Modelling production risk in small scale subsistence agriculture

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Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

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Abstract

In this paper we are investigating how production risk may influence the way a risk averse producer like a subsistence farmer chooses optimal input levels. Risk averse producers will take into account both the mean and the variance of output, and therefore we expect them to choose input levels which differ form the optimal input level of risk neutral producers. Production risk is of particular importance in developing countries, since variance in production here may have grave consequences for the farmer and his family. To model the production decision problem under such circumstances we have made use of the fact that production risk can be treated as heteroskedasticity. Our analysis is based on a dataset obtained from a survey on smallholders in the Kilimanjaro region in Tanzania. Since evidence of output risk in inputs is found, we reestimate the mean and variance function using a maximum likelihood estimator, and correct the standard errors to provide valid inference.

1. Introduction

A common finding is that third world farmers often uses less fertiliser than they would have done if they maximised expected profits (Ramaswami, 1992). It is also common to find that these farmers do not adopt, or only partly adopt, new technologies (including new crops), even when these technologies provide higher return to land and labour than the old technologies (Goetz *et al*., 1988 and von Braun *et al*., 1989). One possible explanation for why subsistence farmers in developing countries are reluctant to implement technologies that apparently will make them better off can be the perceived risk profile associated with the technologies. If this is the case, it is important to obtain knowledge about the risk profile of new technologies to be able to determine strategies for agricultural development.

Aid is often given as fertilizer or seed because these inputs are expected to increase the output. An important characteristic of fertiliser is that it is expected to increase the risk as well (Ramaswami, 1992). Development aid is also used to support local extension service. Even if extension services are not productivity increasing in themselves, it can be positive if it reduces the risk increasing effect of productivity enhancing technologies.

In this paper we will investigate the production function and risk for farmers in the Kilimanjaro region in Tanzania using the Just and Pope (1978) framework for modelling risk. A linear quadratic functional form is used to model the mean function, which is estimated together with a variance function. Tanzania is one of the poorest countries in the world, with a GNP at US$ 260. The economy is heavily dependent on agriculture, which accounts for 50 percent of the GDP, provides 85 percent of the exports, and is, by far, the largest employer. Smallholder peasants with average farm sizes between 0.9 hectares and 3.0 hectares dominate agriculture. In the analysis we will investigate how inputs influence the level of risk. We will also investigate if mean production and production risk are correlated with individual and socio-economic characteristics, and assess the importance of risk to other sources of constraints in farm households' production, such as marked imperfection in credit.

2. Theoretical Background

Most studies dealing with production risk are based on Just and Pope (1978). In their seminal paper they present eight postulates for the stochastic production function which they argued were necessary for the function to be able to reflect all potential risk structures. One of the requirements they propose is that positive, zero and negative marginal risk in input levels each should be possible. In other words, inputs are allowed to increase or reduce the level of output risk. This is in contrast to the commonly used translog production function that restricts output risk to increase in input levels. The Just-Pope production function has the general form

$$y = f(x;\alpha) + h(z;\beta)\varepsilon \qquad (1)$$

where *f*(•) is the mean production function and *h*(•) is the variance function (or risk function) and x and z are vectors of inputs (with parameters α and β). The exogenous stochastic disturbance or production shock is represented by ε, where $E(\varepsilon) = 0$ and $\text{var}(\varepsilon) = \sigma_\varepsilon^2$. A nice feature of the J-P form is the separation of the mean and the variance effect of changes in input levels. Mean output is given by $E(y) = f(x;\alpha) + u$, while the variance of output is given by $\text{var}(y) = [h(z:\beta)]^2 \sigma_\varepsilon^2$. With this formulation we see that the input vector x influences both the mean output and risk through a production function, $E(y) = f(x)$, and a variance (risk) production function, $\text{var}(y) = h(z)^2\sigma_\varepsilon^2$, where z may contain some or all the elements in x and/or additional variables. From an econometric viewpoint, this formulation is also useful because the variance function can be interpreted as a heteroskedasticity disturbance term. This can be seen by reformulating the J-P form as $y = f(x;\alpha) + u$, where u is the error term with variance $\text{var}(u) = [h(z;\beta)]^2 \sigma_\varepsilon^2$ (Asche and Tveterås 1999).

If models of the competitive firm under production risk are within the expected utility framework, risk averse producers choose the input vector *x* which maximise their expected utility based on observed (or expected) output and input prices (p, *w*) and *a priori* knowledge of the structure of the risky production technology (Tveterås, 1998). An important theoretical result provided by Ramaswami (1992) proves that, for all risk averse producers, the marginal risk premium is positive if and only if the input is risk increasing. The importance of this result lies in the fact that it is sufficient to obtain information on the marginal risk of an input in order to determine whether a risk averse producer uses less of the input than a risk-neutral producer. If the marginal risk of an input is positive, then the risk averse producer will use less of that input, and if the marginal risk of an input is negative the risk averse producer will use more of that input.

3. Empirical specifications

The first issue to address when analysing a production sector is to investigate whether any significant production risk is present. Since production risk is specified as heteroskedasticity in the J-P framework, any test against heteroskedasticity can be used. If heteroskedasticity is not detected, this can be regarded as evidence against production risk, and the researcher can proceed within a conventional deterministic production model framework.

Provided that production risk is found to be present, there are two issues of interest- the mean production function $f(\bullet)$ and the risk function $h(\bullet)$. As long as the information of interest is related only to the production function, one needs not be concerned with the risk function. One the other hand, if there is substantial heteroskedasticity that can be attributed to production risk, then the variance function also becomes a subject of interest. There are two estimators that provide consistent estimates of the parameters of the production and variance function; three-stage feasible generalised least squares (FGLS) and maximum likelihood (ML). The FGLS estimator is often used in empirical studies of production risk (Just and Pope, 1979, Griffiths and Anderson, 1982, Hallam *et al.*, 1989, Wan, Griffiths and Anderson, 1992, Hurd, 1994, and Traxler *et at.* 1995.) However, the ML estimator provides asymptotically more efficient estimates of the variance function parameters than FGLS (Harvey, 1976). We will therefore use a ML estimator.[1]

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[1] To get robust standard errors we did the covariance matrix calculation $A^{-1}BA^{-1}$ where A is the information matrix and B is the outerproduct of the gradient (see White (1982), Weiss (1986) and Bollerslev (1986)). The standard errors are robust in the sense that conditional normality of the errors is not assumed.

In the present analysis a linear quadratic (LQ) functional form is used for estimating the production and variance function (Asche and Tveterås, 1999). The linear quadratic allows input elasticises to vary in input levels both in the production function *f*(•) and the variance function *h*(•). The linear quadratic (LQ) production function is given by

$$y = a_0 + \sum_k \alpha_k x_k + 0.5 \sum_j \sum_k \alpha_{jk} x_j x_k + \sum_d \alpha_d D_d + u \qquad (2)$$

where the subscripts j, k = 1,….,N refer to inputs, and the subscript d = 1,….,N refers to the included demographic and socio-economic variables. The general expression for returns to scale (RTS),

$$RTS = \sum_k E_k = \sum_k \left[\frac{\partial y}{\partial x_k} \times \frac{x_k}{f(x)} \right], \qquad (3)$$

is equal to the sum of the *k* output elasticities. If the estimate of RTS is greater than unity the returns to scale are increasing, less then unity the returns to scale are decreasing, or equal to unity the returns to scale are constant.

The variance function is a special case of Harvey's (1976) variance functions specification, var(*u*) = *h*(*z*) = exp[*z*β], where the *z*'s are input levels or transformations of input levels, e.g., logarithms of inputs and second-order terms. A nice property of the variance function in Harvey's formulation is that positive output variance is always ensured in empirical analysis. Note that in the Just-Pope model, var(*y*) = var(*u*). In the specification the argument of the exponent is a linear function:

$$\mathrm{var}(y) = \exp\left[\beta_0 + \sum_k \beta_k x_k + \sum_d \beta_d D_d \right] \qquad (4)$$

The total output variance elasticity (TVE) in inputs is defined as

$$TVE = \sum_k VE_k = \sum_k \beta_k \, , \tag{5}$$

and is the sum of k output variance elasticities with respect to inputs. TVE is the analogue of the RTS elasticity measure derived from the mean function, and if TVE is greater than zero, a factor-neutral expansion of input levels will lead to an increase in total output risk (Tveterås, 1998).

4. Background and data

4.1 The studied area

The Kilimanjaro Region is located in the north-eastern part of mainland Tanzania just north of the equator, and has a total surface area of 13,209 sq.kms. It covers about 1.4 percent of the area of the entire Tanzania Mainland (Kilimanjaro Regional Statistical Abstract, 1994). This makes it the smallest region in the mainland. However, it is the third densely populated area with 158.8 people/sq.km. This is explained by the fertility of the land in the region, which also leads to a high scarcity of land in the area. Total population of the Kilimajaro region is 2,097,166 (2002 projection), which is 4.9 percent of the total Tanzania Mainland population (Government of Tanzania, 2002).

The Kilimanjaro region comprises four ecological zones based on altitude, soils and climate. These zones are the Peak of Kilimanjaro Mountain, the Highlands, the Intermediate zone and the Lowland Plains zone. The Highland zone lies between 1100 and 1800 meters above the sea level. This zone has very fertile soils derived from remains of volcanic racks rich in magnesium and calcium. The area is exceedingly suitable for agricultural activities. The Intermediate zone lies between 900 and 1100 meters above the sea level, and has moderate soil fertility. The Lowland Plains zone lies below 900 meters with an average annual rainfall between 100 and 900 mm, and temperatures above 30°C. The rate of cultivation is low accounting for only 10 percent of total activity. (Government of Tanzania, 2002).

Most of the region's population is heavily dependent on agriculture and livestock keeping for their livelihood, and it is assumed that 75 percent of the region's population lives in rural areas. Farming is ranked as the major economic activity in the region, and subsistence farmers dominate (Government of Tanzania, 2000). Out of the total population of the Kilimanjaro region 45 percent practice agricultural activity as a source of livelihood (Bureau of Statistics, 1994). Today food imbalances are a big problem in the area, and more than 25 percent of the population suffers form protein energy malnutrition, 32 percent from nutritional anaemia, 6.1 percent from Vitamin A deficiency, and 25 percent from iodine deficiency (National Sectoral Report on Women, Agricultural and Rural Development, 1994). With increased production risk, the output will be even smaller than today in bad periods, and today's food imbalance problem will increase.

4.2 Data Collection

The model is estimated on cross-sectional data form a survey on Tanzanian smallholders in Kilimanjaro. The study was done in villages of the Hai and Moshi Rural districts. From these two districts, 11 villages were selected according to how they could best represent the two districts and the various ecological and agro-economic zones. The sample villages Mabogini (Ma) and Himo (Hi) are found in the Lowland Plain zone[2]. Kariwa (Ka), Shiri (Sh), Kware (Kw) and Roo (Ro)[3] are found in the intermediate zone, while Kinde (Ki), Wari (Wa), Umbwe (Um), Ng'uni (Ng) and Nronga (Nr)[4] are found in the Highland Zone (Land Survey Department of the Regional Administrative Office). The survey was conducted during

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[2] Mabogini and Himo have altitudes of 762 and 869 meters above sea level, respectively.

[3] Kariwa, Shiri, Kware and Roo have altitudes of 914, 975, 1036 and 1052 meters, respectively.

[4] Kinde, Wari, Umbwe, Ng'uni and Nronga have altitudes of 1143, 1219 1280, 1524 and 1676 meters, respectively.

June/July of 2002. A total of 213 farmers from the 11 different villages in the Kilimanjaro region were interviewed. Each household was asked questions from a 15-page questionnaire.

The production function for the Kilimanjaro farmers is specified with six inputs: labour (L), land (A), fertiliser (F), pest control (P), seed (S) and irrigation (W). In the model we have also included some demographic and socio-economic characteristics, and assess the importance of risk to marked imperfection in credit. In the analysis we investigate if sex of head of household (sex), age of the decision maker (age), years of education of the head of household (edu), extention service (t) and access to credit (credit) influences the output and output risk. Because of diversity in topography, and the possibility of differences in competence level, education and training possibility, together with varying road condition, we also check for village-specific effects in the model. Output (y) is defined as total value of crop. This value is a production value index, which is estimated by taking the size of the crop times the market price for the relevant product.

4.3 Inputs

While all the inputs in the model are expected to increase the output, some inputs may reduce the level of output risk while others may increase risk. Labour is expected to be the most important input. The lack of machinery means that production depends very heavily on human labour. Increasing the use of labour is expected to have a risk-reducing effect, since the ability to discover unfavourable conditions, like diseases, pest, and lack of water or fertiliser early in the production process increases.

Increasing the use of land is expected to have a risk-increasing effect. This is because when the land area increases the time used per squared meter decreases, and the ability to discover unfavourable conditions early in the production process decreases.[5]

Bad infrastructure and poor farmers make the use of fertiliser relatively low in developing countries. An increase in the use of fertiliser is therefore expected to increase crops and prevent exhaustion of the soil. However, at some point increased consentration of fertiliser ceases to cause an increase in crops, instead possibly resulting in poisoning and reducing the crop. Many farmers in developing countries do not have the necessary training in using fertiliser, and the result might be poisoning the crops. This expectation is supported by earlier work on production risk in agriculture production (Ramaswami, 1992).

Increasing the use of pesticide is expected to keep the crop healthy and give the crop protection from pests. But there are also disadvantages to the use of pesticide. Besides human health risk, pesticides pose danger to the environment. Non-target organisms can be severely impacted. In some cases a pest insect is controlled by beneficial insects, prediators or parasite, yet the insecticide application kills both the pest and the controlling orgamism. The control organism almost always takes longer to recover than the pest. Pesticides are also a factor in pollinator decline, which is a food supply issue.

Because of the lack of money, seed (as well as fertiliser and pesticides) are a scare factor. In subsistence agriculture it is normal to make you own seed. However, commercial seed is expected to result in less variation in crop quantity and quality, and therefore to reduce the risk in production.

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[5] It is in many cases not possible to increase the area, as most people already uses their entire land-share. Especially in the Kilimanjaro region land is becoming scace, with increasing population pressure in the region. The scarcity of land and the scramble for such land is very intense, especially in the highlands zone.

5. Empirical Results

As a first step the linear quadratic mean production function was estimated by OLS.[6] Given that the data is a cross section, the fit is relatively good with an adjusted R^2 of 0.72. Based on the OLS estimates a number of heteroskedasticity tests[7] were carried out to test for the presence of significant marginal output risk in input levels. All the tests rejected the hypothesis of homoskedasticity at all conventional significance levels, which indicates that output risk is present. The test results are reported in Table 1. Since the heteroskedastisity tests provide evidence that production risk is present, the production function was reestimated together with the variance function using a maximum likelihood estimator.

Table 1

To provide a meaningful interpretation of the estimated input parameters, empirical results are presented in terms of elasticities. The elasticity estimates from the production function are reported in Table 2. As expected, we see that the output elasticity, E_k, is positive for all inputs, *k*. This confirms the *a priory* hypothesis that all the inputs will increase the mean output. Returns to scale (RTS) is 0.8981, implying decreasing economics of scale for the sample average farm.

Table 2

Credit is the only socio-economic characteristics that might explain some of the variation in the mean function at a conventional level of significance. Access to credit will increase the production. This might partly be explained by the fact that a smallholder with access to credit

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[6] SHAZAM () software was used for all estimations.

[7] The tests that were used are White's test, Park Harvey test, Glejser test and Breusch-Pagan-Godfrey.

uses intensive inputs more often. The quantity used of fertilizer, pesticides and commercial seed were respectively 9.2, 128 and 130 percent higher if the smallholder had have access to credit. In the survey many households mention disease being their great enemy, preventing them from getting a good harvest from coffee. Lack of money to buy the necessary pesticide was a huge problem for many with 81 percent of the sample farmers reporting that expensive pesticide was a problem in cultivating their crop.

Elasticities from the variance function can been found by looking directly at the parameter estimates from the variance function in Table 3. According to the output variance elasticities both labour and seed have a risk-decreasing effect, while land, fertilizer and pesticide all have a risk-increasing effect. That labour is risk reducing is in accordance with the expectation, and supports the hypotheses that increased use of labour increases the ability to discover unfavourable condition early, and that commercial seed results in less variation in crop quantity and quality. Land used seems to have large effects on the level of risk, with an elasticity of 43% for the sample average firm. This supports the *a priori* expectation that an increase in the use of land will lower the ability to discover unfavourable conditions early, and therefore increase the output risk. The inputs that lead to more intensive farming practices, fertilizer and pesticide, also have a risk-increasing effect.

Table 3

Among the individual and socio-economic characteristics, irrigation, sex of head of household, extension service and credit, beside village-specific effects, must influebce production risk. While access to irrigation and credit will increase the risk in production, use of extension service will reduce the risk. The gender dummy indicates that a male headed household is more risky than a female headed household. For both the production and variance function Wald-tests provided support for the use of village-specific parameters, with a $\chi^2(10)$ statistic of 34.349 and a *p*-value less than 0.0001 in the production function, and a $\chi^2(10)$ statistic of 35.722 and a *p*-value less than 0.0001 in the variance function. Hence, the Killimanjaro villages are heterogeneous with respect to the production and level of production risk. By looking closer at the village specific parameters it is possible to investigate if there is some connexion between the different villages and production or production risk. By sorting the village according to the size of the mean production, we find that the five most efficient villages are Wari, Nronga, Kinde, Roo and Umbwe. These villages are found in the Highland and upper Intermediate zone. This is not surprising since these zones has a very fertile soil that is exceedingly suitable for agriculture activities. However, we are not able to see any correlation between the production risk and the location of the villages. We don't find any correlation between the districts and the production or production risk in the villages either.

The total variance elasticity, which is analogue to the returns-to-scale measure, is 0.3549. In other words, an increase in the scale of operation through a proportional increase in input levels not only lead to an increase in mean output, but also to an increase in the level of output risk for the average farm. The degree of risk aversion will thus determine whether such an expansion will provide a higher expected utility for the smallholder. The more risk averse smallholders are, the more weight they will assign to the increase in production risk relative to the increase in expected output. According to the theory, the rational of the average smallholder for increase the use of an input, is that the increase in mean output associated with the input is sufficiently large to provide an increase in expected utility.

6. Concluding remarks

This paper provides information on the risk properties of input, and how production risk may influence the way a risk averse producer chooses optimal input. In risky production processes input levels influence both the mean output level and the level of output risk. While all inputs are expected to increase the mean output, some inputs may reduce the level of output risk, while others may increase risk. Because of this we expect risk averse producers to choose input levels which differ from optimal input levels of risk neutral producers. To solve the problem we have made use of the fact that production risk can be treated as heteroskedasticity when the Just-Pope postulates hold. The model is based on a system constituted by a mean production function and its variance function. To estimate the parameters a maximum likelihood estimator was used, which provides efficient estimates of the production and variance function parameters.

This approach was applied to a data set obtained from a survey on smallholders in the Kilimanjaro region in Tanzania. In the analyses we have investigated which inputs reduce the level of risk, and which inputs increase risk. We have also investigated if individual and socio-economic characteristics have any influence on output and the level of risk. Since evidence of heteroskedasticity in inputs was found, we reestimated the mean and variance function, and corrected the standard errors to provide valid inference. Elasticity measures enable us to analyse both mean output and output variance. As expected all the inputs to production were found to increase the mean output, and by to the output variance elasticities, we found that labour and seed have a risk-decreasing effect, while land, fertilizer and pesticide have a risk-increasing effect. The estimated model also predicts that an expansion in the scale of operations through a proportional increase in input levels lead not only to an increase in mean output, but also to an increase in the level of output risk for the average farm. By extensive testing we found that access to credit, irrigation and male headed household increase the output risk, while the use of the extension service reduces the output risk. We also find that villages are heterogeneous with respect to mean production and production risk.

These results show why it is important to not only focus on the mean production function, but also include the variance part when working with problems like this. Extension service is one example. Even if extension service is not significantly increasing the mean production, the use of extension service will reduce the production risk and therefore increase the utility of the smallholders.

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Tables and Figures

Table 1. heteroskedasticity tests

Heteroskedasticity tests	**χ^2 test statistic**	**df.**	**p-value**
White's test			
-e^2 on yhat	40.457	1	0.00000
-e^2 on $yhat^2$	26.545	1	0.00000
-e^2 on log ($yhat^2$)	32.583	1	0.00000
Park Harvey test	44.034	26	0.01499
Glejser test	101.163	26	0.00000
Breusch-Pagan-Godfrey			
-koenker (R2)	98.671	26	0.00000
-B-P-G (SSR)	174.491	26	0.00000

Table 2. Sample average elasticity estimates from the mean function.

	E_L	E_A	E_F	E_P	E_S	RTS
Mean	0.12306	0.26951	0.24165	0.035974	0.22791	0.898104
Sdt. Dev	0.05139	0.05458	0.04391	0.035247	0.03809	
t-value	2.39443*	4.93770**	5.50313**	1.020623	5.98366**	

Table 3. Parameter estimates for the variance function.

Parameter	Cofficient	Std. Dev	t-value[8]
β_L	-0.2896195	0.1614766	-1.793570
β_A	0.4270048	0.1440576	2.964125**
β_F	0.3184490	0.0936517	3.400354**
β_P	0.1671899	0.0314816	5.310712**
β_S	-0.2681555	0.0553429	-4.845350**
β_W	0.6215906	0.1871209	3.321866**
β_{SEX}	0.7612193	0.2150620	3.539534**
β_{AGE}	0.0055435	0.0080016	0.692805
β_{EDUC}	-0.0438738	0.0417685	-1.050404
β_T	-0.4633204	0.2279490	-2.032562*
β_{CREDIT}	1.0451810	0.2694035	3.879612**
β_{Hi}	1.2779100	0.4420014	2.891191**
β_{Ka}	1.5231840	0.4453772	3.419986**
β_{Ki}	1.3030250	0.4644548	2.805493**
β_{Um}	1.2650800	0.8153213	1.551634
β_{Kw}	1.1116380	0.3961638	2.806005**
β_{Ng}	1.3035440	0.6168925	2.113081*
β_{Nr}	1.4512410	0.3957074	3.667459**
β_{Ro}	1.0782040	0.5195044	2.075447*
β_{Sh}	-0.6724098	0.4927323	-1.364655
β_{Wa}	1.2574780	0.4283367	2.935723**
β_0	-4.4951810	0.6174353	-7.280407**

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[8] * indicates that the parameter is significant at a 5% level, while ** indicates that the parameter is significant at a 1% level.