

Climatic Risks and Household Vulnerability Assessment: A Case of Paddy Growers in Odisha

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Abstract

The state of Odisha being quite vulnerable to climatic extremes, this paper has analysed the degree of vulnerability of farming households to those climatic extremes in both irrigated as well as rainfed farming ecosystems. Using the expected poverty approach, the study has found that the degree of vulnerability of farming households is mounting with a shift in minimum threshold level of income in both the ecosystems. Again, in both the ecosystems, the marginal farmers have been found highly vulnerable, followed by small farmers. The study has come out with some policy implications and has suggested that the livelihood system of farmers needs to be diversified and their coping mechanisms should be strengthened through various government policies.

Key words: Odisha, agriculture, climatic risks, vulnerability, rice growers

JEL Classification: Q12, Q51, Q54

Introduction

Climate change has been recognized as an existential threat to the planet Earth. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report (2007) observed that 'warming of climate system is unequivocal', as is evident from observations of increase in global mean air and ocean temperature, wide spread melting of snow and ice and rising global sea level (Solomon *et al.*, 2007; Kumar, 2013). Due to these climate changes, many extreme events like increase in frequency and severity of droughts, floods, cyclones, outbreak of pests and diseases, etc. render low crop yields, crop failure, wide spread hunger and livestock mortality (Kevan, 1999; Morton, 2007; IPCC, 2012). The IPCC report (2012) also states that the intensity as well as the frequency of occurrence of these climate extremes have increased over the years and are likely to increase in future also (cited in Bahinipati and Venkatachalam,

2014). The empirical documentation by various studies has also revealed an increasing trend in the direct economic losses caused by such extremes, particularly in developing nations (Mirza, 2003; Stern, 2007; Bouwer, 2011; IPCC, 2012).

The adverse impact of climate change on Indian agriculture has extensively been studied (Kumar and Parikh, 2001; Mall *et al.*, 2006; Birthal *et al.*, 2014). However, studies over the past one decade or so have largely been concentrated on the theoretical contribution or measurement of vulnerability on regional and national levels with selected indicators for each region and identifying regional adaptive strategies that have policy implications for their planning (Brooks *et al.*, 2005; Fussel, 2007; Hinkel, 2011; Islam *et al.*, 2014; Opiyo *et al.*, 2014). But, the vulnerability analysis of households at the micro level is a vital requirement for effective planning and development of coping mechanisms at the local level where the farming community is actually involved in fighting with the climate change menace (Yuga *et al.*, 2010; Fraser *et al.*, 2011).

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The IPCC report (2012) also states that ‘disasters occur first at the local level and affect local people. These localized impacts can then cascade to have national and international ramifications. As a result, the responsibility for managing such risks requires the linkage of local, national, and global scales’. Therefore, it is imperative to study the vulnerability to these climatic extremes at the micro-level taking households as primary unit of analysis.

In this paper, we have analysed the degree of vulnerability of marginal and small farmers to climatic extremes like droughts, floods, cyclones etc. in the state of Odisha. The specific objectives of the study were: (i) quantifying the damages to paddy cultivation due to climate extremes at the aggregate level and also at the farm level in the study region, and (ii) analyzing the household level vulnerability of paddy growers in sample villages in both agricultural ecosystems, viz. irrigated and rainfed. An attempt has also been made to get a comparative picture about the vulnerability of farmers in these regions, given their coping strategies, so that effective policy framework could be evolved about the adaptive strategies.

Vulnerability Assessment: Theoretical Background

The vulnerability is the exposure of groups or individuals to the stress as a result of social and environmental changes, where the ‘stress’ refers to unexpected changes and disruptions to livelihoods (Adgar, 1999). Broadly, there are two approaches to assess the degree of vulnerability of a household, viz. indicator approach and econometric approach (Deressa *et al.*, 2009). The econometric approach includes three categories: (a) vulnerability as expected poverty, (b) vulnerability as low expected utility, and (c) vulnerability as uninsured exposure to risk. We have broadly followed the econometric method and the expected poverty approach in particular.

In the expected poverty framework, a farmer’s vulnerability is the probability of becoming poor in the future if currently not poor or the chance of his continuing to be poor if currently poor (Christiaensen and Subbarao, 2004). So, vulnerability is seen as expected poverty, while consumption or income is being used as proxy for wellbeing. This method finds its root in the methodology devised by Chaudhuri *et*

al. (2002) for estimation of vulnerability to poverty in Indonesia.

Thus, the vulnerability of a household is modelled as per Equation (1):

$$v_{h,t} = \Pr(C_{h,t+1} \leq z) \quad \dots(1)$$

where, $C_{h,t+1}$ is the consumption per capita of h household at the time $t+1$ and z is the minimum threshold level. Vulnerability of household h at time t is defined in terms of household’s consumption prospects at time $t+1$ and the probability of that consumption falling short of the minimum threshold level of income.

Again, household’s consumption in any period depends on a number of factors or household’s characteristics as well as farmers’ own personal characteristics. Thus, it can be written as per Equation (2):

$$C_{h,t} = C(X_h, \beta_t, \alpha_h, \epsilon_{h,t}) \quad \dots(2)$$

where, X_h is the vector of household characteristics, β_t is the parameter vector and α_h is an unobserved time invariant household effect and $\epsilon_{h,t}$ is any idiosyncratic factors (shocks) that contribute to differential welfare condition of households.

Now substituting Equation (2) into Equation (1) we get

$$v_{h,t} = \Pr[C(X_h, \beta_{t+1}, \alpha_h, \epsilon_{h,t+1}) \leq z \mid X_h, \beta_t, \alpha_h, \epsilon_{h,t}] \quad \dots(3)$$

Equation (3) expresses that household’s vulnerability level is derived from the stochastic properties of the inter-temporal consumption stream it faces. These properties in turn depend on a number of household characteristics and environmental characteristics on which its consumption stream depends.

Analytical Framework

The above theoretical explanation of vulnerability can be estimated empirically. To estimate a household’s vulnerability to poverty, we need a minimum estimate of both its expected consumption and the variance of its consumption. Following Chaudhuri *et al.* (2002),

the stochastic process generating the consumption/ income of a household h is given by Equation (4):

$$\ln Y_h = X_h \beta + e_h \quad \dots(4)$$

where, Y_h is per capita farm income¹ of household h , X_h is the set of observable household characteristics and climatic shocks, β is the vector of parameters and e_h is a mean zero disturbance-term that captures the idiosyncratic shocks that contribute to the difference in minimum income levels of the households that share the same characteristics. Following Deressa *et al.* (2009), it is assumed that the variance of e_h will take the form of Equation (5):

$$\sigma_{e,h}^2 = X_h \theta \quad \dots(5)$$

where, θ represents a vector of parameters to be estimated, ε is the vector of residuals of this second estimation. Standard ordinary least square (OLS) regression estimates of β and θ will be unbiased but inefficient since the OLS estimates suffer from homoscedasticity problem. In order to avoid that problem, the vector of parameters β and θ are estimated by adopting the three steps feasible generalized least square (FGLS) procedure suggested by Just and Pope (1978). A detail summary of the estimation procedure is explained in Appendix 1.

Using the values of $\hat{\beta}$ and $\hat{\theta}$, the expected log of income and its variance for each household h can be estimated as:

$$\hat{E} [\ln Y_h | X_h] = X_h \hat{\beta} \quad \dots(6)$$

$$\hat{V} [\ln Y_h | X_h] = \hat{\sigma}_{e,h}^2 = X_h \hat{\theta} \quad \dots(7)$$

By assuming that farm income is log-normally distributed (i.e., $\ln Y$ is normally distributed), these estimates are used to form an estimate of the degree of vulnerability, i.e. the probability of a household falling below the minimum threshold level of income, with the characteristics, X_h . Letting $\Phi(\cdot)$ denote the cumulative density of the standard normal, this estimated probability can be expressed as Equation (8) (Gaiha and Imai, 2009; Günther and Harttgen, 2009; Deressa *et al.*, 2009):

$$\hat{v}_h = \widehat{Pr} [\ln Y_h < \ln z | X_h] = \Phi \left(\frac{\ln z - X_h \hat{\beta}}{\sqrt{X_h \hat{\theta}}} \right) \quad \dots(8)$$

where, $\ln z$ is the log of minimum income level beyond which a household will be called vulnerable and v_h or $\Phi(\cdot)$ shows the probability of a farmer falling below the threshold level where it will be vulnerable. The values of v_h lie between 0 and 1. When it is zero, household h spends/earns adequate amount of income currently and in future that will have zero chance of falling below the minimum threshold level. The value one reflects the reverse case where the household is considered as the most vulnerable. Generally, 0.5 probability level is taken as the benchmark level to define one unit of analysis (here household) as vulnerable (Deressa *et al.*, 2009; Capaldo *et al.*, 2010; Bogale, 2012).

Study Area and Data Collection

The data for this study were collected through a primary survey conducted in two districts of Odisha, viz., Cuttack and Khurda during *kharif*-2012-13. The sample had 300 farming households, mostly belonging to marginal and small farmers group. To have a comparative analysis of vulnerability of farming households in two different ecosystems, the district Cuttack was selected from the irrigated region while the district Khorda was selected from the rainfed region. Then, six villages (three from each region) were selected by adopting a multistage random sampling method. All the three villages were clustered together in each region.

The villages in the irrigated region are well facilitated with assured canal irrigation and rice is a major crop grown twice in a year along with other crops. In the three villages clustered together in rainfed region, farming is practised once in a year after receiving the southwest monsoon and rice is a major crop. The justifications for selecting these villages included their almost equal distances from the local market as well as the R&D institutions. After controlling these two aspects, the differential coping mechanisms of farmers in these ecosystems could be

¹ Following Deressa *et al.* (2009), we have considered farm income of the households rather than consumption. Generally, in backward region, the agriculture sector is dominated by marginal and small farmers who hardly save anything as the marginal propensity to consume is very high.

studied because the climatic risks that farmers face in both types of agriculture are not same in character and magnitude. The irrigated region mostly faces floods/submergence and the rainfed region faces drought-type situation during crop growth.

Table 1 presents the descriptive statistics. The income of a farming household, instead of consumption has been considered as dependent variable in the model. The independent variables have been defined with their respective means and standard deviations.

Empirical Results and Discussion

Climatic Extremes and Loss in Paddy Production in Odisha

The losses in paddy production due to various extreme events during the period 1965 to 2008 have been shown in Table 2. Paddy is grown both during *khari* and *rabi* seasons. Presently, out of total rice area, *khari* season (during which southwest monsoon comes) accounts for 93 per cent and contributes about

Table 1. Descriptive statistics of variables used in regression model

Variable	Description	Mean value	Standard deviation
Dependent variable			
Household's farm income (₹)		321,150	16520
Independent variables			
AMV	Area under modern varieties (acres)	1.54	1.66
AFERT	Area fertilized (acres)	1.76	1.62
APEST	Area under pesticides-use (acres)	0.58	0.74
AGE	Age of farmers (years)	53.12	8.8
EDN	Education level of farmer	1.82	0.98
	0 - Illiterate		
	1 - Primary level (1-7th class)		
	2 - Secondary (8-10th class)		
	3 - Higher (> 10th class)		
HS	Household size (No.)	6.56	1.82
FM	Total farm size (acres)	2.95	1.88
TNCY	Tenancy structure	1.5	0.9
	1-Owned		
	2-Leased-in		
	3-Mortgaged-in		
HE	Healthcare expenditure of family during past one year (₹)	0.13	0.1
CRDIT	Accessibility to credit by farmer (1-If credit accessed, 0 – otherwise)	0.82	0.71
EXTN	Contact with extension services (1-If contacted, 0-Otherwise)	0.27	0.44
MKTD	Distance to local market (km)	2.42	1.13
LVST	Owning livestock (No.)	5.1	4
CLMD	Total area damaged by climatic risks (acres)	0.72	0.85
RPRDL	Ratio of production loss to total production (quintals)	0.14	0.16

Source: Authors' field survey, 2012-13.

Table 2. Climate extremes and loss in paddy production in Odisha, 1965-2008

Year	Natural calamity	Production loss (lakh tonnes)
1965	Severe drought	11.7
1966	Moderate drought	7.3
1967	Moderate drought	8.9
1968	Mild cyclone	4.6
1969	Mild flood	5.2
1970	Mild flood	4.5
1971	Moderate cyclone	6.7
1972	Mild drought	3.0
1974	Severe drought	12.2
1975	Mild flood	1.0
1976	Severe drought	12.3
1977	Mild flood	3.8
1979	Severe drought	17.3
1980	Mild drought	4.4
1981	Moderate drought	5.6
1982	Moderate drought & Mild cyclone	17.6
1984	Moderate drought	8.8
1985	Mild flood	0.3
1987	Severe drought	18.0
1990	Severe flood	11.0
1992	Moderate drought	7.2
1996	Severe drought	23.6
1998	Moderate drought	12.4
1999	Super cyclone	18.1
2000	Severe drought	19.2
2002	Severe drought	37.8
2003	Mild flood	4.23
2006	Mild flood	5.4
2008	Mild flood	7.3

Source: GoO (2013)

89 per cent to the total rice production (GoO, 2013). A perusal of Table 2 reveals that the production losses occurred more due to droughts than floods and cyclones. The probability of occurrence of a drought, flood and cyclone in a year has been estimated as 0.36, 0.20 and 0.11, respectively. Out of 16 years of drought, severe droughts occurred in eight years when production losses varied between 12 lakh tonnes and 38 lakh tonnes and moderate droughts occurred six times when production losses were 2-4 lakh tonnes.

The maximum production loss of 38 lakh tonnes happened in 2002-03 due to a severe drought.

Climate Risks and Paddy Production Loss in Study Area

The damages caused by various climate-induced extremes in the study regions are documented in Table 3. The types of risks that caused production losses are different in each ecosystem. In the irrigated region, the major climatic risks were flood/submergence and wind blow. The drought has never been a threat in the irrigated region, especially in *khari*paddy cultivation. Overall damage caused by submergence and floods was 7.46 acres in the irrigated region. A higher percentage of crop area was damaged by wind blow (17 acres) and weather induced diseases (20 acres). The total crop area damaged by these climatic risks was 44.71 acres which was 7.46 per cent of total rice area cultivated. A close look at the damages caused by climatic extremes revealed that the marginal and small farmers were affected severely in comparison to medium farmers (no large farmers exist in the study area). This is because the marginal and small farmers are unable to cope with these climatic risks.

In the rainfed region, drought at various stages, strong wind blows, cyclones and weather diseases are the major threats. A drought at early stages of cultivation, i.e. during sowing period, comes as a major worry; it affected 28.8 acres of area. Next to drought, wind blows (19.75 acres) and weather-induced diseases (19.48 acres) affected the paddy crop largely. The total crop area damaged has been found to be 68.19 acres, which is 11.24 per cent of total paddy area. The marginal and small farmers are largely affected along with medium farmers. Though flood is not a major cause, still 0.16 acres got damaged due to submergence.

The analysis has shown that flood is the major cause in irrigated region and drought is a major cause in the rainfed region, while weather-induced diseases and tropical wind storms are common threats in both the ecosystems. However, weather-induced diseases are more severe in rainfed region.

Vulnerability Assessment of Farming Households

The vulnerability assessment was done following the expected poverty approach. By using estimated mean income and variance of income (shown in

Table 3. Cropped area affected by various climatic risks in study region

Farmers/ Region	Cropped area affected by climatic risks (acres)				Total area damaged	% of total rice area
	Flood/ Submergence	Drought at various stages	Wind blow	Weather induced diseases		
Irrigated region						
Marginal	2.43	0.00	5.22	4.57	12.22	11.34
Small	3.60	0.00	7.50	11.55	22.65	10.47
Medium	1.43	0.00	4.24	4.17	9.84	5.65
Total	7.46	0.00	16.96	20.29	44.71	7.46
Rainfed region						
Marginal	0.00	6.04	4.10	4.86	15.00	12.68
Small	0.16	9.36	8.57	5.55	23.48	10.57
Medium	0.00	13.40	7.08	5.07	25.55	8.52
Total	0.16	28.8	19.75	19.48	68.19	11.24
Total area						
Marginal	2.43	9.04	9.32	9.43	30.22	12.51
Small	3.76	10.36	16.07	21.1	51.29	11.52
Medium	1.43	14.4	11.32	9.24	36.39	7.08
Total	7.62	33.8	36.71	39.77	117.9	9.35

Note: The classification of farmers into different groups is based on ownership of landholding-size.

Source: Authors' field survey, 2012-2013.

Appendix Table 1), the probability of a household falling below a given threshold level of income (poverty line) was estimated. We analyzed the sensitivity by examining this probability by using three different minimum levels of income: (i) monthly per capita expenditure, as per mixed reference period (MRP)² of ₹ 904.78 for the rural areas of Odisha as defined by the Planning Commission in 2013, (ii) international poverty line of USD 1.25 per day (World Bank, 2008), and (iii) USD 1.50 per day. The rationale behind using these three threshold levels of income was to find how much vulnerable they become when the minimum requirement to sustain a life increases. We have analysed the vulnerability of farmers at the household level and then at the aggregate level for irrigated as well as rainfed regions. In both the cases, the analysis was carried out across the farming groups. The aim was to have a comparison of levels of

vulnerability across different farming groups and also between two ecosystems at different minimum threshold levels of income.

Table 4 shows the degree of vulnerability in both irrigated and rainfed ecosystems. From vulnerability analysis, two points were observed. First, vulnerability of farming households over different scenarios of poverty line increases following an upward shift in threshold level of income, assuming that farmers' income remains the same. The number of vulnerable farmers rises steeply following a shift in the minimum level of expenditure from ₹ 904.78 to international poverty line of USD 1.25 per day (approximately ₹ 2250 as monthly income) and again to USD 1.50 per day. The overall analysis for the irrigated region has shown that only 16 per cent of the farmers were vulnerable and a shift in threshold level of expenditure to USD 1.25 per day turned large number of farmers

² Mixed reference period (MRP) refers to the measure of calculating consumption expenditure where consumption of five low-frequency items (clothing, footwear, durables, education and institutional health expenditure) over the previous year, and all other items over the previous 30 days. In other words, survey respondents were asked about consumption of these five items in the previous one year. For the remaining items, they were asked about consumption in the previous 30 days. The average monthly per capita consumption expenditure as per mixed reference period for Odisha is ₹ 904.78 in rural areas. For details, see 'Press Note on Poverty Estimates, 2011-12' released by the Planning Commission (2013).

Table 4. Vulnerability of farming households in study region

Farmers' category/region	₹ 904.78 as monthly expenditure		1.25 USD per day income		1.50 USD per day income	
	P ≥ 0.5	P < 0.5	P ≥ 0.5	P < 0.5	P ≥ 0.5	P < 0.5
Marginal	15(10)	85(56)	74(49)	26(17)	83(55)	17(11)
Small	18(12)	79(53)	67(45)	33(22)	82(55)	18(12)
Medium	13(3)	87(12)	40(6)	60(9)	67(10)	33(5)
Irrigated region	16(25)	84(123)	67(100)	33(48)	81(120)	19(28)
Marginal	19(8)	86(35)	77(33)	23(10)	86(37)	14(6)
Small	19(16)	81(67)	64(53)	36(30)	76(63)	24(20)
Medium	0(0)	100(26)	12(3)	88(23)	27(7)	73(19)
Rainfed region	16(24)	84(128)	59(89)	41(63)	70(107)	30(45)
Marginal	17(18)	83(91)	75(82)	25(27)	84(92)	16(17)
Small	19(28)	81(122)	65(98)	35(52)	79(118)	21(32)
Medium	07(03)	93(38)	22(9)	78(32)	41(17)	59(24)
Total area	16(49)	84(251)	63(189)	37(111)	77(227)	23(74)

Notes: P is the estimated probability level.

Figures within the brackets indicate number of farmers in each category.

Source: Authors' calculations from field survey data, 2012-2013.

vulnerable, viz. 67 per cent of the farmers would be vulnerable to climatic shocks in the irrigated region.

A similar type of augmentation in vulnerability to climatic shocks was also observed in the rainfed region following the shift in threshold minimum expenditure/income. The percentage of farmers vulnerable to climatic shocks increased from 16 per cent (24 farmers) to 59 per cent (89 farmers) following the shift in the threshold level of expenditure from ₹ 904.78 per month to international poverty line at USD 1.25 per day.

When the minimum threshold level was further set at USD 1.5 (approximately ₹ 90 per day), the level of vulnerability rose in both the regions as more and more farmers became vulnerable. At the threshold level of USD 1.25 per day expenditure, out of 148 farmers, 120 farmers (81%) became vulnerable in the irrigated region, while in the rainfed region, 107 farmers (70%) became vulnerable. It shows that the number of poor households is likely to increase with rise in minimum income level required to sustain daily life.

Second, the analysis has demonstrated that at a particular threshold level in both the regions, the level of vulnerability varied across the farmers' groups. Though, the level of vulnerability in different ecosystems was different, a similar pattern was observed when we looked at the level of vulnerability

across the farmers categories in a particular ecosystem. At a particular threshold level in both the ecosystems, the most vulnerable to those climate-induced shocks were marginal farmers, followed by small and medium farmers.

In the irrigated region, at ₹ 904.78 monthly expenditure, it was found that 15 per cent of marginal, 18 per cent of small and 13 per cent of medium farmers were highly vulnerable to climatic shocks. When the threshold level of income was shifted to the international poverty line of 1.25 USD, 74 per cent marginal, 67 per cent small and 40 per cent medium farmers became highly vulnerable. At the overall level also, the same pattern was observed. In terms of absolute figures, the number of medium farmers who were least vulnerable to the climatic extremes was higher in the rainfed ecosystem. Therefore, we may say that the overall degree of vulnerability is little less in the rainfed ecosystem than in the irrigated ecosystem.

Conclusions and Policy Implications

The study has revealed that occurrence of climate-induced extreme events has become an annual affair causing a huge loss of agricultural production. Using household level data from two different agricultural

ecosystems of Odisha, the study has analysed the damages in terms of affected cultivated area and degree of vulnerability of farming households. It has been observed that in the irrigated ecosystem, floods/submergence along with weather-induced diseases and hailstorm or strong wind blow cause heavy losses in crops production. But, in the rainfed agriculture, drought, particularly at the early stages of cultivation, is a major problem. Due to heavy dependence on rainfall, the farmers sow the seeds instead of planting the seedlings. Thus, the delayed and irregular rainfall creates an early drought.

The vulnerability analysis has revealed two facts. One, in a particular ecosystem and poverty scenario, the level of vulnerability across the farming groups varied and the most vulnerable were the marginal farmers followed by small and medium farmers. Two, the overall level of vulnerability was rising with a rise in the minimum threshold level of income. At ₹ 904.78 monthly expenditure (Indian poverty line pronounced by Planning Commission), we found that 16 per cent of farming households were vulnerable in both the ecosystems. But, it increased to 67 per cent when the threshold level was set at the international poverty line of USD 1.25 per day and again to 71 percent at USD 1.5 per day. Thus, the study has shown that vulnerability of farming household is highly sensitive to the minimum per day income and therefore, the poor farmers are most vulnerable.

Since an increase in the farmer's income will reduce their level of vulnerability, the study has suggested that augmentation of household income is a major step towards reduction in vulnerability to the climatic extremes. The farmers should be encouraged to develop a diversified livelihood system to enhance the total earning of the household. Secondly, the crop diversification should be encouraged so that crop losses due to natural calamities can be minimized. Mainly rice is grown in the study region which needs a balanced and adequate water supply. Thus, it is prone to both droughts as well as floods. Therefore, farmers in the rainfed region should be encouraged to grow drought-resistance crops, mainly pulses like green gram, black gram, finger millet, etc.

The policy interventions should focus on strengthening both household and public level climate risks management thorough mitigation and risk coping

mechanisms. The mitigation strategies at household level should include along with income and crop diversification, membership of different developmental organisations and credit groups, rearing different species of livestock. Moreover, policies that encourage consumption as well as income smoothing coping strategies at the household level should be evolved. At the public level, the climate risk management strategies should focus on water harvesting structures, creation and utilization of irrigation potential in the rainfed regions, voluntary resettlement programmes, provision of early warning system and dissemination of information about the calamities in time, providing relief immediately after the calamity, inception of productive safety net programmes, and crop insurance based on weather index.

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Appendix 1

Feasible Generalised Stochastic Function

The GSF developed by Just and Pope (1978, 1979) is written as follows:

$$Y = f(X) + h^{\frac{1}{2}}(X)\varepsilon; \quad E(\varepsilon) = 0 \text{ \& } V(\varepsilon) = I \quad \dots(\text{A.1})$$

where, Y is actual income per unit of land, X is vector of inputs and ε is error-term. The term $f(X)$ is mean income and $h(X)$ is the term capturing the variability of income. The income variance is measured by $h(x)\sigma^2$ and an input ' i ' is said to have positive (negative) marginal effect on variance if h'_i is positive (negative).

Estimation Procedures

First Stage: For estimating income function (A.1) empirically, we supposed that it follows the log linear function of Cobb-Douglas type given as Equation (A.2):

$$Y_t = f(X_t, \beta) + h^{\frac{1}{2}}(X_t, \theta)\varepsilon_t \quad \dots(\text{A.2})$$

Now the function $f(\cdot)$, following the CD function, can be written separately as Equation (A.3)

$$Y_t = f(X_t, \beta) + \varepsilon_t^*; \quad E(\varepsilon_t^*) = 0, \quad E(\varepsilon_t^* \varepsilon_\tau^*) = 0 \text{ for } t \neq \tau \quad \dots(\text{A.3})$$

where, $\varepsilon_t^* = h^{\frac{1}{2}}(X_t, \theta)\varepsilon_t$, $E(\varepsilon_t) = 0$, $E(\varepsilon_t \varepsilon_\tau) = 0$ for $t \neq \tau$

Equation (A.3) can be considered as a nonlinear, heteroscedastic and auto-correlated regression of Y on X .

$$Y_t = \alpha_0 X_{1t}^{\beta_1} X_{2t}^{\beta_2} \dots \dots X_{kt}^{\beta_k} \varepsilon_t^* \quad \dots(\text{A.4})$$

Following the method of nonlinear least square (NLS), the Equation (A.4) gives the consistent but not efficient (asymptotically) estimators of β . So we have to go beyond this stage.

Second Stage: Using the consistent estimates of β , say $\hat{\beta}$, we can estimate $Y_t = f(X_t, \hat{\beta})$ and then ε_t^* or $h^{\frac{1}{2}}(X_t, \theta)\varepsilon_t$ can be estimated by $\hat{\varepsilon}_t^* = Y - f(X_t, \hat{\alpha})$ under broad range of conditions:

$$(\varepsilon_t^*)^2 = E[(\varepsilon_t^*)^2]u_t = h(X_t, \theta)u_t \quad \dots(\text{A.5})$$

where, $E(u_t) = 1$ by the definition of expectation. The ' θ ' can be estimated by regressing $(\varepsilon_t^*)^2$ on X_t or taking logarithms, this can be achieved by the OLS regression. This can be written as Equation (A.6):

$$\ln(\varepsilon_t^*) = \theta_0 + \frac{1}{2} (\ln X_t)' \theta + u_t^*; \quad E(u_t^*) = 0 \quad \dots(\text{A.6})$$

where, $\theta_0 = E(\ln u_t)$, $u_t^* = \ln u_t - E(\ln u_t)$ and $\ln h(X_t, \theta) = (\ln X_t)' \theta$.

The Equation (A.6) can be written as Equation (A.7):

$$h^{\frac{1}{2}}(X_t, \theta) = \theta_0 X_{1t}^{\theta_1} X_{2t}^{\theta_2} \dots \dots X_{kt}^{\theta_k} u_t^* \quad \dots(\text{A.7})$$

The OLS gives a consistent estimator for θ .

Third Stage: After estimating the θ in the second stage, it is possible to compute the nonlinear generalized least square estimators for the regression Equation (A.4). The third stage uses the predicted error term from the second stage as weights for generating the generalized stochastic function (GSF) estimates for mean yield equation by using the NLS. It may be written as Equation (A.8):

$$Y_t^* = f^*(X_t, \beta) + \hat{\varepsilon}_t \quad \dots(\text{A.8})$$

where, $Y_t^* = Y_t h^{-\frac{1}{2}}(X_t, \hat{\theta})$ and $f^*(X_t, \beta) = f(X_t, \beta) h^{-\frac{1}{2}}(X_t, \hat{\theta})$.

The NLS estimate of ' β ' is consistent and asymptotically efficient. The procedure provides the estimates of impacts of the exogenous variables on mean income and variance of income.

Appendix Table 1. Estimates of farm income and variance of farm income

(N=300)

Variable	Mean farm income function			Variance of farm income		
	Coeff.	Std error	t-stat.	Coeff.	Std error	t-stat.
Intercept	-0.566	0.706	-0.801	-7.260*	4.313	-1.683
Area under modern varieties	0.011	0.108	0.103	-0.276	0.477	-0.579
Area fertilized	0.335***	0.082	4.094	-0.157	0.389	-0.405
Area under pesticide-use	2.197***	0.068	31.997	0.316	0.939	0.336
Age of farmer	0.024	0.035	0.676	-0.129	0.154	-0.837
Education of farmer	0.498***	0.117	4.271	0.666	0.596	1.117
Household size	0.603***	0.063	9.628	-0.377	0.295	-1.277
Farm size	0.029	0.047	0.617	-0.097	0.164	-0.583
Tenancy structure	0.173***	0.033	5.293	0.255	0.196	1.305
Households' healthcare expenditure	-0.032	0.041	-0.772	-0.525***	0.207	-2.538
Credit availability	-0.371***	0.067	-5.546	0.376	0.356	1.056
Extension officers visits	-0.109*	0.061	-1.807	0.228	0.304	0.752
Distance to local market	-0.012	0.033	-0.378	0.193	0.219	0.883
Livestock holding	0.396***	0.041	9.837	-0.450**	0.196	-2.301
Cropped area damaged by climate extremes	-0.036	0.141	-0.258	-0.026	0.467	-0.055
Ratio of production loss to total production	-0.080	0.137	-0.584	-0.463	0.521	-0.889
F stat	285.342			1.735		
Prob. > F	0.000			0.040		
R squared	0.920			0.038		

Note: The symbols ***, ** and * indicate level of significance at 1 per cent, 5 per cent and 10 per cent levels, respectively.