

Stochastic Technology and Crop Production Risk: The Case of Small-Scale Farmers in East Hararghe Zone of Oromiya Regional State in Ethiopia

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Abstract

This study used the Just and Pope stochastic production technology specification to analyse the crop production and supply response behaviour of farmers in East Hararghe zone of Ethiopia under production risk. The results showed that improved seed, human labour, oxen labour and planting date were the most important determinants of yield levels of the crops grown in the area. On the other hand, the use of improved seed and fertilizer were yield risk increasing inputs in the production of maize and sorghum crops. However, early planting for all the annual crops grown, use of human labour for the package crops and oxen labour for all food crops grown in Faddis district were found to have yield risk reducing effects. The results have important implications for agricultural technology development and transfer in the study area. To reduce the yield risk increasing effect of fertilizer, the development and promotion of new crop varieties should consider fertilizer application trails for different levels across different agro-ecologies and farmers' conditions. Also, farmers need to be provided with adequate advice and information on the use and application of fertilizer. Moreover, to overcome the yield risk increasing effect of improved seed, varieties should be tested for their suitability to varying agro-ecologies and management conditions of the farmers in the area. Extension advice and information on the management of the improved crop varieties need to be provided to the farmers to improve the yield stability of the crops. In addition, extension advice on early planting, provision of meteorological information to farmers to aid them in planting date decisions and development of short period maturing varieties could help to reduce variability in the yield levels of crops grown in the area. Finally, improving the small-scale farmers' access to oxen would also enable the farmers to achieve stable yields from crop production.

Key words: Production risk, stochastic technology and farmers supply response

Introduction

Many studies acknowledged the importance of both price and production related risk in determining input use decisions and hence optimal levels of output. Sandmo (1971) showed that under price uncertainty, output is smaller than situations where price levels are known with certainty. Thus, a risk averse firm facing output price risk produces less output than a risk neutral firm. Similar results were derived by Batra and Ullah (1974) with a utility maximization model for a competitive firm facing input price uncertainty. Furthermore, it has been shown that under output uncertainty and fixed

prices, a risk averse firm uses more (less) of a risk reducing (increasing) factor than a risk neutral firm (Just and Pope, 1978; Pope and Kramer, 1979). Policy instruments like insurance and future markets have been developed to overcome the adverse effects of price instability.

Risk and uncertainty are common in agricultural production over the entire world due to several factors. Climatic changes, changing policies and institutional settings and markets are important sources of risk in agricultural production (Hardaker, *et al.*, 1997). The effect of risk and uncertainty is more significant in developing countries due to market imperfections, asymmetric information and poor communication networks. In addition, the stochastic nature of agricultural production is in most cases a major source of risk. Especially in agriculture, variability in yield is not only explained by factors outside the control of the farmer such as input and output prices but also by controllable factors such as varying the levels of inputs (Just and Pope, 1978; Pope and Kramer, 1979; Antle, 1983). A risk averse farmer thus uses more (less) of a risk reducing (increasing) factor than a risk neutral firm (Pope and Kramer, 1979). It follows that production risk has an important bearing in the design and transfer of new agricultural technologies as the rate of adoption is dependent not only on the yield but also on their risk effects (de Janvery, 1972; Anderson and Hazell, 1994; Hassan *et al.*, 1990). Thus, the specification and evaluation of the impact of inputs on output distribution is of paramount importance for policy making and agricultural production technology promotion strategies as farmers can affect the distribution of output and thus income by varying the levels and combination of inputs used in production. In this paper, the Just and Pope Production technology specification was used to analyse the supply response behaviour of farmers in East Hararghe zone of Ethiopia under production risk.

2. The study area

The study was conducted in East Hararghe zone of Oromiya Regional State in Ethiopia during 2001/2002 agricultural production year. The East Hararghe zone is one of the eleven administrative zones of Oromiya regional state and has fifteen districts under its administration. The total number of the population in the zone is estimated to be about 2 million of which 95% live in rural areas (CSA, 1994). Harar and Dire Dawa cities are the major business centres in the zone. Dire Dawa city is the main export destination of agricultural products from the area to Djibouti, the Middle East and European countries.

The agro-ecology of the area can be broadly categorized into low attitude, middle altitude and high altitude areas with rainfall distribution of less than 700mm, 700mm to 1200mm and above 1200mm, respectively. Spring rain (Badheessa) is common in the highlands and middle altitude areas. Summer (Ganna) is the main rainy season in the zone during which most agricultural production activities are carried out. Due to the variations in agro climatic conditions, the area is characterized by complex farming systems with high variation in cropping patterns. Food crops such as maize and sorghum are widely grown across the different agro ecologies of the zone occupying about 60% of the total arable land (Bezabih and Storck, 1992). Other small cereals like wheat and barely are mainly grown in the high altitude areas with relatively better rainfall

conditions. In addition, kaht¹ (*Catha Edulis*), a mild narcotic plant, is common in the area grown primarily for cash. While the extent of kaht production is small in the high and low altitude areas, it occupies a significant proportion of the area under cultivation in the mid altitude areas of the zone. Also, groundnut is widely grown in the low altitude areas of the zone both as food and cash crop.

East Hararghe zone is one of the most densely populated areas in the country. The average household size of the farmers in the area is about seven family members per household. Due to mounting population pressure, the land holding size of the farmers in the area has steadily diminished over the years. About 82% of the farmers in the zone own less than one hectare of land. As a result of diminishing farm size, grazing land has been increasingly converted into crop production. On average, farmers in the area keep about two heads of livestock per household, which are in most cases fed on foliage and crop residues (Bezabih and Storck, 1992). Despite their complementary contribution to the welfare of the family in terms of providing draft power for ploughing, milk and meat for consumption and income, the number of livestock ownership has continuously dwindled due to diminishing grazing land in the zone.

In addition, the zone is characterized by a highly unpredictable rainfall condition and has been affected by drought several times in the past few decades. The farmers in the zone use traditional farming practices and the use of improved agricultural production technologies are limited. Oxen and human labour are widely used methods of ploughing and cultivation practices. Furthermore, small-scale farmers in the zone use low yielding local varieties of seeds for crop production and rely on manure, crop remains and crop rotation as the main means of soil fertility management. The poor resource conditions of the farmers, reliance on rain for crop production and the use of traditional crop production methods have exposed the farmers to high levels of variability in crop yields, low productivity and food insecurity.

Like many other areas of the country, the agricultural extension program designed to increase agricultural productivity through the use of improved seeds, chemical fertilizers and improved crop husbandry practices has been practiced in the zone since its inception in 1994/95 focusing mainly on maize and sorghum production. However, the adoption of the new agricultural technologies being promoted has been slow due to several factors of which variability in rainfall is one. For instance, farmers' expectations about rainfall conditions during the 2001/2002 cropping season was found to be a significant factor affecting the adoption and level of use of fertilizer in Dadar district of the zone (Bekabil *et al.*, 2002). The zone is among the areas that are characterized by a high level of food insecurity in the country. As a result, farmers of the area are not only concerned with the mean yield and returns associated with crop production but also the stability associated with crop yields to ensure adequate food supply for the family. In response to this, the farmers use different management practices such as crop diversification and variation of the levels of inputs used to achieve more stable yield and income from crop production.

¹ is a mild narcotic perennial plant. Its leaves are chewed by people for stimulation.

The sampling units of this study were small-scale farmers in the East Hararghe zone of Ethiopia. This study used a multistage stratified sampling method in which a population was stratified based on attributes relevant to the research questions addressed. The first layer of the stratification was based on agro-climatic diversity of the zone, which is a key attribute that influences production patterns and more specifically crop yield levels and its variability. Accordingly, the zone was stratified into two major agro-ecological zones covering the region: Low altitude and high altitude zones. Two districts were then purposively selected, one from each agro-ecological zone, to represent the two climates and farming systems in the zone. The districts included in the survey were: Faddis district from the low altitude and moisture stressed areas and Dadar district from the high altitude and high rainfall areas. Next, each district's peasant associations were divided into three major groups consisting of 10 to 15 peasant associations based on the district level farming systems diversity such as intensity of kaht and cereal production, the settlement patterns of the farmers and the relative fertility levels of their plots. Then, three peasant associations were selected from each district making a total of 6 peasant associations for the whole sample. Farmers in each peasant association were stratified into users and non-users of the extension package (maize in Dadar district and sorghum in Faddis district) and a sample of farmers was selected from each category in each group. To select farm households for the survey, a list of the names of all farm households (represented by the household head) that were registered to be included in the extension package and those that were not registered was obtained from each of the three peasant association administrative offices in each district. The total sample size was allocated to the various strata (2 zones, 3 groups in each zone) and two types of farmers (users and non-users of the extension package) in each group using uniform sampling fractions. Based on the number of the strata, 17 users of extension package and 17 non-user farmers in each peasant association were selected to make 51 package user and 51 non-user farmers from each district. This gave a total of about 102 sample farmers, which was implemented for the 100 farmers from each district of which 50 were users of the extension package and 50 were non-users.

However, not all the data collected from all the sample farmers was used in the analysis. Few farmers did not use fertilizer for the intended crop for which they were registered. In addition, due to missing data problems (especially crop losses due to frost and rainfall shortage) the data obtained from a few farmers were found to be unusable for the analysis. As a result, the targeted sample size of 100 farmers from each district was not attained leading to the use of full production data on a total of 99 farmers from each of the two districts.

Primary data were obtained from farmers by using structured questionnaires. The questionnaires were pre-tested with small number of representative farmers in the area to make adjustments and corrections before the full-scale survey began. Ten enumerators with adequate level of education and ability to speak Oromiffa, which is the language of the community in the area, were recruited for data collection. Finally, periodic visits (frequent visit survey) to the farm households were made to collect the required data. This was intended to reduce memory bias in the data collection process, as farmers in the area do not keep records of their farm activities.

The primary data on crop production activities were collected from the sample farmers from each district. These included crops yield (quintals²) data on each of the crops grown in the area for the past six years and data on inputs used for the cropping season for each enterprise (human labour in man-days, oxen labour in oxen-days, fertilizer in kilograms, and land allocated in hectares). In addition, dates of planting of the annual crops by each sample farmer were collected during the survey.

3. The analytical framework

Positive approaches to supply response analysis use econometric methods that involve the estimation of the production technology parameters from observed input and output values. The deterministic production technology specifies production relations in terms of mean input and output levels. However, there is considerable evidence in the literature that the distribution of output is a unique function of its moments (Day, 1965; Anderson, 1973; Roumasset, 1976). Thus, a production function can be represented as a stochastic process where the distribution of output (yield) is conditionally determined by input levels and the technology parameters. Alternative specifications of the stochastic production function specification involve the inclusion of the error term to the deterministic production function to reflect the effect of uncontrollable factors such as weather, technical inefficiency, etc. in production. Further concerns about the random error term appended to the deterministic production function found that variability in output (yield) is also explained by endogenous factors and levels of inputs used (de Janvery, 1972; Just and Pope, 1978; Pope and Kramer, 1979).

As a result, several methodologies have been developed to analyse the impact of production related risks and levels of inputs used on the distribution of output (yield). According to the traditional econometric specifications of stochastic production function, if any input has a positive effect on the mean of output, then a positive effect on variability of output is also imposed (Just and Pope, 1979). However, the effects of any input on mean output should not be tied to the effects of inputs on variability of output a priori. Hence, adequate production function specifications should include specifications that show the effect of input on both the mean and the variance of output (Just and Pope, 1979). However, the Just and Pope model imposes restrictions on the relations between inputs and third and higher moments of output. Antle (1983) proposed a flexible moment based approach to stochastic production technology specification where all moments of the distribution of output are considered as function of input levels.

The stochastic production function model and the moment-based model of production technology specification are appropriate for analyzing the risk effects of inputs on output distribution in cross sectional, time series and combination of time series and cross sectional production data. However, moments beyond variance were found to be insignificant components of the distribution of output (Anderson, 1977). In this study, the Just and Pope stochastic production function was used to analyze the supply response behavior of farmers in East Hararghe zone under production risk.

² One quintal is equivalent to 100kgs.

$$y = f(x, \beta) + h(x, \theta)\varepsilon \quad (1)$$

The premise of the above stochastic production technology specification is that the variance of the production function error term may be related to explanatory variables, implying heteroscedasticity. Several econometric procedures have been developed to correct for heteroscedasticity in such cases. Following Just and Pope (1979), a Multi stage Non-linear Least squares (MNLS) estimation procedure can be applied to generate consistent and asymptotically efficient estimates of the parameters of the stochastic production function in equation 1. The proposed MNLS procedure is described below.

a) Let the stochastic production function in equation 1 be represented as $y = f(x, \beta) + u$. Where, $u = h(x, \theta)\varepsilon$. A Non-linear least squares (NLS) estimator of β is obtained from the regression of y on $f(x, \beta)$ or in logarithms, $\ln y$ on $\ln f(x, \beta)$. Under broad range of conditions, the NLS of β and $f(x, \hat{\beta})$ are shown to be consistent. The

residual, \hat{u} from this regression is then calculated as:

$$\hat{u} = y - f(x, \hat{\beta}) = \hat{h}(x, \theta)\varepsilon \text{ or } \hat{u} = \ln y - \ln f(x, \hat{\beta}) \quad (2)$$

b) A NLS estimator of θ and $h(x, \theta)$ is obtained by regressing \hat{u}^2 on $h^2(x, \theta)$ or $|\hat{u}|$ on $\ln h(x, \theta)$ in case of logarithms to produce the consistent estimators of $\hat{\theta}$ and $\hat{h}(x, \theta)$.

c) A NLS estimator of β is finally obtained by weighted regression of y^* on $f^*(x, \beta)$ or $\ln y$ on $\ln f(x, \beta)$ (3)

$$\text{Where, } y^* = \frac{\ln y}{h(x, \hat{\theta})}, f^* = \frac{f(x, \beta)}{h(x, \hat{\theta})} \text{ or } y^* = \frac{\ln y}{\ln h(x, \hat{\theta})}, f^* = \frac{\ln f(x, \beta)}{\ln h(x, \hat{\theta})}$$

If the function $y = f(x, \beta)$ is heteroscedastic, the predicted values of the residuals from the regression on the explanatory variables will enable to capture the values of the residuals related to these variables. The weighting of this function by the predicted values of the residuals from equation 2 will give consistent and asymptotically efficient parameter estimates of the function. The gain in efficiency attained by using the described MNLS procedure ensures desirable statistical properties and valid statistical tests and allows the assessment of the impact of risk effects of inputs as measured in step b.

The above MNLS estimation procedure of correcting heteroscedasticity does not correct for the possibilities of jointness in production, as is the case in multi-product

firms and endogeneity of factor inputs that are common in survey data. Survey data impose the behavioural restrictions that optimal choices of both inputs and outputs are determined jointly through the first order conditions required for optimisation (Marschak and Andrews, 1944). The application of the MNLS procedure could, therefore, lead to simultaneous equation bias in parameter estimates. Several systems method econometric procedures have been proposed to overcome such bias that might arise in the parameter estimates. Limited Information Maximum Likelihood estimators (Indirect least squares and 2SLS) are methods in which the problem of endogeneity is considered for one equation at a time. On the other hand, Hallam *et al.* (1989) modified the MNLS estimator described above by using Instrumental variable Non linear Least Squares estimator (Amemiya, 1974) that is equivalent to Non linear Two stage Least Squares estimators (NL2LS) to cater for the possible simultaneity problem in step a. The Instrumental Variable Multi-stage Non-linear Estimator (IVMNLS) is then employed, in which the consistent estimator of $h(x, \theta)$ is used in the weighted regression of y^* on $f^*(x, \beta)$ as described in step c.

In addition, due to jointness in production, the disturbances of the technological functions estimated for an optimising multi-product firm are said to be related due to factors such as allocative efficiency errors, weather, etc. A systems procedure that takes into account such cross-equation correlations of the disturbances is more efficient in such cases. Full Information Maximum Likelihood (FIML) and Three Stage Least Squares (3SLS) estimation procedures that take into account all the information in the structural equations of the system have been proposed. In situations where simultaneity is not considered in the estimation of systems of equations, the above MNLS estimator was modified by Hallam *et al.* (1989) into Multi-stage Non-linear Seemingly Unrelated Regression (MNSUR). Furthermore, in situations where heteroscedasticity, endogeneity of factor inputs and cross-equation correlations are present, the above MNLS procedure was modified into Instrumental Variable Multi-stage Non-linear Seemingly Unrelated Regression estimator (IVMNSUR) as an alternative that could give consistent and asymptotically efficient parameter estimates (Hallam *et al.*, 1989).

While the systems estimation procedures described above are consistent and asymptotically more efficient, as the farmers of the zone do not grow all the crops uniformly, the MNLS estimation procedure was used in the estimation of the stochastic technology parameters of the crop enterprises considered in this study.

4. Results and discussion

The production data of each crop on the indicated variables for users and non-users of the extension package were pooled and the stochastic production function was estimated for each of the crop enterprises grown by the farmers in each district using the MNLS econometric estimation procedures discussed. Land, human labour, oxen labour and fertilizer were the main inputs of crop production considered in this study. In addition, to take into account the impact of the use of improved of maize and sorghum in Dadar and Faddis districts, respectively, dummy variables (C_1 for improved seed and C_2 for local varieties of the crops) were included in the specification of the stochastic

production technology models. Moreover, planting date was considered as important factor that affects crop yield levels mainly due to the erratic nature of rainfall in the area. Thus, it was included as an additional factor in the specification of the stochastic production for annual crops that are grown in the area. However, as kaht is a perennial crop, planting date is excluded from the specification of the stochastic production function for the crop.

Econometric estimation was performed on alternative functional forms including flexible forms such as the transcendental and translog functions and the Cobb Douglas production function, which is less flexible. Despite its restrictive assumptions, (e.g. constant elasticity of substitution), the Cobb Douglas function gave the best fit to the data in terms of the admissibility and statistical significance of the parameter estimates of the stochastic production functions.

In the initial runs of the regression, interaction terms between fertilizer and other inputs (human labour, oxen labour and planting date) were included but caused the production function parameter values to have the wrong signs. Similarly, the interaction effects of planting date and human labour were included in the initial regression of each annual crop grown in each district. However, those also caused the parameter values of some crops to have the wrong signs. It was, thus, decided to exclude interaction terms from the specification of the stochastic production function parameters of the crops.

4.1. The mean yield effects of production inputs

The estimated parameter values of the mean yield functions of the crop enterprises are presented in Tables 1 and 2. All estimated parameters of the mean yield production functions of the crops grown in the two districts have the admissible signs implying positive marginal productivity of the inputs. As indicated above, in the specification of a stochastic production technology the error terms may be related to explanatory variables, leading to heteroscedasticity in the model. A Multi stage Non-linear Least Squares (MNLS) estimation procedure has been proposed as a method of generating consistent and asymptotically efficient estimates of the parameters of the stochastic production function.

For most of the crops considered in this study, the MNLS parametric values of the different inputs used in the production of the crops showed improved levels of statistical significance over the first stage (mean) production technology representations. Also, the relative contribution (magnitude) of some inputs to the mean yield levels of the crops showed improvements after correcting for heteroscedasticity and when MNLS estimation procedure was used. For instance, human labor was the third in terms of its magnitude and impact on the mean yield (first moment) of sorghum in Dadar. However, the parametric value of the MNLS results of the input showed that it is the second highest contributing input to the mean yield of the crop next to land. Similar results were observed for the use of human labor in the production of maize in Faddis district. Therefore, production technology representation results that are based on MNLS

estimation procedures (including other techniques that are used to overcome the consequences of heteroscedasticity) provide more accurate and reliable information that are crucial in setting priorities and the formulation of policies geared towards improving crop production technologies.

Most improved varieties of crops in Ethiopia are developed (screened) and promoted for use among farmers for their higher mean yield levels compared with local varieties. The use of improved varieties of maize and sorghum in Dadar and Faddis districts, respectively (as indicated by the parametric values of C_1) had higher contributions to mean yield of the respective crops compared to local varieties (Tables 1 and 2). Statistically, use of improved seed for both crops was highly significant indicating their importance in determination of the mean yield.

On the other hand, in terms of magnitude, for most of the crops grown in both districts, increased area planted showed higher contribution to the mean yields of the crops (Tables 1 and 2). This is because of the fact that cultivating bigger plots of land enables the farmers to use relatively abundant factors of production such as human labour more efficiently. Moreover, land was statistically significant in the production of most of the crops grown in the districts implying its importance in crop production in the area.

Fertilizer is one of the inputs promoted for use by the extension package in the study area. It is widely used in the production of maize and sorghum among users of the extension package in Dadar and Faddis districts, respectively. Fertilizer was statistically significant for the mean yields of both crops in the two districts showing its importance as a determinant of crop production (Tables 1 and 2). In terms of magnitude however, the impact of the use of fertilizer was found to be low. This might have been caused by the fact that most farmers applied fertilizer close to the recommended levels and additional units of fertilizer might have insignificant contributions to mean yield. For instance, the recommended amount of fertilizer use is about 25kg/qindi for maize in Dadar and the average amount of fertilizer applied to maize by package user farmers in the district during the survey year was 18 kg/qindi³.

Most farmers in East Hararghe zone heavily rely on human labour to carryout different agricultural operations such as land preparation, planting and cultivation. In terms of magnitude, human labour was the second most important factor affecting mean yield of crops next to land in Dadar (Table 1). In Faddis district however, human labour was the third input in its contribution to mean yield next to land and oxen labour (Table 2). Statistically, human labour was significant in the production of all crops grown in both districts, except for groundnuts production in Faddis.

Furthermore, oxen labour is frequently used by farmers in East Hararghe for primary ploughing, planting and sometimes during cultivation operations. The contribution of oxen labour to the mean yield of sorghum and barely was the second highest in Dadar district. Even though its contribution was low in terms of magnitude, oxen labour was a statistically significant input in maize production in Dadar district. On

³ Is a local measure of land size. 1 ha= 8 qindies

the other hand, oxen labour was at least the second highest in its contribution to the mean yield of crops grown in Faddis. Farmers in the district have large land holding sizes and plots allocated to the individual crops are relatively big compared to Dadar district. This might require the use of more oxen labour in addition to human labour in order to carryout different agricultural operations by the farmers of the district. For instance, while the average land holding in Faddis was about 17 qindies, farmers in Dadar owned about 6.5 qindies on average. In addition, oxen labour was statistically significant for all crops grown in Faddis, except for groundnuts, showing once more its key role in the determination of the mean yield of crops grown in the district.

East Hararghe is among the areas in Ethiopia that are frequently affected by drought resulting mainly from variability in both the time of arrival and the distribution of rainfall during cropping seasons. Early planting enables crops to use available moisture from the rainfall at the beginning of the season for germination. Also, planting early allows plants to reach maturity on time using the available rainfall that is critical for flowering and seeding of crops towards the end of a cropping season. In this study, late planting was negatively related to the mean yield of all the annual crops grown in the two districts. This is in line with the observation of the rainfall distribution in the area during the survey year that was inadequate towards the end of the cropping season.

4.2. Risk effects of production inputs

Mechanisms such as crop insurance and future markets that help farmers manage agricultural production risks are absent in Ethiopia. However, farmers can control production related risks by varying the levels of inputs used in production. Understanding the yield risk effects of inputs is therefore important for formulation of risk management strategies that can be employed by small-scale farmers as well as the development and promotion of appropriate agricultural technologies. The estimated results of the variance (second moment) component of the production technology for the crop enterprises included in the study are reported in Tables 1 and 2.

For the crops used by the extension package (maize in Dadar and sorghum in Faddis), the use of improved seed was associated with high levels of yield instabilities compared with local varieties (Tables 1 and 2). In addition, the use of improved seed was highly significant factor affecting the variance of sorghum in Faddis. The high levels of yield variances associated with the use of improved seed show that the differences in the conditions (i.e. agro-ecological and socio-economic) of the package user farmers are higher than the non-user of the package.

In Ethiopia, improved crop varieties are developed and screened for their high mean yield performances under controlled and uniform conditions at research stations with the best use of the necessary inputs such as fertilizers and pesticides. However, the farming systems of the country show great variations in soils, rainfall and humidity even within short distances. In addition, farmers operate under different socio-economic conditions where some farmers are better off in their ability to generate cash that can be used to purchase critical inputs such as fertilizers while others are desperately poor struggling to satisfy their daily food requirements. Also, some farmers are more educated and well informed about the use of new agricultural technologies and others are not. For instance, about 60% and 78% of the sample farmers were illiterate in Dadar and Faddis districts, respectively. As a result of these, farmers might not be able to use the necessary complementary inputs that go with the improved seed varieties as recommended. Therefore, such differences in the agro-ecological (soils, rainfall, etc.) and socio-economic conditions of the farmers could result in high levels of variations in the yield levels obtained from the improved crop varieties. On the other hand, traditional varieties that have evolved over long periods of farmers' learning and adaptation are more adapted and hence less sensitive to the variations among farmers' conditions (i.e. they perform relatively more uniformly under a wide range of conditions) resulting in more stable yield levels as compared to improved varieties.

In addition, the estimated parameter values of the second moment stochastic production functions showed that fertilizer is a yield risk increasing input (e.g. higher levels of fertilizer are associated with larger yield variances). While the contribution of the level of fertilizer applied to yield variability was almost the same in both crops, fertilizer effect was statistically more significant on the yield variability of sorghum in Faddis. The high level of yield instability associated with the use of fertilizer might have emanated from the variation among extension package user farmers in its application and

management (i.e. rate, time and method of application). The recommendations of both the time and rate of fertilizer application in crop production in Ethiopia are made based on the performance of crops for different levels of fertilizer applied in research stations under good management conditions. However, the yield response of crops to levels of fertilizer under farmers' management conditions depends on a number of interacting factors that include biophysical factors such as the soil type, the time and amount of rainfall, date of planting and management practices like the rate and the method of application of fertilizers.

Also, the interaction between levels of fertilizer used and other inputs is complex having a varied impact on yield stability of crops. For instance, information obtained from farmers during the survey showed that high levels of fertilizer applied with inadequate moisture 'burn the crops' leading to low crop yield levels and in instances where there is adequate moisture, increased use of fertilizer leads to higher crop yields. Therefore, depending on the availability of moisture and the degree of the suitability of other factors that affect crop yield levels, higher levels of fertilizer application could lead to higher levels of deviations from the mean yield of crops across farmers resulting in decreased yield stability. Both the time and amount of rainfall is highly variable even within short distances in the study area. In such instances, higher levels of fertilizer application could lead to increases in the variability of crop yields.

Moreover, the realization of stable yield levels from higher levels of fertilizer applied depends on the extent to which other recommended practices of the technologies in the package are followed appropriately. For instance, the recommended practices of improved maize production include adequate spacing between plants and rows that reduce the competition between individual maize plants for sunlight, soil moisture and nutrients. Line sowing also makes various operations such as weeding, cultivation and fertilizer application easier. Farmers do not follow the same management practices in using fertilizers. In situations where the recommended practices were appropriately followed, increased fertilizer application might have increased the yield of crops. On the other hand, in instances where the recommended practices were not followed appropriately, increased fertilizer application might have resulted in lower yield levels. Therefore, increased use of fertilizer might lead to increased yield variability of crops across farmers due to differences in management practices. For instance, out of the surveyed farmers in Dadar, only 52% of the farmers used line sowing of maize seeds and the rest 48% used broadcasting method.

On the other hand, while the impact of increased area cultivated is positive and significant on the yield variability of sorghum and kaht, it has a negative and insignificant effect on the variability of yield of maize and barely in Dadar district. In Faddis district however, expansion in area cultivated is associated with increased levels of instability in the yields of all crops grown with insignificant effect. The yield risk effect of expansion in area allocated to crops can be affected by two major factors. First, increased area cultivated could be yield risk increasing (decreasing) depending on the extent of variation in the quality of the land used. Second, increased area cultivated could lead to higher levels of crop yield instability if it entails competition among different crop enterprises

for inputs such as human labour that are critical for operations such as cultivation that need to be done timely at critical stages of the crop growth to use the available moisture during a cropping season.

The yield risk decreasing effect of area planted to maize in Dadar could be explained by the fertility status and the topographical conditions of the plots allocated to the crop. It is natural to expect more stable crop yields from flat plots with high levels of fertility as compared to steep and less fertile plots. For instance, out of the total sampled farmers included in the survey from Dadar district, about 30% of them indicated that they have allocated the most flat and fertile plots of their holdings to maize production. Similarly, the yield risk increasing effect of area cultivated to sorghum could be explained by the condition of the plots allocated to the crop by the farmers that were less fertile and steep. For instance, only 14% of the sample farmers in the district allocated flat and fertile portions of their holdings to sorghum production. Also, the yield risk increasing effect of land area cultivated to the crops grown in Faddis district could be explained by the high competition among the crop enterprises for other inputs such as labour that are crucial for operations such as cultivation. Given the erratic nature of the distribution of rainfall in Faddis, some farmers might be able to acquire the necessary labour required to take advantage of the available moisture for critical operations like cultivation of crops such as sorghum and maize (the cultivation of which takes place simultaneously in most cases) while other farmers may not be able to do so. Therefore, due to competition between different crop enterprises for inputs such as human labour during critical farm operation periods and the differences between farmers in their access to such resources, increased area cultivated to the crops might be associated with higher levels of deviations of crop yields from the mean yield levels (higher levels of instability in crop yields).

Moreover, as indicated before human labour is widely used in East Hararghe for various agricultural operations such as planting and cultivation. For the package crops grown in the study area (maize in Dadar and sorghum in Faddis), human labour showed a yield risk decreasing effect. This is normally expected as increased amount of human labour could help to carryout critical agricultural operations on time. However, for some other crops (e.g. barely in Dadar and maize and kaht in Faddis) increased use of human labour was associated with high instability of the crop yields. From the observation during the survey, in addition to own labour, communal labour is widely used in the area for different agricultural operations. However, the farmers tend to use more of communal labour on the non-package crops than the package crops. As the necessary inputs such as improved seeds and fertilizer are obtained through credit from the government that has to be repaid at the end of the cropping season, farmers care more for the crops for which they committed most of their resources. The quality of communal labour is usually low due to incentive problems associated with it and increased reliance on such type of labour could lead to higher levels of variability in crop yields.

In East Hararghe, oxen labor is most commonly used during initial periods of the cropping season, especially for primary ploughing and planting. In moisture stressed areas, the use of oxen labor enables farmers to carryout critical agricultural operations

such as land preparation and planting on time. For most of the crops grown in Faddis district (e.g. maize, sorghum and kaht), oxen labor showed a yield risk decreasing effect. About 70% of the farmers in the district owned at least a pair of oxen. As the farmers in the district own larger plots of land, the use of oxen labor could have yield stabilizing effect as it enables them to carryout agricultural operations timely. On the other hand, the yield risk increasing effect of the use of oxen labor on maize and sorghum in Dadar was not expected. However, the most probable reasons for this might be the interaction of the increased use of oxen labor with other factors such as the cultural practices used (e.g. broad casting method of sowing, cultivation practices, etc) and other natural factors such as the prevalence of frost, outbreak of disease, etc.

One of the critical cultural practices used in crop production having a bearing on the stability of crop yields is date of planting. For all of the annual crops grown in the two districts considered in this study, late planting was associated with increased level of instability in the yields of the crops. Planting date is very crucial in crop production as it determines the availability of moisture at critical stages of growth of crops such as germination, flowering and maturity. Currently, early planting of crops during the start of the rainy season is widely recommended by extension workers in the country. However, farmers in the study area vary greatly on planting date decisions. Due to the erratic nature of rainfall, it is not surprising for late planting to be associated with higher levels of variability in the yields of the crops grown in the study area.

5. Conclusion

To a varying degree, the use of improved seed, land size, human labour, oxen labour and planting date appear to be the most important factors affecting mean yield levels of crops grown in the area. While increased area of land showed a big impact on the mean yield of most crops grown as it allows better use of other resources, possibilities of expansion in land size are limited due to the high density of the population in the area. Moreover, as land is a public property, area expansion through the market mechanism is limited. Accordingly, improvements in mean yield levels of crops grown in the area requires the use of intensive agricultural production method such as improved seed that enable farmers obtain higher mean yield levels from their limited holdings. On the other hand, oxen labour had a relatively second biggest impact on the mean yield of most crops grown in the study area. Oxen labour is crucial for the timely operation of critical crop production operations like planting. Improving farmers' access to oxen could have a big potential for improving mean yield levels of crops as farmers in the area have limited access to the input. In addition, due to the erratic nature of rainfall and the characteristics of most crop varieties grown in the area that are late maturing, late planting had a negative effect on mean yields. Therefore, to increase mean yield levels of most of the crops grown in the area, agricultural research has to pay special attention to the generation of early maturing varieties that are capable of reaching maturity with the available moisture during the production season. Moreover, providing farmers with information and advice on early planting would enable to improve mean yield levels of crops grown in the area.

On the other hand, the results of the second moment stochastic production functions indicated that the use of improved seeds was associated with high levels of variability in crop yields. This might act as a constraint to the wider adoption of the technologies as most of the subsistent farmers in the area are concerned mainly with more stable supply of food for the family than with higher yield levels. It is therefore important for agricultural research and extension to focus on developing crop varieties that give not only high yield levels but also provide farmers with stable yields. This entails the development and screening of crop varieties for their adaptability across a wide range of agro ecologies and management conditions of the farmers in the area. In addition, extension should provide farmers with the necessary information on the use and management of improved seed (i.e. method of planting, time of cultivation, etc.)

Farmers' management practices are in most cases the main reasons for the decrease in the stability of crop yields associated with higher levels of fertilizer. Also, the interaction of the level of fertilizer applied with other factors such as the availability of moisture, the soil type, type of variety used, etc. could lead to higher levels of crop yield variability. Various strategies can be used to overcome the yield risk increasing effect of fertilizer to make it more appropriate to the differing situations of farmers to promote its wider adoption. These include, among other things, the development of improved crop varieties for their yield stability with different levels of fertilizer applied across different agro ecologies under the management condition of farmers before their release. Moreover, the communication and training of farmers on the timing, rate and methods of fertilizer application could also be an important area where major extension work should be emphasised in order to reduce the yield risk increasing effect of fertilizer.

On the other hand, depending on its quality (fertility) and the degree of competition between crop enterprises for inputs such as human labour, land size was found to increase or decrease crop yield variability. Several strategies can be used to reduce the risk increasing effect of increased area cultivated. First, agricultural research has to focus on the development and generation of crop varieties on plots the fertility level of which is similar to the farmers and test for their stability on those plots both across farms and overtime. Second, the promotion of soil conservation technologies such as terracing should also be given adequate emphasis in the extension package to enable farmers achieve stable yield levels from the use of improved crop varieties through expansion in area planted. In addition, the promotion of farm equipment (machinery) that could help farmers to carryout operations such as cultivation could reduce competition between crops for inputs such as labour thereby helping farmers to carryout agricultural operations timely to achieve stable yield levels.

The use of oxen labour was found to have a yield risk reducing effect for most crops considered in this study. Thus, the achievement of stable yield levels of crops produced in the area requires improving farmers' access to oxen (e.g. making available credit facilities for the purchase of oxen). Finally, late planting was associated with decreased yield stability of most crops considered in this study. To achieve more stable yield levels from crop production in the area, extension should provide farmers with better metrological information and improved predictions on onset of rain to assist them

on plating date decisions. Also, early maturing varieties that are capable of reaching maturity with the available moisture need to be given priority in research.

Table 1. Stochastic Cobb Douglas production function regression results of crops grown in Dadar (2001/2002)

| Input | Crops | | | | | | | | | | | |
|--------------------------|---------------------------------|------------------|---------------------------------|------------------------------|--------------------------------|--------------------------------|-------------------------------|------------------------------|-------------------------------|-------------------------------|---------------------------------|--------------------------------|
| | maize ^{Nm} | | | sorghum ^{Ns} | | | kaht ^{Nk} | | | barley ^{Nb} | | |
| | Mean | Variance | MNLS | Mean | Variance | MNLS | Mean | Variance | MNLS | Mean | Variance | MNLS |
| C₁ | 3.49 ^{***} (5.51) | 3.86 (1.16) | 3.35 ^{**} (2.47) | 0.87 [*] (1.79) | 0.09 (0.19) | 0.12 (0.15) | 0.21 (0.73) | -0.03 (-0.06) | 0.44 ^{***} (3.02) | 1.16 ^{***} (4.27) | -0.58 ^{***} (-2.79) | 2.49 ^{***} (5.68) |
| C₂ | 3.05 ^{***} (6.41) | 1.41 (0.64) | 1.94 ^{***} (2.77) | 0.56 (1.24) | -0.96 ^{**} (-2.00) | 0.70 [*] (1.83) | -0.10 (-0.26) | -0.21 (-0.36) | 0.58 (1.00) | 1.15 ^{***} (4.63) | -0.41 [*] (-1.85) | 1.60 ^{***} (4.51) |
| Lad^l | 1.15 ^{***} (8.23) | -0.07 (-0.08) | 0.74 ^{***} (3.61) | 0.46 ^{**} (3.08) | 0.34 ^{**} (2.24) | 0.66 ^{***} (5.23) | 0.99 ^{**} (2.31) | 4.47 ^{**} (2.26) | 0.43 ^{***} (3.31) | 0.08 (0.15) | -0.23 (-1.17) | 2.40 ^{***} (3.08) |
| Fert^f | 0.08 ^{**} (5.69) | 0.03 (0.29) | 0.06 ^{**} (2.00) | - | - | - | - | - | - | - | - | - |
| Lab^g | 0.31 ^{***} (3.46) | -0.77 (-0.27) | 0.61 ^{***} (8.36) | 0.25 ^{**} (2.10) | -0.35 (-1.59) | 0.58 ^{***} (5.74) | 0.55 ^{***} (3.34) | -0.21 (-0.59) | 0.70 ^{***} (5.66) | 0.95 [*] (1.87) | 0.37 ^{**} (2.14) | 1.38 [*] (1.72) |
| Oxlab^o | 0.02 (0.12) | 1.28 (0.33) | 0.09 (0.41) | 0.33 [*] (1.85) | 0.59 [*] (1.88) | 0.11 (0.45) | 0.18 (1.06) | -0.08 (-0.27) | 0.13 [*] (1.81) | 0.34 ^{**} (2.12) | -0.03 (-1.22) | 0.33 ^{**} (2.35) |
| Pltd^{pl} | -0.20 ^{***} (-3.35) | 0.20 (0.29) | -0.22 ^{***} (-3.44) | -0.03 (-0.28) | 0.06 (0.63) | -0.19 ^{**} (-2.14) | - | - | - | -0.47 [*] (-1.86) | 0.02 (0.36) | -0.52 ^{**} (-2.53) |
| R-sq | 0.85 | 0.18 | 0.74 | 0.59 | 0.42 | 0.98 | 0.69 | 0.35 | 0.99 | 0.82 | 0.18 | 0.99 |

^l is land in qindi, ^f is fertilizer in kilograms, ^g is human labour in man-days, ^o is ox labour in oxen-days, ^{pl} is planting date in weeks
Nm=97, Ns=56, Nk=49, Nb=38

are the number of observations for maize, sorghum, kaht and barely, respectively.

*** Significant at 1%, ** Significant at 5%, * Significant at 10%.

Table 2. Stochastic Cobb Douglas production function regression results of crops grown in Faddis (2001/2002)

| Input | Crops | | | | | | | | | | | |
|--------------------------|---------------------|---------------------|-------------------|-----------------------|--------------------|---------------------|--------------------|------------------|-------------------|--------------------|--------------------|--------------------|
| | maize ^{Nm} | | | sorghum ^{Ns} | | | kaht ^{Nk} | | | grod ^{Ng} | | |
| | Mean | Variance | MNLS | Mean | Variance | MNLS | Mean | Variance | MNLS | Mean | Variance | MNLS |
| C₁ | 0.21 (0.89) | -1.48*** (-2.90) | 0.38** (1.96) | 2.61*** (4.14) | 3.38*** (5.33) | 3.44*** (10.83) | 0.91* (1.85) | -1.21 (-0.61) | 0.53*** (2.82) | 4.69*** (4.19) | 5.64 (0.98) | 4.37** (2.59) |
| C₂ | 0.25 (1.34) | -1.39*** (-2.71) | 0.36** (2.05) | 1.84*** (3.58) | -6.35** (-2.41) | 1.89** (2.06) | 0.74 (1.59) | -1.17 (-0.65) | 0.29* (1.84) | 4.29*** (4.15) | 2.69 (0.41) | 4.75*** (5.37) |
| Lad^l | 0.68*** (4.34) | 0.09 (0.57) | 1.43 (9.93) | 0.94*** (14.09) | 0.14 (0.70) | 0.87*** (33.8) | 0.39* (1.91) | 0.39 (0.87) | 0.56*** (3.33) | 0.29 (0.49) | 0.06 (0.08) | 0.94* (1.77) |
| Fert^f | - | - | - | 0.03*** (5.05) | 0.18* (1.72) | 0.01* (1.73) | - | - | - | - | - | - |
| Lab^g | 0.19* (2.34) | 0.15** (2.72) | 0.63*** (6.34) | 0.08 (1.46) | -0.02 (-0.12) | 0.19** (7.49) | 0.24* (1.95) | 0.25 (1.11) | 0.03 (0.35) | 0.33 (0.69) | -0.009 (-0.008) | 0.92** (2.05) |
| Oxlab^o | 0.41* (2.50) | -0.12 (-0.78) | 0.55** (2.47) | 0.14** (2.80) | -0.05 (-0.34) | 0.05 (1.45) | 0.24* (1.82) | -0.21 (-0.77) | 0.32*** (3.38) | 0.38 (0.83) | 0.13 (0.18) | 0.57 (1.14) |
| Pltd^{pl} | -0.23*** (-4.07) | 0.03 (0.45) | 0.44*** (5.15) | -0.008 (-0.29) | 0.14 (1.39) | -0.11*** (-7.29) | - | - | - | -0.63** (-2.08) | 0.29 (0.58) | -0.72** (-2.52) |
| R-sq | 0.98 | 0.28 | 0.99 | 0.93 | 0.11 | 0.99 | 0.60 | 0.25 | 0.96 | 0.37 | 0.13 | 0.40 |

^l is land in qindi, ^f is fertilizer in kilograms, ^g is human labour in man-days, ^o is ox labour in oxen-days, ^{pl} is planting date in weeks
Nm=50, Ns=95, Nk=91, Ng=54 are the number of observations for maize, sorghum, kaht and groundnuts, respectively.

*** Significant at 1%, ** Significant at 5%, * Significant at 10%.

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