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A production function analysis of commercial dairy farms in the Highlands of Eritrea using ridge regression

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Abstract

This study presents a production function analysis of fresh milk production in the Highlands of Eritrea, where most dairy farmers in Eritrea are located. To ensure representative production functions, this region was divided into three relatively homogenous study areas, namely Central Zone, Mendefera and Dekemhare. Most data for the study were collected in a survey of 120 respondents using a structured questionnaire. To obviate the problem of multicollinearity among explanatory variables, ridge regression was used to estimate milk production functions for each study area. Production elasticities of variable inputs, marginal products (MP_x), values of marginal products (VMP_x), marginal rates of input substitution (MRS) and least-cost combinations of purchased concentrates and forage were estimated for the three regions. The VMPs of all inputs for Central Zone dairy farmer respondents were estimated to be greater than their input prices, implying that the resources were under-utilized from a profit-maximising perspective (i.e. where $VMP_x = P_x$). However, respondents in Mendefera and Dekemhare used concentrates in excess of optimum levels (i.e. $VMP_x < P_x$). Analysis of the least-cost combination of purchased concentrates and forage suggests that dairy farmer respondents were also not allocating these resources on a minimum-cost basis. However, the profit maximizing and least-cost criteria assume perfect knowledge, a risk-free environment and competitive markets. Improved information, farmer training and better infrastructure (roads and telecommunications) to promote competitive markets could help to enhance resource allocation decisions by dairy producers.

1. Introduction

Eritrea, which obtained independence in 1991, is geographically located in north-eastern Africa. It has a land area of 121,320 square kilometres and a population of 4.45 million people. Administratively it is divided into six geographical regions referred to as zobatat (singular – zoba). The economy is largely based on subsistence agriculture, with 80% of the population involved in farming and herding. In 2003 agriculture accounted for an estimated 12.4%

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of the country's Gross Domestic Product (GDP) (CIA, 2005), with livestock accounting for about 15% of agriculture's contribution to GDP (MOA, 2002). Although about 80% of the Eritrean people live in rural areas and primarily depend on agriculture or pastoralism for their means of living, the country is only able to meet 60% of its food requirements in a good year, due to various factors such as erratic rainfall, shortage of good agricultural land, soil degradation and disruption of agriculture during the long (30 years) war for independence. This is well below the potential that could be achieved with better land management. Grazing, browsing and barren land is estimated to constitute more than 90% of the total area of the country (MOA, 2000).

Italian settlers initiated commercial dairy farming during the 19th century when Eritrea was under Italian rule. The intensively managed Italian farms clearly demonstrated the progress that can be achieved by proper management and upgrading practices (Teclu, 1995). Teclu (1995) also noted that, even after the British replaced Italian rule and the Imperial rule of Ethiopia replaced the British, the Italian owned dairy farms were operating normally under their original owners. Milk production increased continuously until the mid-1970s, i.e. before the nationalisation of the private sector and the breakdown of institutions and supporting services by the former military government of Ethiopia. Consequently, this growth was geared to the development of small and medium scale commercial farms. However, the breakdown of institutions and supporting services, the prolonged war for independence, and the severe shortage of feed resulting from continuing droughts led to reduced dairy activities and production. Since 1991 the government of Eritrea has taken considerable measures to rehabilitate the livestock sector by providing extensive annual vaccinations against major infectious diseases and undertaking intensive training programmes for livestock technicians and farmers (MOA, 1996).

However, dairy farmers in Eritrea are still faced with key decisions on how best to produce milk and how much to produce, given their limited resources. Thus, the main objective of this study is to conduct production function analyses of commercial dairy farms in the main milk-producing area of Eritrea, the Highlands region, focussing on the most important factors of production affecting milk production in the region, and to determine whether resources are optimally used. The results derived from the analyses may assist agricultural economic advisors and dairy extension agents to advise farmers on how to improve allocation of their scarce factors of production. The results may also provide dairy farmers and policy-makers with a better insight into the optimal allocation of scarce farming resources.

2. Description of study area and sample of dairy farms

The population of commercial dairy farms in the Highlands of Eritrea is mainly concentrated in the Central Zone “Asmara” and the Southern Zone “Mendefera” and “Dekemhare” regions. According to Zeggu (1997), the distribution of the dairy cattle population in Eritrea was 75%, 8% and 4% in the Central Zone, Mendefera and Dekemhare areas, respectively, with pure and grade Friesian breeds respectively comprising 93%, 89% and 100% of dairy herds in the three regions. Dairy farmers in these areas are encouraged to deliver and sell their daily milk output to the milk collecting, cooling and processing centres, where milk is processed and sold to retailers and consumers. Producers benefit from this arrangement by having access to the milk market and to concentrate feed (concentrates) and industrial by-products (such as wheat middling, wheat bran, oilseed cake and brewery by-products). The quantity of concentrates supplied to each farm is based on the number of registered dairy animals in the herd and on the quantity of milk the farm delivers.

A sample of 120 farmers considered for this study was selected in three steps:

1. Farmers were regionally stratified to avoid qualitative differences (farming practice, biodiversity, and management skills) due to location.
2. Farmers were sorted according to the quantity of annual milk output in litres delivered to the milk collecting and cooling centres in each study area. Farmers supplying these centres on a regular monthly basis and producing at least 12,500 litres/year in the Central Zone (larger herd sizes) and at least 4,300 litres/year in Mendefera and Dekemhare (smaller herd sizes) were considered for selection.
3. Based on the above criteria 48 farmers from the Central Zone (74% of identified producers), 42 from Mendefera (63% of total population) and 30 from Dekemhare (65% of total population) were selected. The 72 farmers from the two regions of the Southern Zone (i.e. Mendefera and Dekemhare) are over-represented relative to the distribution of the dairy cattle population in Eritrea in order to achieve sample sizes sufficiently large to obtain reliable estimates for the two regions.

Some characteristics of the sample of dairy farms in each study area are presented in Table 1. It is clear from Table 1 that the Central Zone dairy farms are much larger in terms of number of dairy cows and milk production, and also more productive in terms of annual milk output per cow than the farms in Mendefera and Dekemhare.

Table 1: Characteristics of sample dairy farms in the Highlands of Eritrea, 2002

Variable	Central Zone (n=48)	Mendefera (n=42)	Dekemhare (n=30)
	Mean value/farm	Mean value/farm	Mean value/farm
Number of cows	20	7	7
Concentrate feed (Nakfa*)	27318	12237	15810
Purchased forage (Nakfa)	14647	6192	5216
Labour (Nakfa)	23816	7656	10681
Veterinary & medicine (Nakfa)	1694	629	469
Operating & mechanical (Nakfa)	7574	1486	1912
Milk output/year (litres)	43529	8609	9460
Milk output/cow/year (litres)	2176	1230	1351

Note: *1US dollar was equivalent to about 14 Nakfa at the time of the study.

It is generally believed that, for any farmer in the Highlands of Eritrea, the availability of land for crop and fodder production is important as home-grown fodder provides the cheapest source of feed. However, in Eritrea most dairy farms are concentrated in, or very close to, cities and towns and about one-third of the dairy farmer respondents have no access to irrigable land for forage and pasture production. In fact, all respondents in the three study areas rely on purchased concentrates, and purchased cut and carry green feeds and hay and cereal straw to feed their herds. Besides, as the available industrial by-products (wheat bran, wheat middling and oilseed cake) and concentrates rationed monthly are not sufficient, farmers purchase whole grains like sorghum and maize at a relatively high cost.

3. Classification of inputs and output

Data for the production function analyses were collected from the identified sample of 120 commercial dairy farms for the year 2002 by survey method using a questionnaire. Data obtained included land utilization, herd structure, annual income, and annual expenses on variable inputs and fixed assets. The categories of variables used in the analyses were as follows:

1. Annual milk output is the total milk yield in litres delivered to the milk collecting and cooling centres and milk consumed on the farm.
2. Annual purchased concentrate feeds including licks (Nakfa).
3. Annual purchased forage (i.e. fodder, hay/straw and other green feed) (Nakfa).

4. Annual labour cost, including regular, casual, contract and family labour (opportunity cost) (Nakfa).
5. Annual veterinary service and medicine costs incurred for dairy livestock (Nakfa).
6. A dummy variable scoring 2 for respondents with access to land for feed production and 1 otherwise (about one-third of respondents did not have access to land for feed production).
7. Annual operating and mechanical costs comprising electricity, water, fuel, oil, grease, repairs and spares (Nakfa).
8. Number of milking cows in 2002.

The production functions derived in this study are of the inter-farm rather than intra-farm case. Although they may be looked upon as averages for all farms, they do not necessarily coincide with that of any one farm. Some homogeneity was achieved by grouping farms according to location within the Highlands of Eritrea, namely the Central Zone, Mendefera and Dekemhare areas. Even then a multitude of functions could exist because of the varying combination of techniques employed and commodities produced (Heady, 1946). Besides, certain inputs may be excluded and managers may likely seek to maximize returns over a time period other than the period considered (Plaxico, 1955). Basically, an attempt was made to pool the data of the three study areas, using dummy variables to test if the three study areas' regressions have a common intercept and a common slope. From these analyses, the intercept and slope dummy coefficients for the pooled data were statistically different from zero at the 1% and 5% levels of probability. Thus, it was not statistically appropriate to pool the data from the three regions to estimate a common function that represents the sample of dairy farmers of the Highlands of Eritrea as a whole. For this reason, separate analyses were conducted for each study area.

4. Methods of data analysis

Conventional production function analyses have popularly been based on the double-log (Cobb-Douglas) approach (Heady and Dillon, 1961:228). However, due to high correlations among some factors of production in this study (see Appendix A), some of the estimated parameters had negative production coefficients where *a priori* all such coefficients are assumed to be non-negative (see Appendix B). Thus, to deal with the multicollinearity problem, *ridge regression* (by modifying the method of least squares to allow biased estimators

of the regression coefficients) was used at different levels of the biasing constant, c , where the regression coefficients in the ridge trace started to stabilize and the variance inflation factor (VIF) of each parameter and the average of the VIFs were close to one (Neter *et al*, 1990). The VIF shows how the variance of an estimator is inflated by the presence of multicollinearity. As the collinearity between two variables approaches one, the VIF approaches infinity. For example, for $r_{23} = 0.00, 0.50, 0.70, 0.80, 0.90, 0.95$ and 0.99 the VIF values are 1.00, 1.33, 1.96, 2.78, 5.76, 10.26 and 50.25, respectively (Gujarati, 2003:351). "When an estimator has only a small bias and is substantially more precise than an unbiased estimator, it may well be the preferred estimator since it will have a larger probability of being close to the true parameter value" (Neter *et al*, 1990:412).

Ridge regression estimates tend to be stable in that they are usually little affected by small changes in the data on which the fitted regression is based. In contrast, ordinary least squares (OLS) estimates may be very unstable when the independent variables are highly multicollinear. One of the limitations of ridge regression is that the optimum value of the biasing constant, c , to be used varies from one application to another and the choice of c is thus a judgemental one (usually between 0 and 1). However, a commonly used method for determining the value of c is based on the ridge trace and the VIF values of the explanatory variables (Neter *et al*, 1990). Neter *et al* (1990:414) also discuss the effects on the estimated ridge regression coefficients, VIFs and R^2 as the biasing constant c is changed gradually from zero. They noted that an estimated regression coefficient may fluctuate widely as c is changed slightly from zero, and may even change signs. "Gradually, however, these wide fluctuations cease and the magnitude of the regression coefficient tends to change only slowly as c is increased further." At the same time the VIF values tend to fall rapidly as c is changed from zero, and gradually the VIFs tend to change only moderately as c is increased further.

Vinod (1978), citing Hoerl and Kenard (1970), states that ridge regression offers new hope for avoiding the most serious ill-effects of multicollinearity on OLS regression coefficients, such as wrong signs, drastic changes in regression coefficients after minor data revision or omission of one or two observations, and conflicting conclusions from usual significance tests. Vinod (1978) also mentions that, beyond hypothesis testing, many econometricians are interested in numerical values of regression coefficients (e.g. elasticities). For these applications, reliable (low mean square error) and stable regression coefficients offered by ridge regression may be useful alternatives to OLS, although there is wide disagreement about the "optimum" ridge regression. Nieuwoudt and Nieuwoudt (2004) used ridge regression of a production

function of time series data to estimate the rate of return on R&D in the South African sugar industry.

5. Results and discussion

The estimated ridge regression coefficients for the three study areas, using the SPSS statistical package, at the biasing constants of $c = 0.157$ for the Central Zone and $c = 0.167$ for Mendefera and Dekemhare, are presented in Appendix C. The final estimated models, showing only those variables that are significant at the 1%, 5% and 10% levels of probability, can be written linearly in logarithmic form as follows:

Central Zone:

$$\begin{aligned} \text{LnY} &= 2.371 + 0.311\text{ln C} + 0.190\text{ln F} + 0.221\text{ln L} + 0.402\text{ln Mc} & (1) \\ t &= \text{statistic} \quad 6.218 \quad 4.364 \quad 4.494 \quad 6.914 \\ R^2_{\text{adj.}} &= 0.897 \\ \sum b_i &= 1.124^2 \\ df &= 40 \end{aligned}$$

Mendefera:

$$\begin{aligned} \text{LnY} &= -0.777 + 0.156\text{ln C} + 0.410\text{ln F} + 0.376\text{ln L} + 0.029\text{ln OM} + \\ &\quad 0.664\text{ln Mc} + 0.124\text{lnD} & (2) \\ t &= \text{statistic} \quad 2.249 \quad 5.755 \quad 5.965 \quad 1.700 \quad 11.275 \quad 1.973 \\ R^2_{\text{adj.}} &= 0.944 \\ \sum b_i &= 1.635 \\ df &= 33 \end{aligned}$$

Dekemhare:

$$\begin{aligned} \text{LnY} &= -0.578 + 0.190\text{ln C} + 0.291\text{ln F} + 0.247\text{ln L} + 0.112\text{ln VM} + \\ &\quad 0.205\text{ln OM} + 0.417\text{ln Mc} + 0.133\text{lnD} & (3) \\ t &= \text{statistic} \quad 2.104 \quad 5.500 \quad 3.845 \quad 2.644 \quad 4.399 \quad 7.734 \quad 2.212 \\ R^2_{\text{adj.}} &= 0.961 \\ \sum b_i &= 1.462 \\ df &= 21 \end{aligned}$$

² $\sum b_i$ = sum of production elasticities for significant variable inputs.

Where, Y = annual milk yield (litres);

- C = annual purchased concentrates, including licks (Nakfa);
- F = annual purchased forage (Nakfa);
- L = annual labour cost (Nakfa);
- OM = annual operating and mechanical cost (Nakfa);
- VM = annual veterinary and medicine costs (Nakfa);
- Mc = number of milking cows in 2002; and
- D = dummy variable scoring 2 for respondents with access to land for feed production and 1 otherwise.

The adjusted multiple correlation coefficients of the estimated models for the Central Zone, Mendefera and Dekemhare areas, respectively, indicate that 89.7%, 94.4% and 96.1% of the variability in milk production is determined by the independent variables. The unexplained portion of variance in the total product can be partly attributed to variations between farms in respect of techniques employed, weather conditions and, to some extent, in input prices and scale of operation (Heady, 1946).

5.1 Production elasticities

The estimated regression coefficients shown in equations (1), (2) and (3) are the production elasticities for the individual factors of production as the dependent and explanatory variables are in natural logarithms. The elasticity coefficient shows the average percentage change in milk production associated with a 1% change in the relevant input, *ceteris paribus*. The highest output response to a 1% change in input is due to milking cows, namely 0.402%, 0.664%, 0.417% for the Central Zone, Mendefera and Dekemhare areas, respectively, followed by concentrates and labour for the Central Zone, and forage and labour for Mendefera and Dekemhare. The annual health variable (VM) was not statistically significant in both the Central Zone and Mendefera study areas, which may be an indication of good health care management in the herd. However, for the Dekemhare dairy farms the health variable was statistically significant, implying a need to invest in herd health care. Thus, a 1% increase in expenditure on veterinary and medicine items would be associated with an increase in annual milk yield of 0.112%, *ceteris paribus*. For the Mendefera and Dekemhare study areas the farm feed input variable (entered as a dummy variable) was significant at the 10% and 5% levels of probability, respectively. Thus, milk yield was higher for respondents with access to land to grow feed than for those with no access to land.

All the estimated elasticity (regression) coefficients are less than unity, which indicates diminishing marginal returns to each production factor; i.e. holding other factors constant, the marginal return to each factor will decrease as more of the factor is used. The estimated elasticities of production also indicate the stage of production. Thus, all the estimated regression coefficients indicate use of the resources within the rational area of production (stage II of the classical production function) (Doll and Orazem, 1984:41). The $\sum b_i$ for each study area shows increasing returns to scale, as the sum of the estimated elasticities for each area is greater than unity. Thus, an increase in all factors of production by 1% will increase annual output by $\sum b_i$ percent. However, this will hold true only if the entrepreneur can actually make a proportionate change in every input factor. If certain inputs are not under his control, there is little point in advising him that more profit can be attained by increasing or decreasing his scale of operation (Heady and Dillon, 1961:232).

5.2 Marginal products and values of marginal products

The marginal product of an input (MP_x) indicates the additional output that might be expected from an additional unit of that input, *ceteris paribus*. The value of marginal product of an input (VMP_x) is the marginal product multiplied by the unit price (P_y) of the product (i.e. VMP_x = MP_x.P_y). The MP_x and VMP_x estimated for sample dairy farms in each study area are presented in Table 2. These are estimated at the geometric means of input and output and are derived from the elasticity estimates as follows (Doll and Orazem, 1984:40-41):

$$E_p(b_i) = \frac{\partial Y/Y}{\partial X_i/X_i} = \frac{X_i \cdot \partial Y}{Y \cdot \partial X_i} = \frac{MP_{xi}}{AP_{xi}}$$

$$MP_{xi} = E_p(b_i) \cdot AP_{xi}$$

Where, $E_p(b_i)$ = the elasticity of output (Y) with respect to a

1% change of the i^{th} input,

Y = geometric mean of annual milk yield (Y),

X_i = geometric mean of the i^{th} input, and

AP_{xi} = average product of the i^{th} input.

The milk price per litre in 2002 was 4.85 Nakfa for the Central Zone and 5.00 Nakfa for both Mendefera and Dekemhare. The annual cost of a productive cow is estimated using the capital recovery formula (Monke and Pearson, 1989). Thus, for the Central Zone, a productive cow purchased for 12,000

Nakfa, having an average useful life of eight years, a 6,000 Nakfa salvage value, and generating a rate of return of 5% per annum, is estimated to cost 2,074 Nakfa per year. The Mendefera and Dekemhare dairy farmers replace a milking cow on average after nine years of production, at a 5,000 Nakfa salvage value. Hence, the annual cost of a milking cow purchased for the same price and generating the same rate of return as in the Central Zone is estimated to be 1,688 Nakfa.

Table 2 shows that most of the variable inputs for the three study areas are under-utilized as the VMPs of the inputs are greater than their corresponding unit prices (Px). However, concentrates are over-utilized in both Mendefera and Dekemhare, as the VMPs are less than the unit price of the resource (1 Nakfa). Therefore, assuming perfect knowledge, a risk-free environment and unlimited capital, the under-utilized inputs should be used up to the point where the VMP of the input is equal to the input price (i.e. $VMP_x = P_x$) to maximise net returns to the input (Doll and Orazem, 1984:66). Thus, an additional unit increase in investment in the under-utilized resources will generate revenue of the magnitudes reflected by the VMPs in Table 2. However, with respondents facing limited resources (capital), it may be more useful in the short to medium term to focus on the optimal allocation of inputs at the present levels of milk production. This is the focus of the next section.

Table 2: Marginal products and values of marginal products for various inputs, sample of commercial dairy farms in the Central Zone, Mendefera and Dekemhare regions of Eritrea, 2002

Study area*	Input											
	Concentrates		Forage		Labour		Vet. And medicine		Oper. And mechanical		Milking cow	
	MP	VMP (Nakfa)	MP	VMP (Nakfa)	MP	VMP (Nakfa)	MP	VMP (Nakfa)	MP	VMP (Nakfa)	MP	VMP** (Nakfa)
A	0.496	2.406	0.565	2.740	0.404	1.959	-	-	-	-	886	4297
B	0.110	0.550	0.570	2.850	0.423	2.114	-	-	0.168	0.840	819	4095
C	0.114	0.570	0.528	2.640	0.219	1.095	2.257	11.285	1.014	5.070	564	2820

Notes: *A = Central Zone, B = Mendefera, C = Dekemhare.

**Annual cost per cow = 2074 Nakfa in the Central Zone and 1688 Nakfa in Mendefera and Dekemhare.

5.3 Marginal rates of substitution and least-cost combinations of inputs

In the previous section, for sample farmers in the Central Zone it was inferred that all the resources were being under-utilized relative to the optimum level of production, while respondents in Mendefera and Dekemhare were utilizing concentrates beyond the optimum level and under-utilizing forage and some

other resources. Purchased concentrates and forage are two of the most important inputs in dairy farming in the study areas (see Table 1), and are to some extent substitutes in the production of milk. To assess how respondents can improve the allocation of these two inputs at their *present level of milk production, ceteris paribus*, the marginal rate of input substitution (MRS) and least-cost combination of the two inputs is estimated.

The marginal rate of input substitution (MRS) is the amount at which one input (X_1) must be substituted for another (X_2) to maintain a constant level of output (Y), holding other inputs constant at their respective geometric means; i.e.

$$\text{MRS of } X_1 \text{ for } X_2 = \frac{\partial X_2}{\partial X_1}$$

For the power function equation, the MRS is estimated as follows (Heady and Dillon, 1961: 84):

$$\frac{\partial X_2}{\partial X_1} = \frac{-b_1 X_2}{b_2 X_1}$$

For the sample of dairy farms in the Central Zone the marginal rate of substitution of concentrates for forage at their geometric mean values was -0.878, while for the Mendefera and Dekemhare dairy farms the corresponding marginal rates of substitution were -0.193 and -0.215 respectively. The relatively low marginal rates of substitution (in absolute terms) for the Mendefera and Dekemhare farms suggest that the farmers are utilizing relatively more concentrates than forage (i.e. these farmers operate on the iso-product curve where each additional unit of concentrates replaces a relatively small amount of forage).

The least-cost combination of purchased concentrates and forage, *ceteris paribus*, would occur when the absolute MRS of concentrates (X_1) for forage (X_2) is equal to the price ratio of concentrates to forage, as in the formula (Heady and Dillon, 1961:84; Doll and Orazem, 1984:121):

$$\text{MRS}_{X_1, X_2} = \frac{\partial X_2}{\partial X_1} = \frac{\text{MP}_{X_1}}{\text{MP}_{X_2}} = \frac{b_1 X_2}{b_2 X_1} = \frac{P_{X_1}}{P_{X_2}}$$

The price ratio P_{X_1}/P_{X_2} equals unity because concentrates and forage are both measured in terms of value (cost per year); i.e. the cost to purchase one Nakfa worth of feed is one Nakfa. The least-cost combinations of the two inputs at

the geometric mean levels of annual milk yield, *ceteris paribus*, for the three study areas are presented in Table 3.

Table 3: Actual and least-cost combinations of purchased concentrates and forage at the geometric means of annual milk yield, sample of dairy farms in the Highlands of Eritrea, 2002

Study area	Geometric means of milk yield (litres)	Actual geometric means (Nakfa)		Least-cost combinations (Nakfa)		Cost savings (Nakfa)
		Concentrates	Forage	Concentrates	Forage	
Central Zone	43529	27318	14647	25663	15688	614
Mendefera	8609	12237	6192	3581	9416	5432
Dekemhare	9460	15810	5217	6244	9599	5184

Table 3 shows that for all dairy farmer respondents, the actual cost of concentrates is higher than the least-cost combination of concentrates. At the geometric mean milk yield of the sample of dairy farms in the Central Zone, the actual use of purchased concentrates and forage ($MRS = -0.878$) is close to the optimum (least-cost) combination (i.e. where $MRS = -1$), *ceteris paribus*. Nevertheless, the least-cost combination showed a reduction of 1655 Nakfa in concentrates and an increase of 1,041 Nakfa in forage compared to the actual use, which is a net decrease in purchased feed cost of 614 Nakfa. For the sample of dairy farms in Mendefera and Dekemhare, reductions of 8,656 Nakfa and 9,566 Nakfa in concentrates and increases of 3,224 Nakfa and 4,382 Nakfa in forage, respectively, translate into a net gain (lower cost) of 5,432 Nakfa and 5,184 Nakfa, respectively. Clearly, judging by the possible cost savings, Mendefera and Dekemhare respondents are operating further away from their respective least-cost combination of concentrates and forage than are Central Zone farmers. Respondents may, therefore, reduce overall purchased feed costs at present levels of milk production by using less concentrates and more forage. Generally, the non-optimal allocation of these inputs may be due to factors such as lack of information (knowledge), variable input prices, risk perceptions and other constraints.

6. Conclusions

Production function analyses indicate that dairy farmer respondents are using their resources in the rational area of production where the elasticities of production (E_p) are less than unity, implying diminishing marginal returns to each input. However, profit maximisation analyses suggest that most of the resources are under-utilized ($VMP_x > P_x$), with the exception of concentrates, which are over-utilized ($VMP_x < P_x$) by dairy farmer respondents in Mendefera

and Dekemhare. With limited resources and knowledge, respondents may not, however, be able to achieve profit-maximising levels of milk production, at least in the short run. In the short to medium term it may thus be more appropriate for them to focus on the optimum combination of limited resources to produce their present levels of milk output at minimum cost. Analyses of least-cost combinations of purchased concentrates and forage at the geometric mean levels of milk output suggest that all respondents could reduce total purchased feed costs by buying less concentrates and more forage. The present over-investment in concentrates by Mendefera and Dekemhare respondents in particular – which is reflected in their $VMP_c < P_c$ and the relatively large cost savings in concentrates in the least-cost solution – may in part be attributed to greater risk attached to the availability of forage relative to the availability of concentrates in their regions.

Although it may be difficult to achieve optimum returns (maximum profits) in the short run with the existing knowledge of farmers, risk perceptions, limited resources and breed quality, a better (approaching optimum) allocation of resources by dairy farmers in the medium to long term may be achieved through extension advice on optimum resource allocation; on-farm training on applying appropriate technologies, financial record-keeping systems and the principles of optimum resource allocation; and regular publications of research results and agricultural reviews to provide continuous flow of information to agricultural agents and farmers. The government could also promote competitive markets for inputs and outputs, and improve infrastructure (such as roads and telecommunications) that would help to reduce transaction costs.

This study is based on one year's (2002) data on dairy input expenditures and annual milk output. Therefore, to generalize use of these production functions as planning and decision making tools for commercial dairy farmers in the Highlands of Eritrea may not be satisfactory. However, despite this shortcoming, the results could serve as useful prior information for further study. Thus, to concretise the production function of dairy farmers in the Highlands of Eritrea, and to promote future planning decisions and policy reforms, further analyses based on recorded time-series and cross-sectional data are recommended.

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Appendix A

Table A1: Pearson's correlation coefficients and VIF values of explanatory variables using OLS regression analysis, Central Zone of Eritrea, 2002

Variable	Concentrates	Forage	Labour	Veterinary and Medicine	Operating and Mechanical	Cow	VIF
Concentrates	1.000	0.493	0.645	0.428	0.340	0.803	3.452
Forage		1.000	0.206	0.457	-0.125	0.666	4.535
Labour			1.000	0.406	0.512	0.566	2.170
Vet. & Medicine				1.000	0.266	0.606	1.705
Oper. & Mechanical					1.000	0.311	1.656
Cow						1.000	5.299

Table A2: Pearson's correlation coefficients and VIF values of explanatory variables using OLS regression analysis, Southern Zone "Mendefera" region of Eritrea, 2002

Variable	Concentrates	Forage	Labour	Veterinary and Medicine	Operating and Mechanical	Cow	VIF
Concentrates	1.000	0.686	0.653	0.502	0.198	0.757	3.149
Forage		1.000	0.624	0.483	-0.080	0.694	3.581
Labour			1.000	0.452	0.240	0.740	2.593
Vet. & Medicine				1.000	-0.002	0.372	1.593
Oper. & Mechanical					1.000	0.384	3.221
Cow						1.000	5.049

Table A3: Pearson's correlation coefficients and VIF values of explanatory variables using OLS regression analysis, Southern Zone "Dekemhare" region of Eritrea, 2002

Variable	Concentrates	Forage	Labour	Veterinary and Medicine	Operating and Mechanical	Cow	VIF
Concentrates	1.000	0.822	0.795	0.884	0.867	0.892	8.733
Forage		1.000	0.871	0.766	0.820	0.898	8.776
Labour			1.000	0.728	0.867	0.923	8.513
Vet. & Medicine				1.000	0.821	0.849	5.653
Oper. & Mechanical					1.000	0.908	7.716
Cow						1.000	18.578

Appendix B

Table B1: OLS regression estimates for a sample of dairy farms in three regions of the Highlands of Eritrea, 2002 (dependent variable = natural logarithm of milk output; explanatory variables are also in natural logarithms)

Variable	Coefficients for		
	Central Zone (n=48)	Mendefera (n=41)	Dekemhare (n=29)
Concentrate feed	0.308 (0.084)	-0.023 (0.101)	-0.114 (0.212)
Purchased forage	0.196 (0.085)	0.348 (0.112)	0.315 (0.125)
Labour	0.239 (0.067)	0.362 (0.082)	-0.018 (0.150)
Veterinary and medicine (health)	-0.072 (0.047)	-0.021 (0.062)	0.063 (0.078)
Operating and mechanical	-0.012 (0.037)	0.023 (0.027)	0.238 (0.100)
Milking cows	0.501 (0.119)	0.966 (0.108)	0.905 (0.213)
Dummy (land for feed production)	0.101 (0.112)	0.055 (0.107)	0.114 (0.083)
Constant	2.340 (0.936)	1.103 (1.054)	3.718 (2.135)
F-test	64.418	131.996	140.723
R ² adj	0.904	0.958	0.972

Notes: n = sample size.

R²adj = adjusted multiple correlation coefficient.

Standard errors are shown in parentheses.

Appendix C

Table C1: Estimated ridge regression functions for a sample of dairy farms in three regions of the Highlands of Eritrea, 2002 (dependent variable = natural logarithm of milk output; explanatory variables are also in natural logarithms)

Variable	Coefficients for		
	Central Zone (n = 48)	Mendefera (n = 41)	Dekemhare (n = 29)
Concentrate feed	0.311** (0.050)	0.156* (0.069)	0.190* (0.090)
Purchased forage	0.190** (0.044)	0.410** (0.071)	0.291** (0.053)
Labour	0.221** (0.044)	0.376** (0.063)	0.247* (0.064)
Veterinary and medicine (health)	-0.025 (0.037)	-0.016 (0.053)	0.112* (0.042)
Operating and mechanical	0.003 (0.029)	0.029† (0.017)	0.205** (0.047)
Milking cows	0.402** (0.058)	0.664** (0.063)	0.417** (0.054)
Dummy (land for feed production)	0.077 (0.072)	0.124† (0.065)	0.133* (0.060)
Constant	2.371	-0.777	-0.578
F-test	59.745**	98.24**	99.339**
Σb_i	1.124	1.635	1.462
R ² adj	0.897	0.944	0.961

Notes: n = sample size.

† = significant at the 10% level of probability.

* = significant at the 5% level of probability.

** = significant at the 1% level of probability.

Σb_i = sum of production elasticities for significant variable inputs.

R²adj = adjusted multiple correlation coefficient.

Standard errors are shown in parentheses.