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THE ECONOMICS OF SMALLHOLDER DAIRYING IN BOTSWANA

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I. Livestock Production and Dairying in Botswana

Livestock production is an important part of Botswana's economy. Four fifths of the country is rangeland, which supports a cattle population of almost 2.5 million. Most cattle are found on smallholder farms, where indigenous breeds graze throughout the year on communally-owned natural pasture. Few animals are considered dairy cows; milk production is best considered a by-product of beef. Beef production accounts for about 80 percent of agricultural output (Economist Intelligence Unit, 1992). Despite the large livestock population (Africa's highest ratio of livestock to humans), Botswana currently imports three-quarters of its milk requirements, and demand for milk in urban areas is estimated to be growing at 20 to 25 percent per year (Konandreas, Anderson, and Trail, 1983).

Dairy development in Africa is favoured by a large and growing internal market, low feed to milk price ratios, and low labour costs. However, it is hampered by seasonal fluctuations in the quality and quantity of feed, widespread disease, poor dairy stock, and scarcity of processing and marketing infrastructure (Walshe *et al*, 1991). Botswana's arid climate greatly constrains livestock development, particularly where dairy production is concerned. Low and erratic rainfall, together with recurrent droughts and overstocking, contribute to a shortage and poor quality of natural pastures. Poor diets are manifest in cattle by long calving intervals, short lactation periods, low milk yields, and high calf mortality rates. The vast majority of cattle are indigenous Tswana breeds, which are hardy but poorly suited to milk production. Thus, any effort towards improving livestock productivity must address not only the nutritional constraint but also the upgrading of the indigenous cows with exotic stock.

Milk marketing is poorly developed in Botswana. Rainy season production is usually sufficient to satisfy farm household consumption--often with surplus--but in the dry season many rural families forego milk consumption, and urban demand is satisfied with imports. There is a lack of infrastructure for getting fresh milk from surplus areas to urban consumers, who are mainly in the capital city, Gaborone. An unlimited amount of fresh milk may be sold at the Gaborone Dairy Cooperative at a guaranteed price, but transportation costs inhibit sales. Most milk therefore is sold locally in a sour, fermented state, called *madila*, which takes up to two weeks to make (by intermittently adding any excess milk), and need not be sold immediately thereafter.

Despite these constraints, the government of Botswana is determined to promote a dairy industry in order to conserve foreign exchange and improve rural levels of income, employment, and nutrition. The government plans to do so by upgrading indigenous breeds and promoting supplemental feeding of legumes and crop residues during dry seasons. This new technology has been tested in Botswana, and demonstrates impressive increases in milk production. However, little is known about the economic viability of these dairy operations in the context of the small farm system, since higher milk yields will be offset by additional costs associated with stover and fodder production. These economic considerations are prerequisite to widespread acceptance of the technology, and the subject of this paper.

By adding economic information to existing production data, this study identifies and recommends optimal dairy farm plans for selected smallholders, i.e. farmers participating in the Dairy Development Research Project, and evaluates the stability of such plans under various price, cost, and management scenarios. In doing so, the analysis highlights constraints to dairy development in the traditional livestock sector, and attempts to determine the types of farmers who can most profitably incorporate a dairy component into their farming system.

II. The Dairy Development Research Project

In collaboration with foreign donors, the Animal Production Research Unit (APRU) of the Ministry of Agriculture is undertaking to develop a domestic dairy industry in the region around Gaborone. Leading this endeavour, the Dairy Development Research Project has two broad objectives. The first is to increase domestic milk production through promotion of higher yielding cattle (crosses of indigenous "Tswana" breeds with the exotic Simmentals) and use of crop residues and legume fodder. The second goal is to develop local markets through establishment of milk handling centres.

To explore the use of supplementary feeding for dairy purposes, APRU undertook a series of on-station feeding trials from 1979. These trials revealed the superiority of Simmental-Tswana cross-bred (SX) cows in terms of milk production over the Tswana (TS) cows. Average SX yields were 3.6 and 3.3 times that of TS cows in 1980-81 and 1981-82, respectively (Daniels 1991 p.2). However, these yields characterize carefully controlled situations, with high levels of management and resource availability.

These results encouraged APRU to take the next step--investigation of the possibility of introducing the use of SX cows into small-scale farms. The project began in 1985, funded jointly by the Botswana Government and Canada's International Development Research Centre (IDRC). The main objective of this project is to assess the productivity of the SX cows under small farmers' own communal management. To achieve this, a package was designed for forty participating farmers consisting of a pregnant SX heifer (in exchange for one of the farmer's TS cows), enough *Dolichos Lablab* (a legume fodder crop) seed for one hectare, an extension promotion of the harvesting of crop residues, such as sorghum stovers during the dry season, and artificial insemination with Simmental semen.

The results of the project to date confirm the on-station results; the SX cows are found to produce significantly more milk than the TS cows, yet a much smaller proportion than found with research station results. A comparison of "with project" and "without project" situations showed that average SX yields were 1.7 times higher than TS cows (Daniels 1991 p.11).

Despite large differences with respect to milk yields, little is known about the economic performance of these two breeds, especially when they are raised in communal areas. To date, only one attempt has been made to look at the economics of these new technologies (Daniels 1991). From this preliminary study it has been found through benefit-cost analysis that the "without" project case gave an annual net benefit which was 118.79 Pula[1] per cow greater than that of the "with project" case. The study therefore concludes that the new technology must be rejected as financially unattractive to the average farmer.

A shortcoming of this study was its reliance on a representative farmer as the analytical unit. Botswana livestock farms have different characteristics and endowments of financial, capital and human resources. Therefore, for practical recommendations to be made, it is necessary to use individual farm data so as to determine an optimum farm plan for each farm. Such analysis is described below.

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[1] The average exchange rate in 1991 is P2/$1.

III. Capital Budgeting and the Optimization Model

An analytical framework is developed in two stages. The first involves a net present value approach to establish the value of a dairy cow over its useful life. The second stage used a single period linear programming model to model each of the forty participating farms. Most of the data were compiled by the APRU staff between 1986 and 1990. To supplement these data, a survey was carried out among the project farmers using a questionnaire to collect information not included in project records, such as labour availability and requirement, grain crop yields and sales, and sales of milk and cattle.

Dairy production is a long term investment. Thus, in order to assess the economic returns to a dairy enterprise it is important to look at the life-time production of a dairy cow. The Net Present Value (NPV) approach was used to transform future returns accruing from a single cow over an eleven-year planning horizon to present value. Returns include income from milk, sale of steers, heifer calves, and cull cows. Costs include purchases of SX cows, and expenses for breeding and veterinary service. On the basis of a calving interval of 1.50 and 1.38 years for SX and TS cows, respectively (APRU 1989), each cow in the analysis has seven lactations over the planning period. The returns from an investment in a dairy cow were therefore calculated on the basis of the amount of milk produced in each of the seven lactations, calves and cull cows sales. The cost included SX cow purchase, breeding and veterinary costs.

The NPV is the difference in present value of the cash inflows and cash outflows and can be expressed mathematically as:

$$NPV=\sum_{t=1}^{n}\frac{(B_t-C_t)}{(1+i)^t}$$

where

B_t	is cash inflow in each period *t*
C_t	is cash outflow in each period *t*
i	is the discount rate
n	is the useful life of an asset in years

To estimate milk income the four-year milk records (which comprised a maxmimum of three lactations) were extended over the economic life time of a dairy cow. Unfortunately, farmers were not able to provide data on the yields over the life time of the cow, or even the age of most of their cows. Therefore to achieve an estimate of lifetime yields, results of a similar study in India were used (Shivtar *et al* 1986). Using the percentage increases from one lactation to the next in the Indian study, the milk yield records of the breeds in this study were extrapolated. Actual milk yield observations were plotted against the life time lactation curve from the above study. From this plot, the lactation number for each milk yield observation could be estimated. The curve was then extrapolated either backwards or forwards depending on the lactation number available. This was repeated for each cow on each farm. For farms with more than one cow an average yield was calculated for each farm after the extrapolation.

Using the NPV analysis results, a single period linear programming (LP) model was used to optimize profits for each farm in the study. An LP model is a mathematical technique which has been widely used by farm management economists, particularly in livestock applications. For example, it has been used to specify the optimal organisation of resources and enterprises on farms, determine desirable farm adjustments, specify least-cost feed mixes, and to solve problems such as optimal culling and replacement decisions.

Attributes of the linear programming method make it a very useful tool for comparing the economics of farm technologies. It is a whole farm planning tool which can handle interactions of complex farming systems, as opposed to other techniques such as partial budgeting. The ease with which complex computational problems can be handled makes LP an extremely powerful technique capable of solving problems with thousands of variables and constraints. It can be adapted to deal with multiple objectives, risk and planning over time. LP analysis is able to provide shadow prices--the marginal value products of limiting resources. For a resource that is binding, the shadow price indicates the revenue that will be foregone if one unit of that resource is released. In other words, it represents the maximum amount worth paying for an extra unit of the resource.

The general form of an LP model in matrix notation can be presented as follows:

Maximize:

$$Z=c'x$$

subject to:

$$Ax \leq b$$

$$x \geq 0$$

where

Z	is total farm profit
c'	is a 1xn vector of activity gross margins
x	is a nx1 vector of activities
A	is a mxn matrix of technical coefficients
b	is a mx1 vector of fixed resource availabilities

The objective function maximizes profits from the dairy enterprise and other farm operations. The activities include production of primary products, such as fodder, which are then used to produce milk and beef, the secondary products. In addition to the livestock activities we include crop production, home consumption, sorghum bran purchasing, and labour hiring, since these activities compete for the farm's resources. Home consumption and sale of sorghum were also included.

Profits are maximized subject to a set of resource and technical constraints. Land, as a fixed resource, is one of these constraints. Farmers participating in the project had usufruct rights to areas of land ranging from three to twenty-three hectares. Family labour is also limited, thus the model includes the ability to hire labour. It is assumed that 50 percent of available family labour is spent on non-agricultural household activities.

Eight livestock production alternatives were considered in the analysis:

1. Buying and feeding a cross-bred cow and selling fresh milk.
2. Buying and feeding a cross-bred cow and selling *madila*.
3. Keeping and feeding a Tswana cow and selling fresh milk.
4. Keeping and feeding a Tswana cow and selling *madila*.
5. Raising cross-bred cow through artificial insemination and selling fresh milk.
6. Raising cross-bred cow through artificial insemination and selling *madila*.
7. Grazing Tswana cows and selling fresh milk (without project situation).
8. Grazing Tswana cows and selling *madila* (without project situation).

IV. Results

Three runs of the model were made for each of the thirty-eight farms modelled.[2] The first run determined the optimal farm plans. Results showed that project farms fell into three groups: those which would be expected to completely adopt the new technologies (replace all their indigenous cows with cross-bred cows), those which would partially adopt the new technology (replace some of their indigenous cows with cross-bred cows *or* provide feed supplement to their Tswana cattle to increase milk yields) and those which would maintain the status quo (maintain an exclusively TS herd).

The groups were composed of 2, 17, and 19 farms, respectively. Therefore, half of the farmers, as modelled, would be expected to at least partially adopt the new technology. Table 1 shows the model results for optimal production for selected farms. To facilitate exposition, only three farms--chosen at random--are shown for the latter two categories. Only six of the eight production alternatives are listed on the table, since the activities that involved raising SX cows with artificial insemination were not selected by any farm in any run of the model set.

The land constraint was slack for most of the farms--indicating that land is not a major limiting resource to dairy development in the region. However, animal feed resources and labour were found to be limiting. Although an allowance was made in the model for the sale of surplus sorghum, in most cases only enough land to meet minimum home consumption requirements was cultivated in this staple. Labour was limiting in many of the farms which adopted cross-bred cows, although half of these farms could afford use of hired labour. For the others, the marginal productivity of labour was too low to warrant hiring of labour.

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[2] Two of the forty farmers participating in the project lost their SX cows and were excluded from the analysis.

Table 1. Optimal Production Plans for Selected Farms

	Complete Adoption		Partial Adoption			No Adoption		
farm identification number	17	31	9	13	33	1	8	20
sorghum production (ha)	8.87	6.19	2.67	6.21	1.18	3.00	1.60	1.69
lab-lab production (ha)	2.74	.81	.47	1.21	.47			
lab-lab production (MT)	2.52	2.52	1.11	2.43	.47			
stover production (MT)	5.32	5.32	2.36	5.21	1.00			
sorghum bran production (MT)	1.33	1.33	.59	1.34	.25			
home consumption (MT)	.23	.32	.21	.22	.20	.75	.24	.27
sorghum sale (MT)	.83	1.22	.08	.58				
1. Buy SX, sell milk (head)	7.00	7.00	3.10		1.32			
2. Buy SX sell madila (head)								
3. Feed TS, sell milk (head)				8.99				
4. Feed TS, sell madila (head)								
5. Graze TS, sell milk (head)			8.90	.01	8.68	21.00	10.00	16.00
6. Graze TS, sell madila (head)								
hire labour Oct-Nov (hrs)								
hire labour Dec-Jan (hrs)								
hire labour Feb-Mar (hrs)			41.26					128.21
hire labour Apr-May (hrs)								
hire labour Jun-Jul (hrs)	83.24			75.69	199.78			59.52
hire labour Aug-Sep (hrs)								

Since feed and labour costs were found to be binding constraints, simulation runs of the model were made to establish the sensitivity of the farm plans to these factors. A second run of the model set determined how the optimal plans would change with a 50 percent reduction in the cost of feed. Purchased feed costs are usually out of the reach of the majority of small farmers. It is therefore hoped that home production of animal feeds would reduce such costs and thus enable small farmers to improve their livestock productivity. Results show an increase in the level of activities in the optimal solutions for those farms that were already adopting the new technologies. Eight farms which did not adopt the use of cross-bred cows at first did so when feed costs were reduced. There was an overall increase in farm profitability. For farms whose land was already limiting this change did not have any effect on the optimal farm plan.

The third run simulated a 50 percent reduction in the wage rate. Four farms which did not hire labour in the base case now did so. For some farms however, the marginal value product of labour was so low that even such a large decrease in the wage rate did not have any effect on the optimal farm plans. Only one farm adopted the use of cross-bred cows when the wage rate was reduced. This shows that in terms of overall production, feed costs are more critical than labour costs. To summarize the impact of lower feed and labour costs, Table 2 shows the relative impact on farm profitability for those farms affected by both reductions.

Given that farmers are heterogeneous with respect to the likelihood of adopting the dairy technology, the question remains: What are the characteristics of farmers who are most likely to adopt? Once this is answered, research and extension efforts could be made more effective and efficient by targetting suitable farmers. In order to characterise the three groups presented in the previous tables, discriminant analysis was used based on features of the farms defined in the farm survey. Discriminant analysis is a statistical application of multiple correlation analysis that is used to determine membership in mutually exclusive groups when group membership is known, and is used in situations where the dependent variable is classificatory rather than numerical. The idea is to find a linear combination of characteristics that would efficiently create a score for each group in a way that the difference between the group means is maximized.

Table 2. Relative Impact of Feed and Labour Costs on Farm Profit (Pula)

Farm ID#	Percentage increase in profit with 50% decrease in... Feed Costs	Labour Costs
2	6.3	1.9
9	2.4	1.2
13	19.7	11.3
15	2.7	3.4
17	41.4	14.7
20	0.5	2.0
24	2.0	13.8
25	1.5	10.9
30	0.6	0.6
31	26.9	9.9
Mean	*10.4*	7.0

Table 3 indicates some of the characteristics of the farms used in the analysis. Results of the discriminant analysis were inconclusive. All the variables tested were not significant, indicating that there were no correlations between them and the adoption of the use of cross-bred animals. The significance of the F scores ranged from 0.82 to 0.26. A significance level of 0.05 is usually taken as the cut-off point. A factor in this result was certainly the sample size. In such analysis, groups of at least 30 observations are ideal; the largest population in this case was 19.

Table 3. Characteristics of selected farms (from farm survey)

	Complete Adoption		Partial Adoption			No Adoption		
farm identification number	17	31	9	13	33	1	8	20
Sex of Head of Household	M	F	M	M	M	M	M	M
Age of Head of Household	65	45	50	62	66	60	43	59
Family Size	8	5	4	6	4	25	11	4
Herd Size	12	24	28	24	21	60	27	35
Number of SX cows	1	2	1	2	1	1	2	2
Field Size (ha)	15	7	5	9	10	3	7	15
Distance to Market (km)	15	4	3	8	3	5	13	15
Rainfall (mm)	509	532	532	532	400	532	531	503
Number of milkers	3	1	1	2	2	3	1	2
TS Milk Yield (lt/lact.)	9229	9685	7037	3711	6210	7368	4762	5684
SX Milk Yield (lt/lact.)	3623	3847	4495	5544	3803	4343	3084	3159

V. Conclusions and Policy Implications

1. Due to the heterogeneity of smallholder farmers, development packages intended to improve farm profitability should address a variety of farmers' specific needs. Botswana farmers have different resource endowments, and, as a consequence, different capacities to absorb the new technology. While some farmers may become better off by adopting, some may become worse off.

2. While the use of artificial insemination is being viewed as the cheapest to acquire cross-bred cows, the study has revealed that it is more economic to purchase such cows. The emphasis that has been placed on AI should be reconsidered. Alternative ways of helping eligible farmers to buy cross-bred cows should be sought, such as provision of credit.

3. There is need for further research into lower cost feeds, as this still remains a major constraint to dairy development.

4. If the feed subsidy that is being given to farmers through the project is to be continued, it should not be indiscriminate. It is clear from the study that for some farmers such a subsidy is a dead weight loss, and therefore only results in a decrease in social welfare.

5. Farmers would be better off selling their milk fresh rather than selling it as *madila*. The proposed milk collection centres would be helpful in this regard.

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