean, standard deviation (SD)) for @NORMAL, (minimum, most likely, maximum) for @TRIANG and (mean, SD, minimum, maximum) for @TNORMAL.

The @TRIANG distribution is useful for rough modelling when actual data are not available. The @TNORMAL is used in this analysis where the market destination for steers changes at a certain weight or where a certain proportion of the heaviest females must be retained as replacement cows. For steers, the vealer trade (local butchers or supermarket) commences at about 160 kg dressed weight (or 290 kg liveweight at 55% dressing) (Mr P. Doyle, personal communication). Below this weight steers are generally store quality.

The risk analysis was conducted only for the beef cattle activities within the LP model. The main results from the model for the beef activity with and without the twinning technology were shown in Table 7. Two spreadsheets were developed from these results and these are presented in Tables 9 and 10. These spreadsheets contain the same technical coefficients as in the LP model. The main differences between these tables and the original budgets are that Tables 9 and 10 include actual livestock numbers from the LP results and that they include the supplementary feeding and superphosphate costs.

The key variables subject to risk simulation are weaning percentage, weaning weight and saleyard price for beef. Distributions of these variables are required to conduct the risk analysis. The availability of data on the parameters of these distributions can be limited, especially for new technologies. The types of distributions and the sources of information on parameters are discussed below.

The level and distribution of weaning percentage may be the most important factor in determining the success of twinning in beef cattle. This factor determines the number of calves born and weaned. On the case study farm the distribution of weaning percentage was estimated to be @TRIANG (90,92,94). For twinning the weaning percentage was assumed to rise by 50% (Farquharson and Griffith 1989) so the mean weaning percentage is 138%. Optimistic and pessimistic scenarios for twinning were derived by setting different distributions for weaning percentage. These scenarios were analysed in an attempt to determine whether the distribution of this variable could influence the final choice of technology but there are no experimental data available as a guide to the parameters of the optimistic and pessimistic distributions.

As purely hypothetical cases the distributions of weaning percentage were set as @TRIANG (126,138,150) and @TRIANG (80,155,179) for the optimistic and pessimistic scenarios respectively. Both of these distributions have expected values of 138% so that the comparisons with the LP results are valid. In the @RISK program for a triangular distribution (argument (a,b,c)) the expected value of the random variable is given by (a+b+c)/3. The pessimistic scenario has a wider distribution and a longer tail to the left.

The weaning weight of progeny will vary within a herd in any year. On the case study farm all heifer weaners are weighed as part of the process of selecting heifer replacements. These weights in the last season ranged from 310 kg to 200 kg with an 'average' of 251 kg. By allocating the maximum and minimum weights to probabilities of 0.995 and 0.005 respectively, an estimate for SD of heifer weaning weight of 16.5 kg was derived from the standard normal distribution. Heifer weights were assumed to be distributed normally with mean 251 kg and SD 16.5 kg. However, because a certain percentage of the heaviest need to be kept as replacements the normal distribution of heifers for sale was truncated at a maximum weight (estimated as 266 kg) that allowed the correct number of replacements to be retained.

Table 9

Beef Vealer Spreadsheet for Risk Analysis

Cattle pasture :	650 ha	Weaning percentage :	92
Herd size :	239 cows	Steer progeny :	110
		Heifer progeny :	110

INCOME					
Sale of No.	@ kg	$/kg	$/beast	$	
Vealers	55	290	1.35	-	21532.50
Store steers	55	250	1.45	-	19937.50
Surplus heifers	68	251	1.20	-	20481.60
Cull cows	36	-	-	530	19080.00
Cull bulls	2	-	-	800	1600.00
TOTAL INCOME					82631.60
VARIABLE COSTS					
Bull replacements					
Purchase	2	-	-	2000	4000.00
Transport	2	-	-	5.7	11.40
Beef production					
Cows	239	-	-	7.23	1727.97
Heifer replcmnts	41	-	-	3.39	138.99
Surplus heifers	68	251	.005	-	85.34
Vealers	55	290	.006	-	95.70
Steer stores	55	250	.008	-	110.00
Bulls	8	-	-	3.19	25.52
Selling costs					
Vealers	55	290	.083	-	1323.85
Steer stores	55	250	.075	-	1031.25
Heifers	68	250	.075	-	1280.10
Cows	36	-	-	43.3	1558.80
Bulls	2	-	-	54.1	108.20
Pasture costs					
Super	650	ha @ $	34/ ha		22100.00
Supplementary feed costs					
Molasses and CSM		0 kg	@ $ 16.2/ kg		0.00
TOTAL COSTS					33597.12
TOTAL GROSS MARGIN					49034.48

Table 10

Beef Twinning Spreadsheet for Risk Analysis

Cattle pasture :	650 ha	Weaning % :	138
Herd size :	216 cows	Steer progeny :	149
		Heifer progeny :	149

INCOME					
Sale of No.	@ kg	$/kg	$/beast	$	
Vealers	0	290	1.35	-	0.00
Store steers	149	242	1.45	-	52204.10
Surplus heifers	116	213	1.20	-	29649.60
Cull cows	28	-	-	530	14840.00
Cull bulls	2	-	-	800	1600.00
TOTAL INCOME					98373.70
VARIABLE COSTS					
Bull replacements					
Purchase	2	-	-	2000	4000.00
Transport	2	-	-	5.7	11.40
Beef production					
Cows	216	-	-	27.23	5881.68
Heifer replcmnts	32	-	-	3.39	108.48
Surplus heifers	116	213	.005	-	123.54
Vealers	0	290	.006	-	0.00
Steer stores	149	242	.008	-	288.46
Bulls	6	-	-	3.19	19.14
Selling costs					
Vealers	0	290	.083	-	0.00
Steer stores	149	242	.075	-	2704.35
Heifers	116	213	.075	-	1853.10
Cows	28	-	-	43.3	1212.40
Bulls	2	-	-	54.1	108.20
Pasture costs					
Super	650	ha @ $	34/ ha		22100.00
Supplementary feed costs					
Molasses and CSM		450 kg	@ $	16.2/ kg	7290.00
TOTAL COSTS					45700.75
TOTAL GROSS MARGIN					52672.95

Steer weaners are not individually weighed on the case study farm, although the average weight was estimated to be 285 kg. Without any information on the distribution of steer weights the SD was estimated to be in the same ratio to the mean as for heifers. Thus the SD of steer weights was 18.7 kg. Given this distribution, the proportion of steers above and below 290 kg liveweight was estimated to determine the number of steers going to the vealer and store markets. The weight distributions for steer progeny were truncated at 290 kg for the vealer and store markets. The distributions of weights for steers and heifers used in the risk analysis are shown in Table 11.

For twinning the mean weaning weight is assumed to be 15% lower than for single calves (i.e. 213 kg for heifers and 242 kg for steers). It can be assumed that in comparison with single calves, weights for twin calves are 20% lower at birth, 10-15% lower at weaning and similar at yearling (Dr B. Bindon, CSIRO, personal communication). The distribution of weaning weights is suspected to be wider than for single calves, especially if heifers and young cows are in the twinning herd (Dr B. Bindon, CSIRO, personal communication). The SD of heifer and steer weaning weights under twinning was increased arbitrarily by 10% over the values equivalent to the normal heifer weaning weight. For twin heifers and steers the SD of weaning weight was set at 16.4 and 17.5 kg respectively.

The level and distributions of prices and their relationships with liveweight for different beef types is an area where little information is available. It is considered (Mr P. Doyle, NSW Agriculture & Fisheries, personal communication) that the relationship between price and liveweight is weakly negative for vealers (the local butcher trade may pay more $/kg for lighter vealer carcasses than the supermarket trade pays for heavier carcasses), strongly negative for store steers and strongly positive for heifers (the heavier heifers are in more demand as replacements). Todd and Cowell (1981) estimated the regression coefficient for weight explaining beef auction prices (c/kg basis) at a domestic trade type of cattle auction to be -0.18. Park (1979) found that an increase in liveweight was correlated with a decrease in unit price.

The @RISK program uses dependency coefficients to represent the degree of correlation between dependent and independent variables when sampling, but these are not the equivalent of correlation coefficients. The dependency coefficient can be set between 1 and -1 to determine the type of correlation between two variables in the sampling process. The closer to 1 or -1 the stronger the (positive or negative) correlation. The levels of dependency coefficients between liveweight and price ($/kg) were set as shown in Table 12.

The Livestock Marketing Reporting Service (LMRS) (NSW Meat Industry Authority 1990) provides information on prices for slaughter cattle at regional markets for cattle categorised by age, sex, liveweight, muscle score and fat score. No individual weight data are recorded by the LMRS. Price data from the Armidale and Inverell sales from January 1988 to June 1990 for vealers in the weight range 280-370 kg were analysed to determine the mean and SD. Altogether 12316 vealers were marketed through these two saleyards over the 18 month period with a mean price of $1.29/kg liveweight and a SD of $0.21. Information on store cattle prices ($/kg liveweight basis) and weights is not collected by the LMRS or any other agency. For store steers and heifers triangular distributions were used based on current market experience. All price distributions are shown in Table 11.

Three beef scenarios were analysed - normal vealer production (single-bearing cows) and twin-bearing cows with an optimistic and a pessimistic distribution for weaning percentage. The main @RISK results are shown in Table 13 as TGM of beef activities from 650 ha of land.

In comparison with normal beef the optimistic twinning scenario showed a greater mean and a greater range of expected results - a higher maximum and a lower minimum. The pessimistic twinning scenario resulted in a higher expected result than normal and a much wider range of possible outcomes. These results are shown graphically as CDFs in Figure 2.

Table 11

Types and Parameters of Distributions of Key Variables

Variable	Distribution type (a)	Distribution parameters	Source of information
Weaning percentage			
- normal	@TRIANG	(90,92,94)	CS farm
- twins			
pessimistic	@TRIANG	(80,155,179)	Estimate
optimistic	@TRIANG	(126,138,150)	Estimate
Weaning weight			
- normal			
heifers	@TNORMAL	(251,16.5,0,266)	CS farm
vealer steers	@TNORMAL	(285,18.7,290,1000)	CS farm
store steers	@TNORMAL	(285,18.7,0,290)	CS farm
- twins			
heifers	@TNORMAL	(213,16.4,0,226)	Estimate
vealer steers	@TNORMAL	(242,17.5,290,500)	Estimate
store steers	@TNORMAL	(242,17.5,0,290)	Estimate
Prices			
heifers	@TRIANG	(1.05,1.11,1.20)	CS Farm
vealer steers	@NORMAL	(1.29,0.21)	LMRS
store steers	@TRIANG	(1.40,1.45,1.50)	Estimate

CS = Case study farm
LMRS =Livestock Market Reporting Service
(a) @TRIANG (minimum, most likely, maximum)
@NORMAL (mean, SD)
@TNORMAL (mean, SD, minimum, maximum)

From Figure 2 the normal beef CDF intersects once with each of the twinning CDFs. In comparison with the normal beef CDF the optimistic twinning CDF (which is also normally distributed) has a higher mean and a higher variance. Therefore the (E-V) comparison using means and variances (Anderson, Dillon and Hardaker 1977, p.287) cannot determine stochastic dominance. Anderson, Dillon and Hardaker (1977, p.288) describe distributions which intersect once as 'simply related' and define SSD dominance also in terms of proneness to low outcomes. However, the optimistic twinning CDF is slightly more prone to low outcomes and so this criterion cannot be used to separate it from the normal beef CDFs. And because the pessimistic twinning CDF is not normally distributed nothing can be said of it in comparison with the other two CDFs using these rules.

A microcomputer program developed by Goh, Raskin and Cochrane (1987) was used to conduct the stochastic efficiency comparisons of distributions in Figure 2 using SDWRF. The three distributions were compared pairwise over a range of values for absolute risk aversion intervals. This range included the absolute risk aversion coefficients estimated above from the Bardsley and

Table 12

Correlations between Weights and Prices

Beef Type	Independent Variable	Dependent Variable	Dependency Coefficient	Comment
Heifer	Live weight	Price	+0.75	Strongly positive
Store steer	Live weight	Price	-0.75	Strongly negative
Vealer steer	Live weight	Price	-0.25	Weakly negative

Harris (1987) results. The results of these comparisons are shown in Table 14. At the levels of risk aversion measured by Bardsley and Harris (1987) the optimistic twinning CDF was stochastically efficient and dominated the other distributions. At the higher level of risk aversion the small possibility of a lower outcome under optimistic twinning (Figure 2) has become more important for that class of decision-maker.

Table 13

Results of Risk Analysis

Distribution measure	Scenario		
	Normal vealer production	Twinning optimistic	Twinning pessimistic
	\$(a)	\$(a)	\$(a)
Mean	48295	50573	50534
Maximum	55371	62762	79002
Minimum	40275	36405	13647
Range	15096	26357	65355
SD	2790	4621	13032

(a) Total Gross Margin from beef activities on 650 ha.

Therefore under the assumptions made about the distributions of key variables, the optimistic twinning scenario presented here would be selected by a 'normally' risk averse Australian beef producer, but the pessimistic twinning scenario would not.

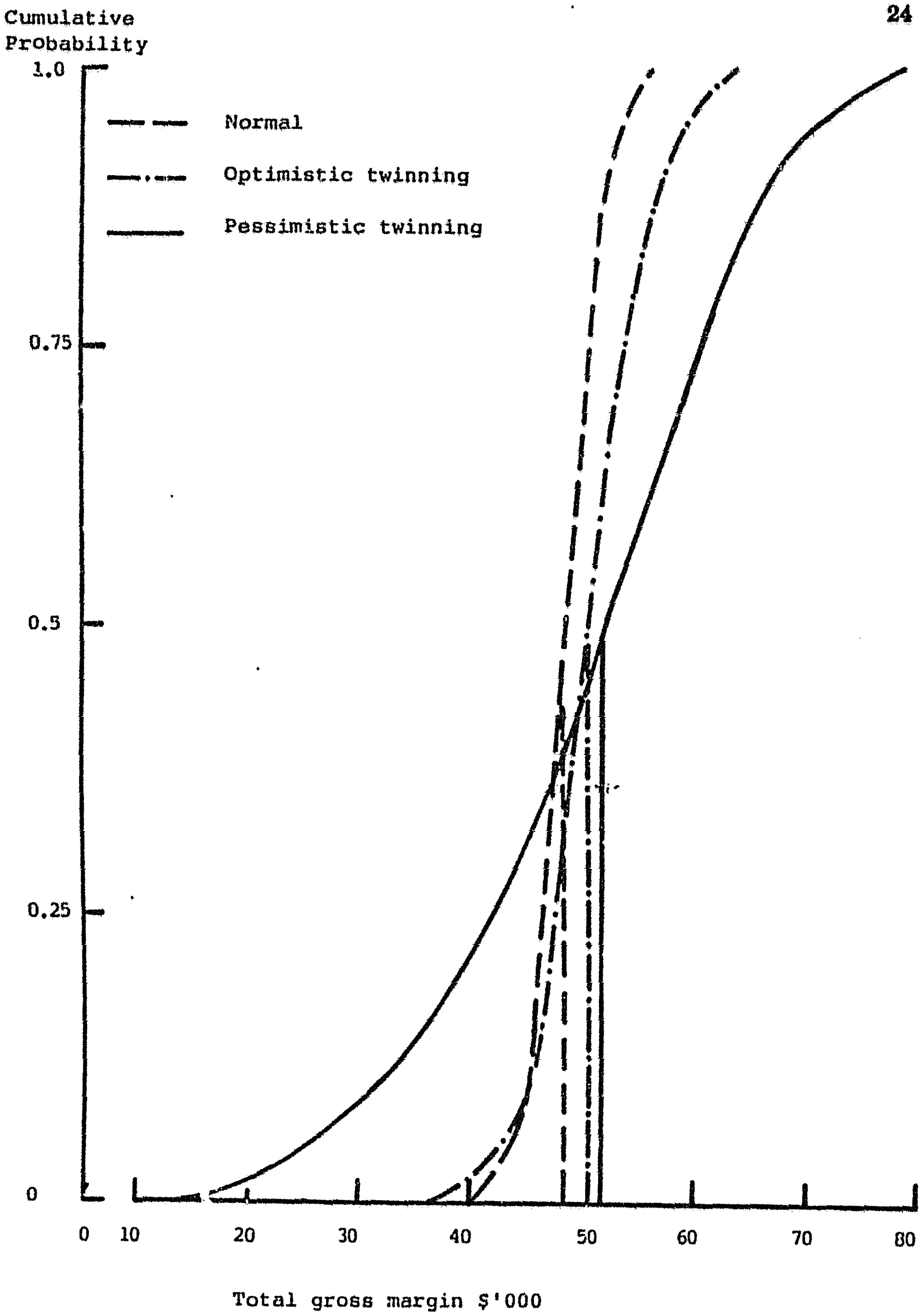

Figure 2 CDF's for normal beef and two twinning activities

Table 14

Dominant Beef Production Strategies for Ranges of Absolute Risk Aversion

Risk Aversion Range (a)	Dominant Technology
1×10^{6} - 1×10^{5}	Optimistic twinning
1×10^{5} - 1×10^{4}	Optimistic twinning
1×10^{4} - 1×10^{3}	Optimistic twinning, normal beef production

(a) Measured by the absolute risk aversion coefficient.

7. Summary and Conclusions

The null hypothesis is that twinning is not economically appealing to beef producers in the target group. This hypothesis has been tested using one principal methodology (LP) and an extension (risk analysis). Both of these were based on detailed financial, labour and energy budgets. Examination of the main LP results from Section 6 clearly indicates that, assuming profit maximisation, beef production using twinning can provide an increased return in a whole-farm context, and therefore the null hypothesis must be rejected. The alternative hypothesis, that twinning provides an economically appealing alternative enterprise to beef producers, is therefore accepted.

However, some qualifications of this conclusion have been indicated from the LP analysis. The number of calves weaned per cow joined is an important factor. The two alternative twinning scenarios under which the weaning percentage was reduced through cows being joined later and/or culled earlier than normal were not economically superior and so this question of overall herd fecundity is an important one for technology developers. Although this result should not be surprising its confirmation by the analysis for two not-unrealistic possibilities is of interest. This result should also be compared with the gross margin budgets summarised in Table 3. The implications of those results are that all three twinning activities would be economically superior to normal beef production, but the LP analysis has shown that by accounting for all resource availabilities the latter two twinning scenarios are not superior. Thus the advantage of using a whole-farm analysis over simple budgeting is demonstrated.

Another important result was that although twinning was still selected when supplementary winter feeding was reduced, when the labour supply was reduced normal beef production proved to be more profitable. Extra feed and labour requirements are both expected *a priori* to be important, but this result indicates that labour availability is a necessary requirement for twinning. This highlights an aspect of the twinning technology - that it is expected to be quite labour-intensive and beef producers would need to have adequate labour available to undertake twinning.

The risk analysis was conducted with respect to the beef activity only. Correlation with the sheep activities was not included, so the spreadsheet-based risk analysis was not as comprehensive in the whole-farm context as, say, a QRP modelling approach might be. However, it did provide other advantages in terms of ability to model variation in specific physical and economic parameters considered important for the technology.

The risk analysis required further ascumptions about the behaviour of twinning in a commercial context. In particular assumptions about the distributions of key variables needed to be made. The approach taken was to use the best available information or opinions of experts in the field, and to apply a sensitivity analysis to investigate the impact of different distributional assumptions for the key variable.

When the risk analysis results were compared for a risk averse beef producer, an optimistic twinning scenario proved superior to normal beef production and the null hypothesis must be rejected. However, under the pessimistic scenario of the distribution of weaning percentage, the probability of a lower financial outcome for much of the time means that the beef producer would not consider twinning given the range of other risks in livestock production and farming generally.

These results can be compared with two other economic studies of twinning in beef cattle. Farquharson and Griffith (1989) used a partial budget to estimate the potential economic benefits from twinning at the farm level. The LP results from this analysis agree with their conclusion that twinning provided significant economic benefits. Parfett (1989) used an LP approach to look at a number of different beef cattle production systems at the farm level (including twinning). He concluded that the beef system based on twinning would be the most profitable to run.

In drawing conclusions from this type of analysis we must always remember the crucial dependance on assumptions about potential impacts of the new technology. Close consultation with scientists and advisory officers has been maintained in attempting to set up a model that is as realistic as possible. The aim should be to do as good a job as possible with the resources and knowledge available at the time, but it must be recognised that the final outcome may be different for unforseen reasons (Anderson, Dillon and Hardaker 1977).

Overall the results of this analysis have indicated that, on the basis of the profit maximisation criterion, the twinning technology for beef cattle might be expected to be appealing to at least some beef producers. When aspects of potential increasing variability in returns associated with twinning are included, risk averse beef producers might still be attracted to twinning depending on the level of variability in the final weaning percentage. The reliability of the commercial product is thus indicated to be of primary importance.

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