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ARTICLES

CROP FAILURE IN THE SEMI-ARID TROPICS OF PENINSULAR INDIA: IMPLICATIONS FOR TECHNOLOGICAL POLICY

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During any cropping season, a farmer in a village in the semi-arid tropics will not harvest one or more of his plots presumably because of low production. Other farmers in the same village may also experience 'crop failure'. Occasionally unfavourable agro-climatic events are strongly covariate across many villages within a region and result in widespread crop failure. Severe crop failure makes news headlines and has been subjected to intensive scrutiny in the famine and natural hazard literature [Sen (10), Jodha (9), and White (12)]. In contrast, crop failure in 'a period of normalcy' that spans some good years and some that are not so good has never commanded much publicity from journalists or received much attention from economists.

In this paper, we analyse the determinants of crop failure to draw implications for technological policy. Crop failure is an extreme and transparent outcome of interacting agro-climatic, biological, and soil events. A more thorough understanding of crop failure provides insight into the potential stability of new technologies. Such knowledge sheds light on the location specificity of improved cropping systems and hence complements base data analysis of agro-climatic and soils information.[1]

The paper is based on data gathered in the ICRISAT Village Level Studies (VLS) in six villages located in three contrasting agro-climatic and soil tracts in peninsular India [Binswanger and Ryan (3)]. Crop failure is analysed over three cropping years from 1975-76 to 1977-78. The unit of observation is the plot or farmer's field.[2] Information on each plot is reported by farmers in the VLS sample at approximately monthly intervals to a resident investigator. Samples were initially drawn in 1975 on the basis of

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1. In a forthcoming study, the authors use the results from descriptive research on crop failure to identify disparities in the quality and stability of farmer resource endowments within and across villages.

2. We have also analysed crop failure at the household level, but such an analysis is neither as clear or as rich as a plotwise evaluation. It is difficult to identify causal mechanisms that operate between household variables and crop failure. Household differences in socio-economic characteristics are usually swamped by agro-climatic, biological, and soil variation. Moreover, a household analysis relies on average data that result in valuable plot information being condensed into fewer data points.

operated area and include 30 cultivator and 10 landless labour households in each village.

The paper starts with a conceptual definition of crop failure and a brief description of its incidence in section II. Limited dependent variable models that are used to explain what is an all-or-nothing outcome are specified in section III. Expected determinants of crop success is dealt with in section IV. Empirical results on determinants of crop failure are presented in section V which includes probability predictions on the incidence of crop failure with changes in the independent variables. The paper concludes with a brief summary of implications for technology generation.

II

CONCEPTUAL DEFINITIONS AND INCIDENCE OF CROP FAILURE

Crop failure is identified with a plot that is not harvested.[3] A plot may not be harvested for a number of reasons. Low or nil production is certainly not the only one, but in the semi-arid tropics non-harvest and crop failure are likely to be highly correlated. In most cases, information is not available on why a farmer in the VLS sample did not harvest the crop nor can we unambiguously attribute crop failure to specific causes such as drought or insect damage. But casual empricism by the resident investigator and visitors to the village suggests that the overwhelming majority of non-harvested plots were due to crop failure. Non-harvest implies that it simply did not pay the cultivator to put forth the effort to harvest the plot. In commercial agriculture, non-harvest is often associated with low output prices; in semi-subsistence agriculture, non-harvest is much more directly related to low yields.

Although crop failure would appear to be a simple outcome to describe, description becomes complex in intercropping systems or even in sole cropping where joint production of grain and fodder is the rule rather than the exception. Because we want to test hypotheses on comparative crop failure in sole cropping and intercropping, we have chosen several alternative definitions for crop failure. These are listed in Table I and are grouped in two broad categories, complete and partial crop failure. The first category encompasses those plots where no main product, usually grain, was harvested [definition 1 (*b*)]. A plot where no grain but fodder or byproduct was harvested is considered a failure under definition (1 *a*) and a success under definition (1 *b*).

A definition of complete crop failure favours rejection of the null hypothesis that crop failure is *ceteris paribus* a more frequent outcome in sole cropping than in intercropping. As long as one crop in an intercrop combination is harvested, the plot is considered a success although many components in the intercropping system may fail. One way to redress this

3. Crop failure does not apply to prevented plantings where land was left fallow because conditions at sowing were not favourable. Crop failure implies loss of resources invested in the plot by the cultivator. Most plots did not fail at germination but later in the physiological life of the crop. Failure at germination often induces farmers to replant to improve stand establishment. Plots that were replanted and subsequently harvested are considered successes in this study.

bias is to develop definitions for partial crop failure. Partial crop failure applies to plots where the main product from the dominant crop is not harvested. Sole cropped plots where the main output is not harvested are also classified as failures by this definition.

Based on these definitions, the average incidence of crop failure over the three regions ranged from about 9 to 17 per cent for the 3,805 plots planted by cultivator households in the VLS sample from 1975-76 to 1977-78 (Table I). On average over the three cropping years, weather was fairly normal. Rainfall across the six villages was 99 per cent of the district average for the three regions. Nevertheless, rainfall was erratically distributed across the three years in each village.

TABLE I—DEFINITIONS AND INCIDENCE OF CROP FAILURE FROM 1975-76 TO 1977-78

Definitions	Regions			All regions
	Mahbubnagar	Sholapur	Akola	
	Percentage of non-harvested plots to total			
1. Complete crop failure				
(a) Main product output	6·1	17·4	3·7	11·6
(b) Main and byproduct output ..	4·6	13·3	3·6	9·1
2. Partial crop failure*				
(a) Main product from dominant crop	8·9	24·2	6·9	16·7
Average rainfall**	736	659	806	737
Total number of plots	826	2,058	921	3,805

* Includes sole crops as well as intercrops.
** Simple average of daily recordings from rain gauges in the two villages in each region for the three cropping years.

The data reveal sharp disparities across regions with respect to crop failure. By any definition, crop failure is highest in the drought-prone villages in Sholapur district. These villages are located in a tract of deep black soils near a rainfall shadow zone that is drier than the rest of Semi-Arid Tropics in India. On average more rain falls in the shallow red soil Mahbubnagar region, but distribution across years is also irregular. Greater access to tank and well irrigation imparts some stability to crop production in these villages particularly in Dokur. Rainfall is more assured in the cotton-growing medium black soil belt in North Central Maharashtra where the two Akola villages are located.

About 35 per cent of the fields in the sample were planted to intercrops and mixtures. For these plots, the joint probability that all crops failed was extremely small—it ranged from 0.01 in Akola to 0.03 in Mahbubnagar (Table II). But the probability of non-harvest of any one component in an intercropping system was high; the estimated probability that one or more crops failed ranged from 0.14 in Akola to 0.39 in Sholapur. Crop failure

TABLE II—INCIDENCE OF CROP FAILURE OF MAIN COMPONENTS IN INTERCROPS AND MIXTURES FROM 1975-76 TO 1977-78

Component*	Regions		
	Mahbubnagar	Sholapur	Akola
	Percentage of non-harvested plots to total		
First crop only	1·2	5·1	1·8
Second crop only	6·5	15·0	3·9
Third crop only	7·1	3·9	4·9
First and second crops	1·2	8·8	1·4
Second and third crops	8·9	2·8	1·1
First and third crops	0·6	0·8	0·0
All three crops	3·0	2·6	1·1

* Ranking of the components in intercrops and mixtures is based on relative area occupied by each species.

was particularly common in intercropped pulse species that were attacked by multiple pests.

III

THE PROBIT MODEL

Because crop success and failure are discontinuous outcomes, application of linear least squares regression results in many conceptual and empirical problems. A linear probability model leads to a heteroscedastic error structure and inefficient estimates. A related problem is that the error distribution is non-normal in a binary choice model. Therefore, classical hypothesis testing is not appropriate. If a linear probability model is used, predicted values may fall outside the interval between 0 and 1 which violates the basic tenets of probability.

A probit or comparable dichotomous variable model can overcome most of these difficulties.[4] The probit procedure uses a maximum likelihood method to calculate estimated coefficients that are asymptotically efficient and normally distributed. Predictions made on the estimated probit coefficients are also unbiased.

4. The probit model is discussed in Finney (6) in the analysis of biological assay data and has evolved into a commonly treated topic for econometric text books in the analysis of data with limited dependent variables [Theil (11) and Goldberger (7)]. The term probit means "probability unit" and was first applied by Bliss (5) in 1934. A comprehensive recent review is contained in Amemiya(1). The probit specification has been used most extensively in the agricultural development literature to understand adoption, fertility, and labour supply behaviour.

The probit specification views crop success as an all-or-nothing decision conditioned by a threshold level l*. The decision to harvest the plot (or crop success) is specified as :

$$CPS_j = \begin{cases} 1 \text{ if } l_j \geq l_j^*; \\ 0 \text{ if } l_j < l_j^*. \end{cases} \quad \ldots\ldots (1)$$

The farmer harvests plot j provided the stimulus index l_j is greater than or equal to threshold l_j^*. This is equivalent to saying that there is a cut-off point above which a plot is harvested and below which it is not. In commercial agriculture, this threshold level is equivalent to the point where per unit harvest and post-harvest costs are equal to the price the farmer receives for his output In semi-subsistence agriculture, farmers make similar calculations that are based more on opportunity than on monetary costs. The stimulus index l is determined as a linear combination of the explanatory variables. l* is assumed to be distributed normally N (0,1) and is equivalent to the disturbance term.

The conditional probability of crop success for a fixed level of l is given from the cumulative normal probability function in (2).

$$P(CPS = 1 \mid l) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{l = b_0 + b_1 x_1 + \ldots + b_n x_n} \exp \frac{-u^2}{2} du \quad \ldots\ldots (2)$$

In order to gauge the relative strength of the dependent variable it is useful to calculate predicted probabilities based on the estimated probit coefficients. One procedure for doing this for binary variables is to set all other variables at their arithmetic mean levels and then calculate probabilities from the cumulative normal distribution as the value of the binary variable of interest goes from 0.00 to 1.00. By repeating this procedure for each variable, we obtain a measure of the importance of each as a determinant of crop success. Thus, the criteria for interpreting the probit model focus on the consistency of signs of estimated coefficients, significance of asymptotic t values, and the magnitude of probability predictions for average or representative cases.

IV

EXPECTED DETERMINANTS OF CROP SUCCESS

It is perhaps easier to think in terms of crop success or the converse of crop failure, and we use crop success as a dependent variable. Crop success is hypothesized to depend on temporal, site specific, institutional, and management variables. The independent determinants explaining crop success (CPS) for plot j are specified in (3).[5]

$$CPS_j = f\ (VIL_j, YER_j, SES_j, SOL_j, IRR_j, CSY_j, e_j) \quad \ldots\ldots (3)$$

These variables are described in Table III with their expected signs. Crop success is assigned a one and crop failure receives a zero in the explana-

5. Alternative specifications that feature interactions do not change the results appreciably.

tory models. A positive sign for an estimated coefficient, therefore, is associated with increasing success and a negative sign with increasing failure. All independent variables are binary or 0-1; hence, their estimated coefficients imply additive shifts up or down from the intercept of the model. The size of the shift is interpreted relative to the first or reference category in Table III.

TABLE III—DESCRIPTION OF THE EXPECTED DETERMINANTS OF CROP SUCCESS

Explanatory variables	Frequency of plots (per cent)	Crop failure(*a*) Complete — Percentage of total plots	Crop failure(*a*) Partial — Percentage of total plots	Expected sign
Village				
Aurepalle	11·9	8·5	12·5	(*c*)
Dokur	9·9	3·2	4·7	+
Shirapur	22·8	22·3	26·2	—
Kalman	31·3	13·9	22·7	—
Kanzara	13·4	4·5	8·2	+
Kinkheda	10·7	2·7	5·4	+
Year				
1975-76	33·3	10·7	14·8	(*c*)
1976-77	33·2	11·8	13·0	?
1977-78	33·5	12·4	17·3	?
Season				
Kharif	58·0	13·2	18·9	(*c*)
Rabi	42·0	9·4	13·7	+
Soil				
Deep	9·2	8·6	16·3	(*c*)
Medium	43·2	9·1	14·6	—
Shallow	40·7	12·2	16·3	—
Poor(*b*)	6·9	28·5	33·1	—
Irrigation				
Non-irrigated	74·7	13·6	19·1	(*c*)
Irrigated	25·3	5·8	7·8	+
Cropping systems				
Sole	65·4	13·9	14·0	(*c*)
Intercropping(*d*)	34·6	7·2	21·8	?

(*a*) Refers to definitions 1(*a*) and 2(*a*) in Table I.
(*b*) Refers to gravelly and other soils.
(*c*) Indexes the binary variable of reference against which the other variables in the same category are evaluated.
(*d*) Intercropping also includes some plots that are mixed cropped.

The variables in equation (1) represent a continuum on a scale of what the farmer can and cannot control. Ideally, we want to place only pre-determined variables in equation (1); otherwise, the resource endowment determinants of crop failure condition the level of management and it becomes empirically difficult to discern what causes what. In the short run, farmers have little control over site (village), the weather (cropping year), soil type, and access to irrigation. They exercise more control over the choice of what type of (cropping system) and when (cropping season) to plant. Hence the specification in equation (1) implies strong causality for some variables and only perhaps correlation for others.[6]

The village dummy variables capture residual agro-climatic, biological, and site-specific effects that are not absorbed by the other variables. We would expect that the drought-prone villages of Shirapur and Kalman would have a higher incidence of crop failure than Aurepalle which in turn is a more unstable and heterogeneous production environment than Dokur. The two Akola villages, Kanzara and Kinkheda, embody more attributes for crop success than the other four villages.

Access to irrigation and deeper soils should enhance the prospects for success. Although it is less evident, we hypothesize that cropping in the *rabi* season when soil moisture is known is more dependable than cropping during the *kharif* season. The effects of the type of cropping system are less predictable and would appear to turn on the definition of crop failure.

V

EMPIRICAL RESULTS

The estimated probit results presented in Table IV are based on definitions of complete (1*a*) and partial crop failure (2*a*) given in Table I. Judging from the size of the values for the likelihood ratio test, the independent variables account for a considerable proportion of the variation in crop success. The signs of the estimated coefficients in Table IV are consistent with our expectations in Table III. There are sharp village level differences in determining crop success. The likelihood of crop success is significantly lower in the two drought-prone villages in Sholapur district compared with the reference village of Aurepalle.

The general level of statistical insignificance of the cropping year variables supports the hypothesis that weather in one cropping year was not sufficiently uniform to produce covariate outcomes in crop success across the six villages. In contrast, the positive association between cropping in the rainy season and crop failure comes through loud and clear. The chances for crop success are much higher during the *rabi* season. This result applies primarily to the drought-prone, deep black soil Sholapur region and supports the finding from base data analysis of agro-climatic and soils information that the probability of crop failure in the same region is markedly increased with rainy season cropping [Binswanger *et al.* (4)][7].

Access to irrigation significantly enhances the prospects for crop success. Even a small amount of irrigation from wells and tanks is valuable for safeguarding crop production. Likewise, deeper soils insure crop success. The

6. Two other determinants also suggested themselves, bunding and distance to the plot. They were statistically insignificant, consistently of the wrong sign, and were dropped early in the analysis.

7. The opposite result is obtained for the Mahbubnagar region where *rabi* cropping on red soils is not commonly practised and is exceedingly risky. The estimated cropping season coefficient is statistically significant at ($p \leq 0 \cdot 05$) in a regional probit specification. Therefore, the results on cropping season apply only to the Sholapur region. This was the only case where within-region results differed markedly from those obtained in a pooled analysis across regions.

TABLE IV—ESTIMATED PROBIT RESULTS OF THE DETERMINANTS OF CROP SUCCESS

Explanatory variables	Complete crop failure		Partial crop failure	
Constant	1·326		1·226	
Village				
(Aurepalle = 0)				
Dokur	0·405	(2·55)*	0·370	(2·60)*
Shirapur	—0·724	(—6·91)**	—0·701	(—7·17)**
Kalman	—0·477	(—4·67)**	—0·472	(—5·08)**
Kanzara	0·293	(2·08)*	0·445	(3·62)**
Kinkheda	0·499	(3·17)**	0·746	(5·67)**
Year				
(1975-76 = 0)				
1976-77	—0·064	(—0·91)	—0·123	(—1·94)
1977-78	—0·120	(—1·67)	—0·092	(—1·41)
Season				
(*Kharif* = 0)				
Rabi	0·561	(8·62)**	0·451	(7·56)**
Soil				
(Deep = 0)				
Medium	—0·178	(—1·58)	—0·049	(—0·51)
Shallow	—0·306	(—2·69)*	—0·096	(—0·97)
Poor	—0·480	(—3·56)**	—0·293	(—2·41)*
Irrigation				
(Non-irrigated = 0)				
Irrigated	0·468	(5·76)**	0·390	(5·25)**
Cropping system				
(Sole = 0)				
Intercrop	0·472	(6·61)**	—0·358	(—6·07)**
Likelihood ratio test	377·66		424·39	

Asymptotic t ratios are in parentheses; * and ** denote statistical significance at the 0·05 and 0·01 levels respectively.

size of the estimated coefficients suggest a soil gradient from deep to poor in relation to crop failure.

If definitions of complete crop failure are used to measure outcomes, intercropping is significantly associated with crop success. In contrast when partial crop failure of the first dominant crop is used as a yardstick, intercropping significantly contributes to failure. The truth probably lies somewhere in between as either definition biases the odds in favour of rejecting the null hypothesis that intercropping or sole stands lead to equal probabilities of success. Conflicting results that hinge on the choice of the dependent variable strongly suggest that we are not picking up the effect of intercropping *per se* but rather the impact of diversification within a plot when we change definitions.

Predicted probabilities of crop failure are calculated with the methodology outlined in Section III and are presented in Table V. Note that this discussion is in terms of estimated probabilities of crop failure that are calculated by subtracting the estimated probabilities of crop success from one. The village

TABLE V—PREDICTED PROBABILITIES OF CROP FAILURE

Explanatory variables	Complete crop failure		Partial crop failure	
	Predicted probability	Percentage change*	Predicted probability	Percentage change*
Village				
Aurepalle	0·061	—	0·108	—
Dokur	0·026	—50·0	0·054	—54·5
Shirapur	0·206	250·0	0·295	172·7
Kalman	0·142	150·0	0·221	100·0
Kanzara	0·033	—50·0	0·047	—54·5
Kinkheda	0·021	66·7	0·024	—81·8
Year				
1975-76	0·076	—	0·119	—
1976-77	0·087	12·5	0·147	23·1
1977-78	0·095	12·5	0·140	16·7
Season				
Kharif	0·129	—	0·180	—
Rabi	0·046	—61·5	0·085	—50·0
Soil				
Deep	0·055	—	0·100	—
Medium	0·078	33·3	0·127	27·0
Shallow	0·099	66·7	0·134	34·0
Poor	0·131	116·7	0·187	87·0
Irrigation				
Non-irrigated	0·106	—	0·136	—
Irrigated	0·043	—63·6	0·068	—50·0
Cropping system				
Sole	0·115	—	0·109	—
Intercrop	0·048	—58·3	0·192	72·7

* With respect to the binary variable of referene.

binary variables are the most influential determinants of crop failure. In going from Aurepalle to Shirapur, the probability of complete crop failure increases from 0.06 to 0.21. For complete crop failure, it is ten times more likely that the dominant crop will not be harvested in a plot in Shirapur than in Kinkheda. For partial crop failure, the difference is even greater. These are truly large predicted differences given only about a 100 millimetre difference in average rainfall between the two villages over the three cropping years.

An abrupt change from a deep to a poor soil is accompanied by about a 140 per cent increase in the predicted incidence of crop failure. In terms of size of effects, planting in the *rabi* season, irrigation, and intercropping substantially reduce the likelihood of complete crop failure. Predictions for partial crop failure are less sensitive to changes in soil quality, and intercropping is associated with considerably higher probabilities of non-harvest of grain from the dominant crop.

VI

CONCLUDING COMMENTS AND TECHNOLOGICAL IMPLICATIONS

Crop failure was a relatively frequent visitor to farmers' fields in the Semi-Arid Tropics of peninsular India. The mean incidence of complete crop failure for the 3,805 fields planted by the 180 farm households in our six village, three-region sample was about 12 per cent from 1975-76 to 1977-78.[8] Still, this estimate may seem low for the Semi-Arid Tropics. The low opportunity cost of labour is probably one reason why many fields were harvested despite exceedingly low yields.

Intercropping appears to be a perfect hedge against complete crop failure, but specific components in intercrops and mixtures are frequently not harvested. The empirical probability that one or more crops failed in an intercrop or mixture averaged 0.27 across the three regions.

The analysis of crop failure reinforces and deepens our knowledge about the prospects for *kharif* cropping in the drought-prone deep vertisol areas typical of the Sholapur villages. Planting in the *rabi* season on inferior soil was less risky than sowing in the rainy season on deep soil. Farmers were better off (in terms of crop failure) to fallow in the rainy season and crop in the post-rainy season. Therefore, increased crop productivity in dryland agriculture in the Sholapur region will have to come through improvements in *rabi* cropping systems.

Subtle agro-climatic differences within the Semi-Arid Tropics are responsible for sharp differences in the incidence of crop failure. The estimated results generate probabilities of complete and partial crop failure of 0.02 for Kinkheda. Comparable predicted probabilities for Shirapur are ten to twelve times higher, yet over the three cropping years rainfall in Kinkheda exceeded that in Shirapur by only about 100 millimetres. These predictions are consistent with the observations on disparities in fertilizer adoption between the two regions [Jha and Sarin (8)] and underscore the potential for financial risk to constrain investment in improved practices in the Sholapur region. They also yield the inference that technology has to be more rigorously tested both across space and time in the Sholapur region.

The difference in inter-village effects highlights a recurring theme in agricultural development—disparities in regional resource endowments often play a much more important role in conditioning consequences in socio-economic and agronomic dimensions than differences in endowments within a village.

8. Data are available to carry out an analysis with data from 1975-76 to 1979-80 for three of the six villages. The addition of two more cropping years—1979-80 was a drought year—does not significantly change our findings. In a severe drought year we would expect more crop failure, but the opportunity cost of harvest labour would also be lower; thus, for a given yield level it is more likely that a plot would be harvested in a drought relative to a good rainfall year.

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