DIVERSIFICATION ECONOMIES AND SPECIALISATION EFFICIENCIES IN A MIXED FOOD AND COFFEE SMALLHOLDER FARMING SYSTEM IN PAPUA NEW GUINEA

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ABSTRACT

Smallholder farming systems in Papua New Guinea are characterised by an integrated set of cash cropping and subsistence food cropping activities. In the Highlands provinces, the subsistence food crop sub-system is dominated by sweet potato production. Coffee dominates the cash cropping sub-system, but a limited number of food crops are also grown for cash sale. The dynamics between sub-systems can influence the scope for complementarity between, and technical efficiency of, their operations, especially in light of the seasonality of demand for household labour and management inputs within the farming system. A crucial element of these dynamic processes is diversification into commercial agricultural production, which can influence factor productivity and the efficiency of crop production where smallholders maintain a strong production base in subsistence foods.

Data are used on coffee and food crop production for 18 households in the Benabena district of Eastern Highlands Province to derive technical efficiency indices for each household over two years. A stochastic input distance function approach is used to establish whether diversification economies exist and whether specialisation in coffee, subsistence food or cash food production significantly influences technical efficiency on the sampled smallholdings.

Diversification economies are weakly evident between subsistence food production and both coffee and cash food production, but diseconomies of diversification are discerned between coffee and cash food production. A number of factors are tested for their effects on technical efficiency. Significant technical efficiency gains are made from diversification among broad cropping activities.

Keywords: diversification economies, specialisation efficiencies, input distance function, Papua New Guinea, smallholders, technical efficiency

INTRODUCTION

This paper reports on an analysis of diversification economies and the impact of specialisation on the technical efficiency of smallholder production in a farming system characterised by a combination of cash cropping (of coffee and food) and subsistence food crop production. The dynamic processes of change in these three integrated farming sub-systems can influence the potential for productivity gains and technical efficiency in their operations.

The first major stage in this dynamic process is the diversification of production away from a long-established, well-adapted and well-understood cropping system for subsistence purposes, with carefully refined cultivation methods that have proven an efficient way of feeding people (Fleming and Hardaker 1994, p. 33), to less well-understood commercial cropping activities. These commercial activities nevertheless offer potential for diversification economies to smallholders, leading to productivity gains that increase returns to their land and labour inputs. The second stage is greater specialisation in the commercial activities of coffee production and/or food for domestic cash sale. Productivity gains in cash cropping activities from this process and the seasonality of demand for household labour and management inputs within the farming system are expected to influence diversification economies and technical efficiency.

According to Fleming and Hardaker (1994, pp. 44, 77), smallholders have been most successful in increasing productivity when diversifying their activities through an adaptive growth strategy, entailing a combination of new cash cropping activities with established subsistence food activities rather than a major transformation into various cash cropping ventures. In respect of input usage, Fleming and Hardaker (1994, p. 99) observed that the main path to the development of smallholder farming systems has been through improved 'technologies, management practices and field husbandry methods [that] are simple and mostly inexpensive in cash terms'. This path requires considerable ability to make efficient use of family labour and management resources.

The analysis undertaken in this study is based on the results of detailed monitoring by the Coffee Industry Corporation of households in Benabena District located in the Northern Valleys region of Eastern Highlands Province. Overfield (1995) described in detail the monitoring work undertaken as well as production relations in the smallholder food and coffee sectors in Papua New Guinea, in general, and the Benabena district, in particular. Analysis in this paper focuses on diversification economies and specialisation efficiencies in the integrated coffee and food sub-systems. Information is provided on the extent of technical inefficiency in smallholder crop production and we present results of tests of the relevance of a number of factors that are expected to influence technical inefficiency.

METHOD OF ANALYSIS

Data

The panel data used in this analysis were collected by Overfield (1995) from three smallholdings in each of six villages in the Benabena district. He has described the data collection procedures in detail. The smallholder households were selected in a two-stage random sample, stratified by altitude. Village-based recorders monitored the households over a two-year period, 1992 and 1993 (Overfield 1995, p. 28). Data were collected on perceptions of household heads, demographic factors, coffee output, cash and subsistence food crop output, and farm expenditure for each farm household. The proportion of crop output derived from cash cropping covers a wide range among observations, from 21 per cent to 92 per cent.

Economies of scope and economies of diversification

Economies of scope are traditionally defined relative to a cost function.[1] For example, consider the case where a firm produces two outputs, $y = (y_1, y_2)$, with a particular vector of fixed input quantities, z, and facing a particular vector of variable input prices, w. We define the variable cost function of this firm as

$$C = c(y, z, w), \tag{1}$$

where $c(.)$ is a function satisfying the usual homogeneity, monotonicity and curvature properties.[2] Scope economies are said to exist if a particular firm can produce the two outputs using a lower cost, relative to the case where two separate firms specialise in the production of the two individual outputs.

For example, Deller, Chicoine and Walzer (1988) examined scope economies in the provision of rural road services, by estimating an econometric cost function and then using information on the second cross partial derivatives of the cost function to test for scope economies. That is, they observed that economies of scope exist between outputs i and j if:

$$\frac{\partial^2 C}{\partial y_i \partial y_j} < 0, \qquad i \neq j,\ i, j = 1,\ldots,m, \tag{2}$$

where C is the cost of m outputs and y_i is the i-th output variable. The logic behind this measure is that the addition of an extra unit of output i reduces the marginal cost of producing an extra unit of output j. That is, it implies cost complementarities, or economies of scope.

In this study, we diverge from this standard approach in two ways. First, we estimate an input distance function instead of a cost function.

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[1] See Baumol, Panzar and Willig (1982).
[2] See Chambers (1988).

This is done because (i) we do not have access to cost data, because of the unpriced nature of many inputs in the production system under study, and (ii) we believe that the cost minimisation assumption, implicit in the dual cost function approach, is unlikely to be applicable to these smallholders. Second, we allow for the possibility of inefficiency in production in our production model.

As a result of these two factors, we are unable to calculate scope economies relative to a cost function. Instead we calculate what we term *diversification economies* relative to an input distance function.

Following Coelli, Rao and Battese (1998, p. 64) we define the input distance function as:

$$d(x,y) = \{D: (x/D) \in L(y)\}, \tag{3}$$

where $L(y)$ represents the set of all input vectors, x,[3] that can produce the output vector, y. The expression, $d(x,y)$, is non-decreasing in the input vector, x, and increasing in the output vector, y, and linearly homogeneous and concave in x. The value of the distance function is equal to or greater than 1 if x is an element of the feasible input set, $L(y)$. That is, $d(x,y) \geq 1$ if $x \in L(y)$. It is equal to 1 if x is located on the inner boundary of the input set. That is, it equals 1 if the firm is technically efficient and exceeds 1 if the firm is technically inefficient.[4]

We now define a measure of 'economies of scope' relative to an input distance function, which we will call a measure of *economies of diversification*. First, we note that the first partial derivative of the input distance with respect to the i-th output is negative. This indicates that the addition of an extra unit of output, with all other variables held constant, reduces the amount by which we need to deflate the input vector to put the observation onto the efficient frontier. Thus, we observe that the second cross partial derivative would need to be positive to provide evidence of economies of diversification. That is, economies of diversification exist between outputs i and j if:

$$\frac{\partial^2 D}{\partial Y_i \partial Y_j} > 0, \qquad i \neq j,\ i, j = 1,\ldots,m. \tag{4}$$

Note that this measure is not identical to the measure defined in equation (2) because its calculation is conditional upon the input mix being held fixed, while the cost function measure allows the (variable) input mix to be adjusted so as to achieve minimum cost. Thus, one could view this diversification economies measure as a lower-bound estimate of the traditional cost function measure of scope economies. This is why the term, *diversification economies*, is used to distinguish this measure from the normal definition of *scope economies*.[5]

Specialisation efficiencies

The above discussion of how one can measure the technical advantages associated with diversification (or specialisation) involves an analysis of the parameters of the production frontier, and hence concentrates on the shape of the 'efficient technology'. Given that our model also allows for the possibility that firms may be below this frontier (and hence be technically inefficient), we should also be interested in investigating the distribution of these inefficient firms. For example, is the degree of inefficiency of a firm related to its degree of specialisation?

In this study we make use of the Battese and Coelli (1995) inefficiency effects stochastic frontier model[6] to investigate this issue, which we will name *specialisation efficiencies* to distinguish them from our previously defined *diversification economies*.

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[3] Note that this input vector includes both fixed and variable inputs.

[4] The input distance function value is the inverse of the traditional input-orientated technical efficiency measure defined by Farrell (1957), which lies between 0 and 1.

[5] Note that for the special case where no inputs are variable in the short run, the diversification economies measure will equal the negative of the scope economies measure.

[6] Battese and Coelli (1995) estimated a production frontier. In the present study, we amend their approach to accommodate an input distance function.

Specialisation efficiencies are concerned with how firms with different output shares are distributed underneath the production possibilities frontier. The opposite of product specialisation is diversification, whereby resources are allocated to a variety of activities, the outcomes of which are not closely related. Specialisation efficiencies occur when increased specialisation among outputs leads to lower technical inefficiency, and vice versa for diversification efficiencies.

Specialisation in production is expected to lead to efficiency gains through the division of labour and management resources, to take advantage of specialist skills and knowledge and ‘learning by doing’, product-specific scale economies, the saving of time in labour use by not having to switch between tasks, and the avoidance of bottlenecks in the allocation of labour and management resources caused by their simultaneous requirement in different activities during peak periods of the production cycle.

Diversification efficiencies act in the opposite direction to specialisation efficiencies. They derive from the longstanding reliance by smallholders on flexibility in their production processes that is provided by a portfolio of different farming activities. The strong regional specialisation in coffee production also means that all smallholders are likely to be well versed in the agronomic requirements of this cash crop and have successfully integrated it into their semi-subsistence farming systems. In an uncertain production environment, the ability of family members to vary their levels of participation among different activities can help overcome difficulties arising from unanticipated events. These events would otherwise hinder the tasks they perform if they adopted the less familiar role of specialising chiefly in one particular production activity.[7]

The specialisation variable is specified as an ogive (pointed arch) index of concentration of output shares of coffee, food for cash sale and subsistence food. This index measures deviations from an equal distribution of output shares between production activities. It is a widely used measure of concentration, and was used, for example, by Ali, Alwang and Siegel (1991) to specify the concentration of export shares in their analysis of export diversification and stability in three African countries.

Following Ali et al. (1991, p. 11), the ogive index is defined as:

$$Ogive = \sum_{n=1}^{N} \frac{(X_n - 1/N)^2}{1/N} \tag{5}$$

where N is the total number of production activities under consideration; $1/N$ is perfect diversification of output among activities (equal to 1/3 for all observations); and X_n is the share of output of the n-th production activity.

Other factors affecting technical efficiency

A numbers of explanatory factors can be included in the Battese and Coelli (1995) efficiency effects model. A total of 12 efficiency variables were tested for inclusion in our estimated model. All but one of these variables had been used by either Overfield and Fleming (2001) or Overfield and Fleming (2002), in their separate estimations of stochastic frontier production functions for food and coffee production using the same data set. The additional variable in this study is specialisation in production, which is of particular interest.

Other variables tested for their relevance in explaining changes in technical inefficiency in smallholder crop production are: proportion of female labour employed in production; incentives to female labour in coffee production; male and female attitudes to cash cropping; ages of the male and female household heads; polygynous household dummy variable; education level of the male household (unfortunately, no information is available on the education level of the female household head); family and social obligations; accessibility to the main town; male and female labour constraints during the coffee-harvesting season; and household size as a proxy for the presence of underemployment.

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[7] Diversification of production activities can also provide substantial benefits as a price risk management tool in smallholder agriculture in Papua New Guinea (Fleming and Yala 2001, p. 79), but such gains are not considered in this study.

Overfield and Fleming (2001, 2002) provide some evidence on how these factors are expected to influence the technical efficiency of coffee and food production, except for the specialisation variable. They also present the rationale for inclusion, measurement and expected signs of the above variables.

ESTIMATED MODEL

Technical inefficiency was measured in indices for each sampled farm over the two years of the study period using the distance function approach. A multi-input multi-output stochastic input distance function was applied to calculate technical efficiency indices for each sampled smallholder in each year, and mean technical efficiency by year and for the whole period. The model was based initially on a Cobb-Douglas functional form because the small number of observations (36) made it impossible to estimate a model with a fully flexible functional form. In order to allow for diversification economies, it is necessary to allow the frontier to be more flexible than the Cobb-Douglas in the output variables. To achieve this end, we specified a partial translog function by adding the second-order terms to the Cobb-Douglas model for the three output variables only. Also note that, prior to estimation, the means of the log variables were adjusted to zero so that the coefficients of the first-order terms could be interpreted as elasticities, evaluated at the sample means.

Following Coelli and Perelman (1996), the (partial) translog input distance function used in this analysis can be defined as:

$$\begin{aligned} ln\, d_{it} &= \beta_0 + \beta_1 \ln A_{it} + \beta_2 \ln FL_{it} + \beta_3 \ln ML_{it} + \beta_4 \ln X_{it} + \alpha_1 \ln YC_{it} + \alpha_2 \ln YFC_{it} \\ &+ \alpha_3 \ln YFS_{it} + 0.5\alpha_4 \ln(YC_{it})^2 + 0.5\alpha_5 \ln(YFC_{it})^2 + 0.5\alpha_6 \ln(YFS_{it})^2 \\ &+ \alpha_7 (\ln YC_{it})(\ln YFC_{it}) + \alpha_8 (\ln YC_{it})(\ln YFS_{it}) + \alpha_9 (\ln YFC_{it})(\ln YFS_{it}) \end{aligned} \qquad (6)$$

where A is the total area planted to food crops and coffee trees; FL is female labour inputs in days; ML is male labour inputs in days; X is purchased inputs in kina; YC is the output of coffee in kilograms of green bean equivalent; YFC is the value of output of food crops for cash sale in kina (the local currency, equal to about US$0.30); YFS is measured as annual subsistence food output, in imputed kina values; and the subscript, *it*, denotes the *i*-th producer in the *t*-th year (1992=1, 1993=2).

Again following Coelli and Perelman (1996), we set $-ln\, d_{it} = v_{it} - u_{it}$, and impose the restriction required for homogeneity of degree +1 in inputs ($\beta_1 + \beta_2 + \beta_3 + \beta_4 = 1$) to obtain the estimating form of the stochastic input distance function:

$$\begin{aligned} -\ln A_{it} &= \beta_0 + \beta_1 \ln(FL_{it}/A_{it}) + \beta_2 \ln(ML_{it}/A_{it}) + \beta_3 \ln(X_{it}/A_{it}) + \alpha_1 \ln YC_{it} \\ &+ \alpha_2 \ln YFC_{it} + \alpha_3 \ln YFS_{it} + 0.5\alpha_4 \ln(YC_{it})^2 + 0.5\alpha_5 \ln(YFC_{it})^2 + 0.5\alpha_6 \ln(YFS_{it})^2 \\ &+ \alpha_7 (\ln YC_{it})(\ln YFC_{it}) + \alpha_8 (\ln YC_{it})(\ln YFS_{it}) + \alpha_9 (\ln YFC_{it})(\ln YFS_{it}) + v_{it} - u_{it}, \end{aligned} \qquad (7)$$

where the v_{it}s are assumed to be independently and identically distributed with mean zero and variance, σ_v^2; and the u_{it}s are technical efficiency effects that are assumed to be independently distributed such that u_{it} is defined by the truncation at zero of the normal distribution with unknown variance, σ_u^2, and unknown mean, μ_{it}, defined by:[8]

$$\mu_{it} = \delta_0 + \sum_{m=1}^{12} \delta_m z_{mit}, \qquad (8)$$

where z_1 is the concentration of output shares, measured by the ogive index; z_2 is the proportion of female labour, measured as female labour in days worked divided by total labour in days worked. z_3 is the return to female labour in coffee production, calculated as the cash returns per day that women derive from coffee output for their own use. z_4 is the attitude to cash cropping of the male head of the household, measured subjectively, on an ascending scale between 1 and 3, by surveying people about the priorities they place on different activities; z_5 is the attitude to cash cropping of the female head of the household; z_6 is the age of the male head of household in years; z_7 is the age of the female head of household in years; z_8 is a dummy

[8] Note that Coelli and Perelman (1996) assumed the u_{it} to be half normal.

variable for a polygynous household, which equals one if the household is polygynous, zero otherwise; z_9 is the education level of the male household head, measured in years of schooling; z_{10} is the expenditure on social and family obligations, measured as annual expenditure on family and social obligations; z_{11} is the accessibility of the village in which the household is located, subjectively measured on an ascending scale from 1 to 5; and z_{12} is household size, measured as the number of people dependent on the production of the food and coffee gardens.

We follow Battese and Corra (1977) in replacing the variance parameters, σ_v^2 and σ_u^2, with $\gamma=\sigma_u^2/(\sigma_v^2+\sigma_u^2)$ and $\sigma_s^2=(\sigma_v^2+\sigma_u^2)$ in the estimating model. This is done so that a grid search over values of γ between 0 and 1 can be used to obtain good starting values for the iterative search routine used to obtain the maximum likelihood estimates.

Following Coelli and Perelman (1996, p. 14), the input distances are predicted as:

$$D_i = E[\exp(u_i) \ e_i]$$

where $e_i = v_i - u_i$.

Estimates of the parameters of the model were obtained using maximum-likelihood procedures, detailed by Coelli and Perelman (1996), by running the FRONTIER 4.1 program (Coelli 1996).

Table 1. Estimates of the Stochastic Input Distance Function.

Variable	Coefficient	Estimated coefficient	Standard error
Production variables:			
Constant	β_0	0.292	0.049
ln (FL/A)	β_1	0.051	0.051
ln (ML/A)	β_2	0.387	0.045
ln (X/A)	β_3	0.038	0.010
ln C	α_1	-0.149	0.030
ln FC	α_2	-0.644	0.044
ln FS	α_3	-0.439	0.046
0.5 * ln C^2	α_4	0.017	0.027
0.5 * ln FC^2	α_5	0.055	0.047
0.5 * ln FS^2	α_6	-0.394	0.192
ln C * ln FC	α_7	-0.012	0.050
ln C * ln FS	α_8	-0.064	0.071
ln FC * ln FS	α_9	0.009	0.098
σ_s^2		0.063	0.017
γ		0.999	0.011
Efficiency variables:			
Constant	δ_0	-0.163	0.309
Concentration of output shares	δ_1	0.787	0.194
Age of the female head	δ_7	0.005	0.006
Education of male head	δ_9	0.028	0.041
Family and social obligations	δ_{10}	-0.007	0.001
Log-likelihood value	22.97	Likelihood-ratio test of the one-sided error	23.64

RESULTS

Results of the maximum-likelihood estimation of the stochastic input distance function model are presented in Table 1. The sum of the coefficients, α_1, α_2 and α_3, of the three output variables, coffee, cash food and subsistence food, is 0.652.

The inverse of this figure, 1.53, provides a measure of ray scale economies (at the sample means), suggesting increasing returns to scale. This finding contradicts the assertion by Fleming and Hardaker (1994) that smallholders are unlikely to benefit from significant economies of scale.

Three sets of hypothesis tests were undertaken using likelihood-ratio tests. First, the value of the test statistic for the null hypothesis of no technical inefficiencies of production was found to be greater than the critical value obtained from Table 1 of Kodde and Palm (1986) for six restrictions. We thus conclude that the technical inefficiency term (u_{it}) is a significant addition to the model.[9] Second, we found that the four z-variables included in Table 1 contribute significantly (jointly and individually) to the explanation of technical inefficiencies in smallholder crop production. Third, it was found that the other eight z-variables did not contribute significantly to the explanation of technical inefficiencies in smallholder crop production. These variables were omitted from the estimated model reported in Table 1.

For direct comparison with the technical efficiency indices used by Overfield and Fleming (2001, 2002), the inverse of the distance function measure ($1/D$) is reported in this section so that the indices lie between 0 and 1. Technical efficiency indices (which have a feasible range from zero to unity, with unity being fully efficient) vary from 0.38 to 0.99, a wide range but one that is less than the range of indices for food production alone (0.25 to 0.98) and coffee production alone (0.10 to 0.98). The mean technical efficiency in total crop production is 0.78. This figure is similar to the estimate for food production and higher than that for coffee production, which was 0.57 (Overfield and Fleming 2001, 2002). This may indicate that opportunity exists to expand crop output without using more inputs or introducing improved production technologies. The distribution has a strongly negative tail, with about one-third of the indices below 0.7. There is a high frequency of observations in the top decile range (39 per cent), which is more than the proportion for coffee production alone (22 per cent) but less than the proportion for food production alone (47 per cent).

EVIDENCE OF ECONOMIES OF DIVERSIFICATION

The coefficient estimates reported in Table 1 were used to calculate the measure of diversification economies, defined in equation (4), for each pair of outputs at the means of the sample data. The results provide values of -0.003 for the combination of coffee and cash food output variables, +0.002 for coffee and subsistence food output, and +0.037 for cash food output and subsistence food output. These values are quite small, indicating that the potential for diversification economies or diseconomies is small, but it should be kept in mind that they are lower-bound estimates of the traditional cost function measure of scope economies.

In order to test the hypothesis that there are no diversification economies in this production system, we calculated standard errors for these measures of diversification economies using a Taylor series expansion. The estimated standard errors were calculated to be 0.052, 0.070 and 0.113, respectively, for the above three measures. These standard errors indicate that we would be unable to reject the null hypothesis of no diversification economies (or diseconomies) at any normal level of significance.

Bearing in mind the weak evidence on the existence of diversification economies and diseconomies observed above, these results are nevertheless consistent with the observation made by Fleming and Hardaker (1994) that farmers have had most success in commercialising their operations through adaptive strategies of combining cash cropping with subsistence production. Increased productivity occurs with diversification from subsistence food production into cash cropping activities while still retaining a significant subsistence base, given that the farming system under observation continues to rely heavily on the farm inputs of household labour, management and land resources. The ability of 'best-practice' smallholders to make productive use of surplus family labour in slack periods and avoid bottlenecks in labour usage, especially female labour, that detract from overall crop productivity is crucial in the production of subsistence and cash crops in a mixed-cropping setting. When a smallholding diversifies into cash production, the farmer has the opportunity to select those activities that complement each other given the seasonal nature of their labour demands to utilise family labour resources fully throughout the year. It is largely for this reason that the implementation of an adaptive growth strategy by smallholders has been so pervasive.

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[9] All hypothesis tests conducted in this paper use a 5 per cent level of significance, unless otherwise stated.

The observed diseconomies of diversification for the combination of coffee and cash food outputs suggest that smallholders find it difficult to achieve productivity gains when attempting to diversify simultaneously into these two quite different forms of cash cropping, with their different and often overlapping labour and management demands. Overfield and Fleming (2002) noted that the labour demands for coffee production are especially likely to clash strongly with those for cash food production in the case of female household labour, which is used intensively in food production and marketing and subject to severe constraints at certain times of the year.

FACTORS INFLUENCING TECHNICAL INEFFICIENCY IN CROP PRODUCTION

Table 1 shows that the coefficient on the efficiency variable, concentration of output shares, is significantly greater than zero. As reported above, a likelihood-ratio test that this coefficient is zero is rejected, indicating that the variable contributes significantly to an explanation of technical inefficiency in crop production in the smallholder mixed food and coffee cropping system in Benabena district. This result indicates that greater specialisation leads to higher technical inefficiency, suggesting that the benefits smallholders derive from flexibility in production operations significantly outweigh the benefits of specialising mainly in one production activity.

Thus, we observe that specialisation has two effects on productivity that operate in the same direction in this farming system. The first effect is a negative impact on productivity via loss of diversification economies. The second effect is to reduce productivity via specialisation inefficiencies (or loss of diversification efficiencies).

Only three efficiency variables, in addition to the specialisation variable, were found to influence technical efficiency significantly on the basis of likelihood-ratio tests. One of these variables, the age of the female head of household, significantly increases technical inefficiency. This result accords reasonably well with the results obtained by Overfield and Fleming (2001, 2002) of no significant impact on technical inefficiency in coffee production and a positive effect on technical inefficiency in the separate analysis of food production. It suggests that older female household heads find it more difficult to manage their many tasks and adapt to new commercial activities than younger ones, increasing technical inefficiency in the farming system as a whole.

Family and social obligations have a negative impact on technical inefficiency, suggesting that the compulsion to obtain cash to meet obligations leads to greater productivity, outweighing any demotivating effect of these obligations as a burden on cash crop producers. This result contrasts with the findings by Overfield and Fleming (2002) for food production analysed separately but is consistent with the finding, reported by Overfield and Fleming (2001), of a negative but only weakly significant impact of these obligations on technical inefficiency in the separate analysis of coffee production.

The education level of the male household head was found to have a positive effect on technical inefficiency, although its significance is marginal. This result is at odds with the results of the estimated model for coffee production alone (Overfield and Fleming 2001), where more years of schooling were found to be associated with lower technical inefficiency, suggesting that it could be misleading to examine efficiency effects on one production activity independently of other activities in the farming system. The result is consistent with the finding by Fleming and Lummani (2001) for cocoa smallholders in Papua New Guinea that a higher education is often associated with more off-farm employment that limits the time and attention given to growing crops. Fleming and Lummani (2001) found that this effect outweighs the greater capacity of more educated cocoa smallholders to make better use information in taking decisions and be more open to improved farming methods.

A number of variables that were found to be significant explanators of technical inefficiency in either food or coffee production were found not to influence technical inefficiency in total crop production. In most cases, these results are understandable because the factors that were causing inefficiency in one activity were likely to have a favourable effect on technical efficiency in the other activity.

Such variables include attitudes to cash cropping, accessibility, male and female labour constraints during the coffee-harvesting season, proportion of female labour in coffee production, and degree of subsistence orientation.[10]

CONCLUSION

This study has provided information about economies of diversification, scale economies and specialisation efficiencies in farming systems comprising the three broad cropping activities of subsistence food, cash food and coffee in the Highlands of Papua New Guinea. Information is also provided on the extent of technical inefficiency in smallholder crop production. Diversification economies were found to exist between subsistence food production and the production of either coffee or cash food items, while diversification diseconomies were found between coffee and cash food production, although the evidence is quite weak. Ray increasing returns to scale are evident in crop production.

Results indicate that substantial technical inefficiency exists, which means there may be opportunity to expand crop output without resort to greater use of factor inputs or the introduction of improved production technologies. Four variables were identified that significantly influence technical inefficiency. Most notable among these variables is the concentration of output shares, suggesting that specialisation leads to greater technical inefficiency. That is, less inefficiency exists in diversification, adding to possible gains from diversification in managing price risk that are not taken into account in this study. Significant effects on technical inefficiency exist for the age of the female household head and the education level of the male household (increasing technical inefficiency) and the level of family and social obligations (decreasing technical inefficiency).

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[10] The presence of size efficiencies was tested by including the size of cropping operations (measured as the total area under crops) as an efficiency variable in an *output* distance function model. This approach was used because the left-hand-side variable in the input distance function is the natural logarithm of cropped area, and hence this test could not be undertaken using the estimated input distance function model. The likelihood-ratio value was less than the χ^2 critical value, and hence no evidence could be adduced of either efficiencies or inefficiencies of size in crop production, in line with the evidence assembled for coffee and food production separately by Overfield and Fleming (2001, 2002).

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