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RISK, RECIPROCITY AND CONDITIONAL SELF-INSURANCE IN THE SAHEL: MEASUREMENT AND IMPLICATIONS FOR THE TRAJECTORY OF AGRICULTURAL DEVELOPMENT IN WEST AFRICA

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Abstract

Using panel data from Burkina Faso, this paper estimates the severity of specific and covariate agricultural risks in West Africa, and the effectiveness of self-insurance and reciprocity devices in reducing it. The estimates are used to bracket the impact of risk on the likely agricultural development trajectories in West Africa. The magnitudes of the estimated risks, and the likelihood that development will take place in an institutional environment of greater individual vulnerability, supports a presumptive case for public intervention in the sphere of risk management to avoid a stunted and perhaps socially unstable agrarian growth trajectory.

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Risk, Reciprocity and Conditional Self-Insurance in the Sahel:
Measurement and Implications for the Trajectory
of Agricultural Development in West Africa

Risk, variously defined and infrequently measured, finds its way into most discussions about agricultural development in the arid, rainfed areas of Sub-Saharan Africa. In these discussions, risk derives its importance from one of two principal preoccupations. The first is a *production-minded* preoccupation that risk will blunt adoption of the technologies, strategies of specialization, etc. necessary to get agriculture moving, even if "prices are right" (e.g., see Platteau 1990, Bromley and Chavas 1989). The second is a *distributional or class differentiation* preoccupation that within a liberalized market economy, risk becomes a mechanism which perpetuates and deepens the poverty and food insecurity of some individuals, perhaps even as aggregate food availability improves (e.g., Watts 1983, Carter 1988).

These two preoccupations are not mutually exclusive. Superficially, they share the common concern that a neo-liberal twist to agricultural policy is insufficient to resolve the Sub-Saharan food crisis. At a deeper level, the two preoccupations are more intimately interrelated. In a pair of compellingly straightforward theoretical papers, Eswaran and Kotwal (1986, 1989) argue that in an economy characterized by the insurance and capital market imperfections typical of rainfed agriculture (see Binswanger and McIntire 1987), an identical technological opportunity presents an *objectively* greater (consumption) risk to a poorly endowed than to a wealthy individual. Confronted by different risk, the individuals' behavior in the sphere of production bifurcates, crystallizing initial wealth differences into a class differentiation with its implications for the rate and distributional pattern of accumulation and growth.

The goals of this paper are two. This first is the fundamental empirical task of operationalizing and measuring extant levels of agricultural risk and risk management using a panel dataset collected by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in Burkina Faso. This empirical measurement complements other work on risk management in low income agrarian economies and tests economic anthropology propositions about the functionality of self-insurance and extended family reciprocity.[1] Throughout the empirical analysis, the focus is maintained on how risk varies according to objective circumstance (endowments, markets, tenure rules, social structure). This focus is predicated on the notion that, absent complete capital and insurance markets, variability in objective risk across individuals, is of greater significance for the development trajectory of the agrarian economy than is variability in individuals' subjective fear of a given objective risk.[2]

This paper's second goal is to develop the implications of the risk measurement for both the production-minded and the differentiation preoccupations about the trajectory of agricultural development. Because the analysis here is not linked to a model of behavior, it does not pretend to yield final a answer on rate and distributive consequences of nature of agrarian growth trajectory.[3] Nonetheless, the analysis makes an empirically compelling case for the significance of risk, underwriting the presumptive case, expressed by Platteau and others, for a public role in promoting risk management.

Section 1 below defines the elemental components of risk (specific and covariate), and of risk management (self-insurance, and endogenously or exogenously enforced horizontal and vertical reciprocity). Section 1 also functionally specifies the stochastic structures to be estimated here. Section 2 then econometrically estimates the distributions for covariate and specific risk components, and uses them to construct the joint distributions which determine returns to agricultural activities. Section 3 evaluates the objective risk exposure, expected utility value and social costs for alternative self-insurance and reciprocity portfolios. Section 4 draws together the empirical results, doubling emphasizing the severity of underlying agro-climatic risk, and the relative effectiveness of the reciprocity and conditional self-insurance which are embedded in traditional social structure. Under assumptions about the longevity and replaceability of those forms of risk management, Section 4 then closes the paper with consideration of risk's magnitude and its potential for blocking production increases and for powering problematic processes of class differentiation.

SECTION 1 COMPONENTS OF RISK AND RISK MANAGEMENT

Poor soils and rainfall levels which are meager and highly variable conspire to create a risky agricultural environment in the West African semi-arid tropics. Figures 1 and 2 display measures of that risk under current technologies for two West African environments: the Southern Sahel, and the Sahel-Savannah Transition Zone (data and estimation procedures are detailed below). The plotted (joint) cumulative density functions show the probability that per-hectare yields for a single field of the indicated crop will fall below the amounts shown on the horizontal axis. The dashed vertical line in each figure marks the grain yields necessary to provide physical subsistence given the number of consumer equivalents per-cultivated hectare on the average production unit.

Despite *average* yields which are at least 50% higher than these subsistence requirements, Figures 1 and 2 show that a socially and economically isolated household cropping a single large field of the dominant grain crop (millet in the Sahel, sorghum in the Transition Zone) would face a 24% probability of a subsistence shortfall in the Sahel, and a 20% probability in the Transition Zone. While maize, a third cereal grown by nearly all households in the regions, dominates yields of the other cereal crops, the extent of its adoption is limited by resource constraints. As can be seen in Table 1, maize cultivation takes place only on tiny plots, close to the household residence where relatively high dosages of labor and animal fertilizers can be applied. The other cereal crops (sorghum in the Sahel, millet in the Transitional zone) present the tradeoffs with the dominant cereal crop which are apparent in Figures 1 and 2.

Any production unit which year-after-year faced a 20% starvation risk, would presumably not persist for long, much less adopt risky high-yielding varieties. In reality, of course, despite the absence of formal insurance and capital markets, production units employ a variety of non-market devices and income diversification strategies to manage this potentially overwhelming risk. Indeed, the social boundaries of the stylized West African rural consumption unit are more extensive than those of the production unit, reflecting the fact that the individual's consumption is not limited to the output realized by his or her production unit. In recognition of these non-overlapping boundaries which invalidate the conventional concept of peasant household as a unified production/consumption unit, this study takes as its basic unit of analysis the production unit, augmenting its boundaries as appropriate when consumption issues are discussed.

Within the peasant economy literature, there is a tendency to sharply divide the menu of possible non-market insurance instruments into individualistic *agricultural self-insurance* and morally-sanctioned *reciprocity* devices (Platteau 1990). However, this bifurcation is potentially misleading for two reasons. First, self-insurance devices (e.g., field scattering, variety diversification) are in general *endowment-dependent*, meaning that access to particular kinds of land or other endowments are necessary to use them. In order to stress that dependency, which creates an interface between self-insurance and the rules and norms of resource access, the term *Conditional Self-Insurance* will be utilized here.

Second, it is also misleading to describe reciprocity as necessarily or exclusively dependent on "moral economy" or other norms for their functioning. Following Coate and Ravallion (1989), it is useful to distinguish between *exogenously* versus *endogenously* enforced reciprocity. Under exogenously enforced reciprocity, sharing rules are enforced by some internalized or externally enforced social norms. Put differently, exogenous sharing rules need not be incentive compatible with narrowly self-interested utility maximization, meaning that absent enforcement, self-interested individuals would have incentives to shirk their duty to share with the less fortunate. By contrast, endogenously enforced reciprocity denotes rules which are self-enforcing and incentive compatible. In Coate and Ravallion's analysis, the latter yields markedly lower levels of sharing than exogenously enforced reciprocity.

Section 4 below returns to questions of non-market insurance devices, their embeddedness in traditional social structure and their reproducibility in transitional market economies. The remainder of this section, and Sections 2 and 3 which follow, explore the potential effectiveness of conditional self-insurance and reciprocity given the magnitude and structure of risk in West African agriculture.

1.1 Covariate and Specific Components of Risk

The data for this study come from a three year survey of agricultural producers in two agro-ecological regions in Burkina Faso.[4] The Djibo region in northern Burkina Faso is part of the southern Sahel, and the Yako region is best described as a transition zone between the Sahel and the Sudanian savanna of southern Burkina Faso. In each region, random samples of 25 producers were selected from each of two (purposefully selected) villages.[5] Detailed input-output data were gathered on a weekly basis for all major agricultural fields of each producer for the period 1981-1983.[6]

Typical of the southern Sahel, the Djibo region is characterized by a long term average of 400-600 millimeters of total annual rainfall, and a rainy season of 3 to 5 months. As can be seen in Table 1, the principal crop is millet (93% of cropped area), which is frequently intercropped with cowpea. Almost all work in the Djibo region is done by hand-tool, with some isolated use of animal traction. There are few opportunities for cash cropping and livestock production is of major importance in the region.

The transitional Yako region has a long term average total annual rainfall of 600-800 millimeters distributed over 4 to 5 months. Because of more favorable environmental conditions, sorghum plays a more dominant role here than in the Sahel. White sorghum and millet, often intercropped with cowpea, are the major crops in terms of cultivated area. Maize is also grown. Groundnuts and, to a lesser extent, cotton serve as cash crop. Donkey drawn ploughs and weeders have been distributed in the area since the 1960's, but the actual use of animal traction equipment is low in this area. Increasing population pressure in this region has been associated with the gradual deterioration of the bush fallow system, and a general deterioration of soils.

Table 2 presents mean annual yields and cropping season rainfall data[7] for the 1981-1983 sample period. 1982 was a year of severe drought; 1983 had close to normal rainfall levels; and, 1981 was intermediate to 1982 and 1983 in terms of rainfall. The resulting year-to-year, or inter-annual, variation in yields is apparent in Table 2. Mean annual millet yields in the Sahel, for example, ranged from a low of 205 kilograms per-hectare in 1982 to a high of 504 in 1981.

In addition to its inter-annual variability which creates a *covariate risk* across fields and production units, rainfall is also variable spatially within years. The short and localized heavy rain-torrents characteristic of this region create intra-annual rainfall variation not only between agro-climatic zones, but also between villages and even between fields within a village. Within a drought year, some fields can receive relatively adequate moisture, while in years of better average rainfall, some fields may suffer localized water shortfalls or other microclimatic misfortune. Some portion of the variation around annual means shown by the standard deviations in Table 2 reflects this intra-annual or spatial rainfall variability within villages which creates a *specific risk* which is uncorrelated across fields and households. Specific risk is further augmented by illness and other misfortune which limits individuals' work capacity, as Udry emphasizes.

Using conventional analysis of variance notation, realized yields on cross-sectional unit "i" in year "t" can be expressed as the sum of two orthogonal components:

$$y_{it}= \bar{Y}_t + \varepsilon_{it}. \tag{1}$$

Note that $\bar{Y}_t$ captures the covariate risk across fields and production units (e.g., year "t" might exhibit severe drought and low average yields?). The residual ε_{it} includes the specific risk (reflecting intra-annual or spatial variation in rainfall and other microclimatic factors) which determines whether unit "i" does better or worse than the mean annual yield. While uncorrelated with $\bar{Y}_t$, higher moments of ε's distribution would in general be expected to vary with $\bar{Y}_t$, or the conditions which generate it. For example, in a year of severe drought and a near zero $\bar{Y}_t$, the variance of ε would be expected to be quite low.

As written, expression (1) lumps all deviations between realized and unconditional mean yields into the single residual component "ε". Interpreting ε as a measure of specific risk would, however, overstates the magnitude of specific risk. Some portion of the deviation between realized and unconditional mean annual yields would be non-stochastic to the production unit, reflecting systematic differences between cross-sectional units in terms of production unit resource and skill endowments, and quality characteristics of the land they cultivate. Expression (1) can be appropriately modified by redefining $\bar{Y}_t$ as a (conditional) mean annual yield ("MAY") function,

$$y_{it} = \bar{Y}_t\,(\theta_t | e_{it}, f_{it}) + \varepsilon_{it}. \tag{1'}$$

where the function $\bar{Y}_t$ defines mean annual yields as a function of the stochastic <u>village-level</u> annual rainfall of "θ_t", controlling for characteristics of the cross-sectional unit of observation. For any given village rainfall realization, mean or expected yields will differ according to characteristics (which may or may not be constant over time) of the cross-sectional unit. The vector f_{it} represents land characteristics, such as toposeqeunce position and distance from the residence[8], and e_{it} measures production unit endowments of labor time, farming skill, etc. The residual "ε_{it}" remains a specific risk component, orthogonal to, but not independently distributed of, $\bar{Y}_t$.

1.2 Distributional Specification of Risk and Yields

In the analysis which follows, the random variables "Θ" and "ε" are assumed to respectively have the following marginal and conditional distributions:

$$\theta \sim \Gamma[\alpha(t), \beta(t)]\,, \tag{3}$$

$$\varepsilon | \theta \sim N[0, \sigma^2(\theta, f)]. \tag{4}$$

Let $f_\theta(\cdot)$ and $f_\varepsilon(\cdot)$ denote the probability density functions for these distributions. Note that the rainfall distribution is specified to vary over time as the gamma distribution function parameters, α and β, are expressed as functions of the historical year "t". This time-varying specification allows for the possibility of diminishing rainfall and desertification in the Sahelian region. The specific risk component, ε, is heteroscedastically normal, with its variance conditional on the realized value of θ as well as of characteristics of the cross-sectional unit of observation. While not independent (because of this heteroscedasticity), θ and ε are uncorrelated as specified above.

At a given point in historical time, fixing $\alpha(t)$ and $\beta(t)$ at values α^* and β^*, and given the definition of $\bar{Y}_t$ and expression (3), the probability density function for Mean Annual Yields is:

$$f_{\bar{y}}(\bar{y}) \begin{cases} = \Sigma_{k=1}^{m(\bar{y})} f_{\Theta}(\theta_k)|\partial\bar{Y}(\theta_k)/\partial\theta|^{-1}, & \text{if } m(\bar{y}) > 0 \\ = 0, & \text{if } m(\bar{y})=0, \end{cases} \tag{5}$$

where $m(\bar{y})$ is the non-negative integer which counts the number of rainfall values, $\theta_1(\bar{y})$, $\theta_2(\bar{y})$,..., $\theta_m(\bar{y})$, for which it is true that

$\bar{Y}(\theta_k(\bar{y}))= \bar{y}$; and ,

$\partial\bar{Y}(\theta_k)/\partial\theta \neq 0$.

Note that if $\bar{Y}(\cdot)$ is monotonic, $m(\bar{y})=1$ and the right hand side of (5) reduces to $f_{\Theta}(\theta_k)|\partial\bar{Y}(\theta_k)/\partial\theta|^{-1}$. In the empirical analysis which follows, only the estimated MAY function for millet is non-monotonic over the relevant rainfall range.

Realized plot yields are the sum of $\bar{Y}_t$ and ε and the joint distribution of these two random variables can be expressed as the product of their respective marginal and conditional distributions:

$$\begin{aligned} f(\bar{y}, \varepsilon) &= [f_{\bar{y}}(\bar{y})][f_{\varepsilon}(\varepsilon|\bar{y})] \\ &= \Sigma_{k=1}^{m(\bar{y})} \{ f_{\theta}(\theta_k)|\partial\bar{Y}(\theta_k)/\partial\theta|^{-1} \} \{f_{\varepsilon}(\varepsilon|\theta_k)\} . \end{aligned} \tag{6}$$

Finally, using (1) which defines realized yields, y_{it}, as the sum of the two random variables, the distribution of yields, $f(y_{it})$, can be expressed as the convolution of the distributions given on the right hand side of (6):

$$f(y_{it}) = \int f_{\varepsilon}(y-z|z)f_{\bar{y}}(z)\, dz \tag{7}$$

For expository purposes, it will sometimes be useful to refer to variance components (or second moments of the distributions discussed above) rather than to the distributions themselves. Under the assumptions made above and suppressing the notation indicating conditioning on field quality and production unit endowments, the variance in yield can be written as:

$$V(y_{it})= (\sigma^2)^s + (\sigma^2)^c \tag{8}$$

where

$$(\sigma^2)^s = E_t\{E[y_{it} - Y_t]^2\} \tag{8a}$$

$$(\sigma^2)^c = E_t[\bar{Y}_t - \mu]^2 \tag{8b}$$

$$\mu = E_t[\bar{Y}_t] \tag{8c}$$

where $(\sigma^2)^c$ is the inter-temporal variance of mean annual yields around the long term mean μ defined over the distribution $f_{\bar{y}}(\bar{y})$ given in (5) above, and $(\sigma^2)^s$ is the expected value of the cross-sectional variance around the mean annual yield. Finally, suppressing the notation for production unit and year, the variance for a portfolio composed of claims to two real income streams $[y_1 + y_2]$ can be written as:

$$\mathrm{Var}\{[y_1 + y_2]\} = \{(\sigma_1^2)^c + (\sigma_2^2)^c + 2\rho^c \sqrt{(\sigma_1)^c(\sigma_2)^c}\} + \{(\sigma_1^2)^s + (\sigma_2^2)^s + 2\rho^s \sqrt{(\sigma_1)^s(\sigma_2)^s}\} \tag{9}$$

where ρ^c and ρ^t respectively are the covariate (interannual) and specific (intra-annual) risk correlation coefficients. As is apparent in (9), total portfolio variance is reduced by adding entitlements to the portfolio which either themselves have intrinsically stable returns (low σ_2^2), or exhibit low or even negative inter-temporal or intra-annual correlation with other activities in the portfolio. The size and sign of the variance-covariance components for the activities and entitlements available to the production unit under conditional self-insurance and reciprocity ultimately determine the prospects for risk management.

1.3 Tactics and Costs of Risk Management: Self-Insurance and Reciprocity

Conditional self-insurance operates by allocating resources to a variety of uses which successfully diversify the unit's real income stream. Conceptually, it is useful to distinguish between two diversification tactics:

> *Activity Diversification* in which resources are allocated to different activities which respond differently to the *same* stochastic shocks.
>
> *Environment Diversification* in which the *same* activity is pursued in independent environments and therefore experiences different stochastic shocks.

Examples of activity diversification are inter-cropping two crops on the same field to diversify against specific, micro-climatic risk (low ρ^s in notation of expression (9) above), and non-specialized production patterns in which different fields are placed in different crops which respond differently to co-variate risk (low ρ^c, e.g., millet fields do on average relatively well in low moisture yields, while sorghum fields do relatively better in years of higher moisture). Field-scattering across micro-climates and topographical niches is an example of environment diversification against specific, or intra-annual risk ($\rho^s = 0$). Environmental diversification against covariate risk is possible only by inter-temporal savings devices which carry forward in time yield achieved under one annual macro environment to another.

The endowment dependence, or conditionality, of self-insurance mentioned in the introduction to this section should now be clear. Production units can only pursue activity and environment diversification to the extent they have access to the qualities and quantities of land needed to grow different crops in different places. As Section 4 below discusses, traditional tenure systems seem to guarantee access to that diverse resource base, at least for recognized members of the relevant social group. The ability of individuals to maintain resource diversity in a market environment is less certain.

As a substitute for the full and complete markets which would--if they existed--permit risk to be independently insured and resources to be allocated to maximize income, the cost of conditional self-insurance appears as the reduction in the expected returns to production which results when resources are allocated to meet insurance goals. Intercropping, as an activity diversification tactic, has been hypothesized to stabilize returns at the cost of reduced yields because of moisture competition between intercropped plants (see Norman's 1975 discussion). Adoption of non-specialized, multiple crop production patterns will have a positive cost if there are gains to be had (on average) from specialization, or if some crops included in the self-insurance crop mix exhibit, *ceteris paribus*, lower mean returns. Finally, the widely observed environment diversification tactic of field scattering fields potentially has costs in the form of labor time lost in travelling from field-to-field, and in any failure to equalize marginal returns to different factors of production (e.g., fertilizer) because of transport costs barriers. These latter considerations suggest that for a given level of resources, output by the production unit will decline as field scattering increases.

Reciprocity schemes, be they exogenously or endogenously enforced (see the discussion above), can be described as vertical or horizontal. *Horizontal reciprocity* refers to conditional sharing rules between units with approximately equal endowments. Horizontal reciprocity essentially extends the resource base over which the resource allocation tactics of self-insurance can be pursued. Horizontal reciprocity would permit the group to enjoy benefits of field scattering at lower cost in terms of lost labor time and transport costs (i.e., fields could be scattered across individuals in the group even as each individual cultivates a single contiguous field). The costs associated with the activity diversification tactics discussed above would still occur under self-insurance. In addition, to the extent that reciprocity works like a marginal tax on supra-normal output levels, it would depress work incentives and potentially have a cost in the form of reduced mean output.

Vertical reciprocity (or redistribution) refers to sharing between unequally endowed units. Patron-client and caste systems are examples of vertical reciprocity schemes which exhibit what might be called *conditional inequality*, meaning that in good years, the patron fully privately appropriates the surplus generated by his or her relatively abundant resources, but shares the surplus in bad years (see Scott and Kerkleviet 1973, Epstein 1965, Platteau 1989 for examples). Note that conditional inequality can cushion the covariate risk which can be difficult to deal with on a horizontal reciprocity or self-insurance basis.

In West Africa, compound heads (where a compound is a lineage-based grouping of production and consumption units) enjoy a sort of conditional inequality. Typically these heads organize and control production on communal or compound fields, drawing on the labor of subordinate units. While the head controls the output of these fields, his or her control is circumscribed by obligations to help subordinate units. While compound fields might be viewed as an incentive compatible way to actually implement horizontal reciprocity among equal farm units (Binswanger and McIntire 1987), it will be here treated as a form of vertical reciprocity in which the compound head conditionally owns the compound fields. While primarily a matter of semantics for purposes here, this labelling reflects the observation that compound fields are sometimes appropriated as private property by compound heads as communal tenure systems breakdown and land rights are privatized, crystallizing a modest degree of initial asset inequality.

The cost of vertical reciprocity as insurance depends on two sets of incentive factors:

(1) Those which affect the relative economic efficiency of production on communal fields; and,

(2) Those which affect returns (to the relevant decisionmaker) of longer term investment in communal lands.

While the econometric analysis in subsequent sections does attempt to estimate the costs and net-benefits (in utility terms) of conditional self-insurance, the potential disincentive costs associated with both horizontal and vertical reciprocity insurance cannot be measured. Instead, the analysis will only be able to explore the benefits attainable when reciprocity devices are added to observed patterns of conditional self-insurance.

SECTION 2 ECONOMETRIC ANALYSIS OF RISK IN THE SAHELIAN AND TRANSITIONAL ZONES OF BURKINA FASO

This section proceeds in three steps to estimate the yield density functions (7) for the three basic agricultural activities (millet, sorghum and maize production) available to West African Transition Zone and Sahelian producers:

1. Longer term historical rainfall data will be used to estimate the rainfall distribution (3).
2. The mean annual yield predictor function, $\bar{Y}_t$ in (2) above, will be estimated as an envelope or predictor function using the panel dataset described above. Together with the results of Step 1, these estimates will be used to derive the distribution of mean annual yields, $f(\bar{Y})$ given in (5).
3. Finally, the distribution of the specific risk component will be estimated as the residual of a production function regression. Convolution of this distribution with that generated by Step 2 will yield the final yield density functions shown in (7) above.

Along the way, the impact of inter-cropping and the costs of field scattering will be explored. Section 3 below will employ these estimates to explore the effectiveness and value of conditional self-insurance and reciprocity.

2.1 Probability Estimates of West African Rainfall

Rainfall station data for the Sahelian and Transition Zones of Burkina Faso is available for the periods 1951 to 1982 and 1942 to 1979, respectively. The data report average rainfall for the 26 fortnights in each year. For each region crop (millet, sorghum and maize), the rainfall data were aggregated to crop season rainfall measures by summing the rainfall between the average planting and harvest dates for each crop. Average planting and harvest dates for millet and sorghum fall in the same fortnights, making the data for those two crops indistinguishable. Maize has a slightly shorter cropping season.

As expressed by (3), total relative rainfall is assumed to be generated by a gamma distribution. This specification eliminates non-negative values and admits a variety of plausible shapes for the rainfall density function. As mentioned above, the two parameters of the gamma distribution were permitted to vary over time according to the following specification:

$$\alpha(t)= [\alpha_0 - \alpha_1(\ln(t))]^2 \tag{9a}$$

$$\beta(t)= [\beta_0 - \beta_1(\ln(t))]^2 \tag{9b}$$

Permitting both the "shape" (β) and "scale" (α) parameters to shift with "t", allows both the mean and skewness of the rainfall distribution to vary over time. The particular functional forms given in (9a-b) were chosen as the best-fitting among a range of similarly simple functional forms.

Table 3 displays the results of the maximum likelihood estimates for the relative rainfall distribution for millet and sorghum in the two regions. In both regions the mode of the estimated rainfall density function has shifted back over time, with the distributions becoming slightly more skewed rightwards. In the Sahel, the underlying parameters are all statistically significant at conventional confidence levels as judged by the asymptotic t-statistics in Table 3.Results for the maize cropping season rainfall data are nearly identical to those shown in Table 3. Figure 3, discussed in detail in the next section, displays the shape of the estimated density functions when the time-varying parameters α and β are set to their values for 1980.

2.2 *Estimation of Mean Annual Yields and Intertemporal or Covariate Risk*

The Mean Annual Yield function given in (2) above defines as a function of annual village-level rainfall the mean yields attainable on a field of given physical characteristics, when cultivated by a production unit with given resource endowments. As such, the function predicts mean yields given rainfall (*and* whatever endogenous variable input reactions households make to it), and does not identify the marginal impact of rain holding variable input choice constant. In yield-rainfall space, the Mean Annual Yield function can be conceptualized as the outer envelope of the *ceterius paribus* production functions defined for given levels of variable inputs.[9]

As indicated in section 1.1 above, the three years covered by the data collection exhibited rather different rainfall patterns. The basic rainfall measures are village-specific, although for the statistical analysis they are adjusted to a field-specific cropping season rainfall measure based on the field's planting and harvesting date. Additional rainfall variation was added to the regression analysis by pooling matching data collected by ICRISAT from two villages in southern Burkina Faso's rainier, Savannah Zone (average total annual rainfall of 1000 mm).

As the goal of the MAY function estimates is to obtain "reasonable-appearing" yield-rainfall functions within the confines of the available (finite) sample, rather than to test hypotheses about specific parameters, a non-classical regression strategy was employed.

The regression strategy began with the following specification of the predictor function <u>for each crop</u>:

$$E[y_{it}] = [\delta_{0i} + \delta_1(S_{it})] + [\delta_2(Ic_{it}) + \delta_3'(Ts_{it}) + \delta_4(Pl_{it}) + \delta_5(Dp_{it})] +$$

$$[\delta_6(\theta_t) + \delta_7(Ic_{it}\theta_t) + \delta_8(\theta^2_t) + \delta_9(Ic_{it}\theta^2_t) + \delta_{10}(\theta^3_t) + \delta_{11}(Ic_{it}\theta^3_t)] \qquad (10)$$

where the three groups of variables in square brackets represent:

1. *Household Endowments*

δ_{0i} is a production unit-specific "fixed effect" which is likely to capture household attributes like labor endowment and farming skill which change little over time;

S_{it} is a Simpson index of land dispersion defined as

$$S_{it} = 1 - \Sigma(a_{it}^2/A^2)$$

where $A = \Sigma(a_{it})$ and the summations are across all fields, regardless of crop, cultivated by production unit "i" within year "t" (note 3 discusses the data's unconventional panel structure). The index takes the value of zero when cultivation takes place on a single field, and approaches one as the number of fields becomes large. Mean value of index in sample is 0.81 in the Transition Zone and 0.68 in the Sahel. This use of the Simpson index follows Blarel *et al.* (1990).

2. *Field Characteristics*

Ic_{it} is a dummy variable which equals one when the field is intercropped, typically with a legume.

Ts_{it} is a <u>vector</u> of two dummy variables indicating position of the field in the toposequence (see note 5). The first dummy variable (Topo1 in Table 4) indicates fields located in low laying areas which tend to collect moisture; the second, Topo2 indicates mid-slope fields, while the excluded category is for upper slope fields most prone to drought.

Pl_{it} is a <u>vector</u> of two dummy variables indicating the place or position of the field in the "ring management" sequence (see note 5). The first dummy variable (Place1 in Table 4) indicates compound fields close to production unit's residence; the second indicates village fields, a bit more distant from the residence compound; and, the excluded category is distant bush fields.

Dp_{it} is date of planting for the field calculated as the number of days the field was planted after March 1 of year "t".

3. *Macro-Environment*

θ_t, as before is a cropping season rainfall, measured at the village level for year "t" and adjusted on a field-specific basis according to the field's planting date.

$Ic_{it}\theta_t$ interaction terms are included to test the notion that intercropping stabilizes (flattens) the yield-rain relationship.

Finally, output per-hectare, y_{it}, is a relative price-weighted measure of the total output on the field. The price weights equals one for the grain output (millet, sorghum or maize) and p_l/p_g for the output of the intercrop, where p_l is the price of cowpeas and p_g is the price of the field's grain crop.

The residual error associated with (10), $\varepsilon_{it}= y_{it}- E[y_{it}]$, is assumed to be independently distributed across observations with the following heteroscedastic specification:

$$E[\varepsilon^2]=\sigma^2(\theta_t, f_{it}) = (\gamma' z)^2, \text{ or} \tag{11}$$

$$E[|\varepsilon|] = c\gamma' z, \tag{11'}$$

where "c" is a constant which equals $\sqrt{(2/\pi)}$ under the normality assumption made in (4) above (see Judge *et al.*). The z variables hypothesized to affect the magnitude of residual variation are:

Field size, reflecting the likelihood that relatively modest measurement errors on small fields translate into large errors in per-hectare yield basis.

Intercropping, Ic_{it} which as a form of activity diversification may be expected to reduce the magnitude of specific risk as reflected in the residual variation.

Village Rainfall, θ_t, which should relate inversely to the magnitude of specific risk.

Estimation of (10) and (11') followed a four stage, double GLS procedure.[10]

GLS estimation of (10) produced a "reasonable-appearing" mean yield-rainfall relationship for millet and maize. Table 4 presents these GLS results for millet, and Figure 3 graphs the fitted value of the millet MAY regression function holding all variables except rainfall at their mean value for the Sahelian production units. The maize results in Tables 4 and Figure 3 are a restricted version of (10) in which all production unit fixed-effects were constrained to be identical within villages. This restriction gave a modestly more reasonable maize-rain relationship over the range of very low rainfall.

GLS estimation of (10) for sorghum generated coefficients which suggested that mean yields *increase* dramatically as rain falls below 200 mm. Such a relationship is obviously not agronomically possible, and use of that GLS-estimated relationship would seriously overstate the insurance value of sorghum production. In an effort to obtain more reasonable finite sample estimates, mean absolute deviation regression results were used as starting estimates for the iterative outlier-trimming procedure which generated the sorghum estimates displayed in Table 4 and Figure 3.[11]

Overlaid on Figure 3 are the estimated 1980 rainfall probability density functions for the two zones. As can be seen, for nearly all probable rainfall levels in the Sahel, predicted mean yields for millet exceed those for sorghum. For the Transition Zone, the mean annual yield functions for millet and sorghum cross near the mode of that region's rainfall probability function. Millet provides steady, if unspectacular mean yields over low ranges of the rainfall distribution, while mean sorghum yields quickly outpace the falling millet yields over the higher ranges of the rainfall distribution.

Table 5 presents simulation results which demonstrate the prospect for effective activity diversification against covariate or inter-temporal risk using crop mixes in the Transition Zone. The inter-temporal correlation coefficients reported in Table 5 were calculated on the basis of simulated long term (1000 year) rainfall time series. Each year in the simulated time series was generated by a random draw from the estimated 1980 rainfall density functions for each zone. The estimated Mean Annual Yield regression functions were used to calculate a corresponding 1000 year simulated time series of mean yields. The statistics in Table 5 are descriptive statistics calculated from these simulated time series. The lack of diversification prospects against inter-temporal risk in the Sahel is seen in the inter-temporal correlation coefficients (ρ^c in equation 9 above) which are in the range of 0.92 to 0.99. By contrast, millet actually exhibits *negative* intertemporal correlation with sorghum and maize in the Transition Zone.

Inter-cropping, as another form of activity diversification within a given macro-environment, was specified to shift the yield-rainfall relationship. However, it proved impossible to precisely identify the impact, if any, of inter-cropping on mean yield stability and covariate intertemporal risk.[12] The impact of inter-cropping on specific risk will be discussed in the next section.

Controlling for household endowments and other fixed effects, the coefficient on the Simpson land deconcentration index should indicate the cost of field scattering. The coefficients reported in Table 4 are all negative as expected, with values in the range of -127 to -583, indicating per-hectare yield declines of about two thirds of those magnitudes for a production unit which went from a single field to the observed level of plot scattering. However, the reported point estimates are very imprecise, making it impossible to reject hypotheses that the Simpson effect is zero or even positive. Moreover, for the unrestricted fixed effects GLS estimates for sorghum and maize (not reported in Table 4), the point estimates of the Simpson effect were actually positive.

The Simpson indices (which change little over time for most production units) are highly collinear with fixed effects, making it difficult to precisely identify the impact of both. Because of this lack of reliable evidence the cost to field scattering, the analysis in subsequent sections will assign zero cost to this practice.[13]

The estimates in Tables 3 and 4 could be combined using expression (5) to calculate the crop- and region-specific probability distribution functions for mean annual yields. The simulation results in Table 5 indicate the degree of variability of those distributions, give some indication of the degree of macroenvironmental, or covariate, risk. As discussed earlier, this covariate risk is only a portion of the total risk faced by production units. Before discussing the magnitude of covariate risk, the next section goes on to estimate specific risk component as a basis for the derivation of total risk.

2.3 *Estimation of Intra-Annual or Specific Risk*

As measures of the conditional variation in yields, controlling for the macroenvironment, field characteristics and production unit characteristics, the residuals from the Mean Annual Yield regressions estimated in the previous section are measures of field-specific risk. However, these residuals are likely to systematically overstate the magnitude of specific risk since they also contain yield variation resulting from unanticipated input dosages (given household endowments) and from measurement error. In an effort to control for the former problem, this section employs a regression strategy designed to control for as many inputs as possible, reducing residual variation to a more appropriate approximation of the true specific risk faced by production units.

For this purpose, the Mean Annual Yield function (10) was augmented with variable per-hectare inputs in a quadratic approximation to a constant returns to scale production function. These inputs were:

Manual Labor used in tasks other than weeding;

Weeding Labor, entered separately from overall manual labor because labor shortages are most likely to constrain the timely completion of this task;

Animal Traction Labor, that is labor used in conjunction with animal-drawn implements; and,

Fertilizer.

In addition, the *Time Elapsed* between planting and first weeding was entered as an additional explanatory variable likely to reflect yield-affecting labor constraints. As with the MAY functions, the residuals to these production function regressions are assumed to follow the heteroscedasticity specification given in (11) above. For all crops, estimation conformed to a classical regression approach using the fixed effect GLS procedure outlined in note 6.

Because the production function parameters themselves are of no immediate interest, Table 6 presents only regression statistics related to the error structure. As revealed by the R^2 figures, the production functions gave extraordinarily good fits for microeconomic production data. The production unit fixed-effects explain between 20% and 40% of total variation in yields. The reported GLS estimates of the heteroscedasticity coefficients ($c\gamma$ in equation [11']) of rainfall and field size conform to prior expectations. The intercropping dummy variable, however, continues to show no identifiable systematic impact on the magnitude of risk.

The estimated heteroscedasticity regression coefficients, together with (11), completely specify the probability distribution (4) for the specific risk components. As indicators of the magnitude of specific risk, Table 6 presents simulated long term average values of the standard deviation of the specific risk component for each crop and region. These average values were calculated by using the crop- and region-specific simulated rainfall time series discussed in section 2.2 to generate a simulated time series of annual specific risk variance terms using expression (11). Relatively large field sizes (of 5 hectares) and mean values for intercropping were used in calculation of the simulated variance terms. The values reported in Table 6 are mean values over these simulated time series. As can be seen, specific risk in the Sahel, with its depressed rainfall levels, is smaller for all crops. Within each region, millet proves to be the steadier performer, as expected, with the lowest specific risk variance, while the maize specific risk distributions have the highest simulated variances.

How reliable are these specific risk estimates? Besides true specific risk, these estimates are still likely to contain measurement error. In an *ad hoc* effort to further purge the specific risk estimates from the influence of remaining measurement error, the alternative specific risk standard deviation estimates presented in the bottom of Table 6 assume that one half of the residual variation is due to measurement error, while the remaining 50% is true specific risk confronted by the production unit. It is these "1/2 Variance" estimates in Table 5 which will be used in subsequent analysis.

Using these purged specific risk estimates, and comparing them with the Table 6 covariate risk results shows that the standard deviation of the specific risk component is in two cases smaller than the standard deviation of the covariate risk component, and larger in four cases. These ratios are roughly comparable to results found by Udry. Based on a substantially different methodology, Udry reports that covariate risk is sightly larger than specific risk, accounting for 58% of the portion of yield variability explicable by risk components in his Nigerian data, with specific risk accounting for the complementary 42%. In no case here is the specific risk standard deviation more than 50% of mean yields, and in most cases it is approximately 30%, figures roughly in line with Udry's estimates.

2.4 Cumulative Density Functions for Crop Yields

Figures 1 and 2, discussed briefly in Section 1 above, display the cumulative density functions (cdf's) for yields of the different crops calculated using (7) and the parameters estimated in sections 2.1 through 2.3. In calculating the cdf's, the time-varying parameters of the rainfall probability functions are fixed at their 1980 levels. Because specific risk has zero expectation, and is uncorrelated with rainfall, the mean yields for the different crops are approximated by the Table 5 average values for simulated mean annual yields.

In the Sahelian zone, where low rainfall levels compress the variability of specific risk as shown in Table 6, millet stochastically dominates sorghum. As can be seen in the portrayal of the MAY functions in Figure 3, millet's dominance is rooted in the fact that nearly all the density in the 1980 Sahelian rainfall distribution occurs before the sorghum mean yields function turns up in response to higher rainfall levels. As mentioned in Section 1 above, the relatively favorable cumulative density profile for maize yields reflects the careful cultivation of tiny household plots of this crop rather than any intrinsic drought resistance of maize.

The cumulative density functions for sorghum and millet in the Transition Zone cross at a yield level of 625 kilograms/hectare and a probability level of 40%, as can be seen in Figure 2. At the rainfall levels characteristic of this zone, the standard deviations of the specific risk distributions are about double their values in the Sahel, with the sorghum value more than double that of millet. With this relatively greater variability around mean annual yields in mind, the cumulative density pattern in Figure 2 can be understood in terms of the information graphed in Figure 3. In the Transition Zone, mean annual millet yields exceed those for Sorghum up to rainfall levels of 700 millimeters, which is close to the mode of the Transition zone rainfall pdf.[14] Beyond 700 millimeters, mean sorghum yields quickly outpace mean millet yields, meaning that for realizations in the upper half of the rainfall distribution sorghum is on average a much better performer. Nonetheless, at the lower rainfall levels characteristic of the complementary lower portion of that rainfall pdf, millet would on average provide higher yields. While thus characterized by greater downside risk, sorghum would over the longer term be expected to yield some 10% more grain per-hectare than millet in the Transition Zone, as the Table 5 figures show. Valuation of this tradeoff between expected returns and risk, and, more generally, measurement of the insurance value of reciprocity and conditional self-insurance, is the topic of the next section.

SECTION 3 OBJECTIVE RISK EXPOSURE FOOD AVAILABILITY AND THE BENEFIT AND COSTS OF SELF-INSURANCE AND RECIPROCITY

The dotted vertical lines in Figures 1 and 2 show the yield levels which would be necessary to generate 200 kilograms of grain per-adult consumer equivalent per-year given the amount of land cultivated per-consumer. The intersection of these food shortfall lines with the cdf's measure the *Objective Risk Exposure* for a production unit under the counterfactual circumstance that the unit monocrops its entire endowment as a single large field located in a single microclimate. This circumstance will be labelled the "Monoculture Counterfactual." In the Sahel, objective risk exposure is 24% for millet monoculture and 39% for sorghum monoculture. In the Transition Zone, the figures are 10% and 24% respectively.

This objective risk exposure measure will be carried throughout the analysis of alternative production strategies and portfolios. While convenient as a single-valued measure of the down-side risk of agricultural production, the risk exposure measure is not an indicator of the *starvation* risk faced by production units. Because individuals may enjoy entitlements to a broader portfolio than current year production unit agricultural output, the objective risk numbers indicate the probability that other entitlements and accumulated assets must be tapped to realize a minimal subsistence level of consumption.[15] But within a subsistence agrarian economy, the food shortfall risk is obviously an important number, indicating the probability of a crisis situation, if not a literal starvation probability.

Complementing the objective risk exposure measure, and permitting an analytically more flexible subjective valuation of objective risk exposure, is the following *Certain Grain Equivalent* measure:

$$Y^c = \{ Y \mid U(Y)=E[U(Y_i)] \} \tag{12}$$

where Y^c is the certain grain equivalent for a stochastic portfolio Y_i--i.e., Y^c is just the grain amount that if received with certainty would yield the same expected utility as the stochastic portfolio. The utility function $U(\cdot)$ is assumed to be a member of the class of constant relative risk aversion utility functions:

$$U(y) = y^{1-r}/(1-r) \tag{13}$$

As the parameter "r" approaches a value of one, relative risk aversion approaches one, and it is this parameterization which will be used in the analysis here.

Table 7 gives the Certain Grain Equivalents for the sorghum and millet monocrop counterfactual regimes described above.[16] In the Sahel, the millet monocrop (with an expected long term food availability of 337 kilograms per consumer) has a certain grain equivalent of 274 kilos per-consumer. For sorghum in the Sahel, the certain grain equivalent is only 194 kilograms per-consumer. In the Transition Zone, where the cdf's for the two crops cross, the certain grain equivalents for millet and sorghum monocrops are nearly identical at 272 and 267 kilograms respectively, despite the fact that sorghum cultivation would on average make available about 10% more grain per-consumer than millet.

3.1. Net-Benefits of Conditional Self-Insurance Devices

The 24% objective risk exposure which individuals would face under the Monoculture Counterfactual is an indicator of the potential risk within West African agricultural systems given the nature of technology, environment, endowments and markets. As a first step toward measurement of the risk actually borne by these individuals, and valuation of the insurance-like devices they employ, this section analyzes the risk management devices available for agricultural self-insurance. As the estimates in Section 2 were unable to identify any systematic impact of intercropping on risk, the analysis here will focus only on field scattering (as a form of environment diversification against specific risk) and non-specialized multiple cropping (as a form of activity diversification against both covariate and specific risks).

In both the Sahelian and Transition Zones, field scattering reduces objective risk exposure and increases the certain grain equivalence of agricultural production. The "Environment Diversification" figures reported in Table 7 correspond to the case where the production unit's resources are located in distinct microenvironments so that each field receives its own specific risk component. The same crop is assumed to be grown on both fields (millet in the Sahel and sorghum in the Transition Zone). This environment diversification has a relatively large impact on objective risk exposure in the Transition Zone (risk drops from 20% to 13%) where specific risk was estimated to be greater.

The "Activity Diversification" entries in Table 7 analyze the case where all production unit resources are concentrated on a single large field, but that single field is then split between millet and sorghum cultivation. In the Sahel, addition of sorghum to a millet monoculture portfolio decreases expected yields and certain grain equivalence. As explored in Table 6, at the rainfall levels characteristic of the Sahel, intertemporal correlation is quite high between the two crops, so that the addition of the lower yielding sorghum does nothing to enhance portfolio stability. In contrast, in the Transition Zone, the addition of millet to a sorghum-based portfolio reduces expected yields, but actually increases certain grain equivalence of the portfolio (from 267 to 283 kilograms per-consumer). Besides exhibiting greater yield stability, the addition of millet to the portfolio further reduces risk exposure because of the low intertemporal correlation between millet and sorghum in the Transition Zone.

Finally, the "Mix and Scatter" portfolio joins the activity and environment diversification tactics just discussed. Under the Mix and Scatter portfolio, production unit resources are assumed to be split into two scattered fields, one of which is put into millet, the other into sorghum. In the Transition Zone, this portfolio dominates the other hypothetical portfolios in terms of certain grain equivalent. In the Sahel, scattering millet fields remains the most effective risk management tactic.

The final column in Table 7 presents indicators on the cost-effectiveness of these forms of self-insurance. The reported benefit-cost ratios report the ratio of net private benefits (defined as the change in certain grain equivalence of the portfolio compared to the reference Monoculture Counterfactual) to long run, or social, cost (defined as the change in expected yields compared to the same reference counterfactual). As a minimal cost-effectiveness standard, this ratio should exceed one, as it does in all cases where there is a positive private net-benefit to the insurance strategy.

As discussed in Section 2.3 above, it was econometrically impossible to precisely identify any cost to field scattering. To the extent such costs really exist, or will come to exist as fertilizer and other input usage increase, the reported social costs of self-insurance are understated. Subject to this caveat, the privately dominant field-scattering tactic in the Sahel is obviously very cost-effective. In the Transition Zone, the expected cost of the dominant "Mix and Scatter" tactic, which increases certain grain equivalence by 23 kilograms, is 17 kilograms per-consumer per-year.

3.2 Observed Patterns of Conditional Self-Insurance Among Heterogeneously Endowed Production Units

Conditional on their endowments, production units have the basic tactics of crop mixing and field scattering available to assemble an agricultural self-insurance strategy. Table 1 presents average cereals cropping patterns for the production units in the sample. For purposes of portfolio simulation, this information was rounded off as follows: In the Sahel, the average production unit is assumed to have 2 millet fields of 3 hectares each, one sorghum field with an area of 0.25 hectare, and a single maize field of 0.07 hectare; In the Transition Zone, the average production unit is treated as having 2 millet plots of 0.6 hectares each, 5 sorghum plots of 0.5 hectares each and 1 maize plot of 0.07 hectare. The data further indicate that the average Sahelian production unit contains approximately 7 consumers (or 0.90 hectares per-consumer), and that the average Transition Zone unit has 10 consumers (or 0.43 hectares per-consumer).

The "Observed Self-Insurance" rows of Table 7 report the portfolio simulation results for these average production units. In the Sahel, where the average portfolio is in fact primarily composed of two scattered millet fields, the observed pattern of self-insurance in nearly identical to the "Scatter Fields" counterfactual analyzed in the Section 3.1 above. In the Transition Zone, the well diversified pattern of observed self-insurance has an objective risk exposure of only 4% and a certain grain equivalence of 308 kilograms per-consumer. This increase of 41 kilograms of certainty grain over the reference counterfactual of sorghum monoculture is bought at a price of only a 4 kilogram decrease in expected grain yield. As mentioned above, this cost figure is an understatement to the extent that field scattering has positive costs in terms of reduced food availability.

Surrounding these average units, there are relatively land scarce and land abundant households. In the Sahel, approximately 27% of the production units appear to be land scarce, with between 0.35 and 0.7 cultivated hectares per-consumer. Another 30% households are relatively land abundant with between 1.2 and 1.7 cultivated hectares per-consumer. Among this latter group are production units which correspond to a stylized notion of a compound head because they both cultivate large extensions and have large numbers of consumers. For the average land scarce household which cultivates only 0.37 hectares per-consumer scattered across four separate fields, expected food availability is 135 kilograms per-consumer, objective risk is 85% and certain grain equivalent is 118 kilograms. The compound head (with 1.22 hectares cultivated per-consumer and 5 fields) would produce with expected food availability of 448 kilograms per-consumer, objective risk of 10% and certain grain equivalent of 396 kilograms.

In the Transition Zone, a strata of approximately 25% of land scarce households exist which cultivate only between 0.06 and 0.30 hectares per-recorded consumer. For the average land scare unit (with 0.15 cultivated hectares per-consumer scattered across 7 fields), expected food availability, risk exposure and certain grain equivalent would be 136 kilograms, 95% and 131 kilograms per-consumer. The 20% strata of better endowed units cultivate from 0.6 to 1.0 hectares per-consumer. Among this group, an apparent compound head cultivates 14 hectares (divided into 21 fields) with 24 consumers, and has expected yields of 405 kilograms per-consumer, objective risk exposure of almost 0%, and a certain grain equivalent production of 400 kilograms.

In summary, this section has explored the limits and endowment dependence of self-insurance. The harsh agro-climatic reality of the Sahel gives few options for diversification, especially against covariate risk. While the ability to pursue the limited self-insurance options reduces risk exposure by 15%, it remains a hefty 20% for the average production unit in the Sahel. In the Transition Zone, conditional self-insurance is much more effective in large measure due to the effectiveness of activity diversification against covariate risk. In both regions, land scarce production units are observed to pursue diversified strategies, but the low absolute quantity of their land endowments leaves them with astronomically high estimated risk exposures of 85% to 95%.

3.3 Horizontal and Vertical Reciprocity--Scope and Benefits

For the analysis here, ten average production units (as defined in section 3.2 above) comprise a horizontal reciprocity group. A vertical reciprocity group is formed by the addition of one compound head production unit (with the endowments given in section 3.2) to the horizontal group. Sharing among members of the reciprocity group can be defined in terms of either a unit's food production relative to average realized production for the group, or relative to a subsistence norm. Under the former definition, units producing less than the average are eligible for transfers, and those producing more would share out at least some portion of their supra-normal production. Under the latter definition, a unit receives transfers only if its subsistence is threatened (production falls below 200 kilograms per-consumer), and would share out only some portion of its supra-subsistence production. The latter sort of sharing relative to a subsistence norm corresponds more closely to at least the discussions of vertical reciprocity arrangements, and will be used as the basis for the analysis here. Parenthetical comparison will be made to the sorts of welfare outcomes which results from complete income pooling.

Table 7 presents simulation results for both horizontal and vertical reciprocity schemes. Under *exogenously* enforced horizontal reciprocity, production units are assumed to share up to 100% of their supra-subsistence production in order to lift subsistence crisis households as close to the subsistence line as possible. In the Sahel, such a scheme reduces the objective risk exposure of the average household from 21% under full self-insurance to 16%. With relative risk aversion equal to one, the certain grain equivalent rises modestly from 290 to 292 kilograms per-consumer. Assuming that under *endogenous* enforcement, production units will share no more than 10% of their supra-subsistence production, horizontal reciprocity decrease objective risk exposure to only 19.6% and certain grain equivalence to 291 kilograms/consumer. Complete income pooling by the horizontal reciprocity group would increase the certain grain equivalent measure to 299 kilograms per/consumer in the Sahel (although it would leave the objective risk exposure at 20%).

The impact of the addition of a relatively well endowed compound head household to the ten production unit Sahel reciprocity group is shown in the Vertical Reciprocity row of Table 7. The compound head unit is assumed to always share up to 100% of its supra-subsistence production to meet subsistence shortfalls of dependent units. When its associated horizontal units share up to 100% of their supra-subsistence production, risk exposure and certain grain equivalence are 14.7% and 296 kilograms/consumer for the average household. The results are slightly less favorable when the associated horizontal units share up to only 10% of their supra-subsistence production. When there are only vertical transfers and no horizontal sharing, risk and certain grain equivalence are 17.2% and 294 kilograms/consumer in the average production unit.

In the Transition Zone, where self-insurance lowers objective risk exposure to approximately 4%, exogenously-enforced horizontal reciprocity reduces that risk to 1.6%. The addition of a vertical reciprocity component drops risk to just under 1%. Full income pooling among the horizontal units leaves risk exposure at 2.1%, and increases the certain grain equivalent measure to 312 kilograms/consumer.

In summary, the various reciprocity schemes examined here do enhance insurance beyond that attainable with self-insurance tactics. It should be stressed, however, that it was not possible to measure the foregone output costs of the disincentive effects (if any) associated with these forms of sharing. The transfers from the compound head to the ten subordinate production units average 210 kilograms per-year in the Sahel, and 100 kilograms per-year in the Transition zone.

SECTION 4 RISK, RISK MANAGEMENT AND THE PROSPECTIVE TRAJECTORY OF AGRICULTURAL DEVELOPMENT IN WEST AFRICA

The representative production unit cumulative density functions (cdf's) in Figures 4 and 5 summarize risk and risk management in two arid agro-ecological environments in West Africa. The Monoculture functions correspond to the case where production units hold their land endowment in a single undiversified block appropriate only for the cultivation of millet in the Sahel and sorghum in the Transition Zone. These Monoculture cdf's, with their food shortfall probabilities of 24%, give an indication of the extraordinarily high levels of underlying risk which confront these West African agricultural producers.

The Conditional Self-Insurance cdf's display the ability of production units to manage risk when their land endowment is diversified to permit utilization of activity and micro-environment diversification tactics. In the Transition Zone, self-insurance increases the certain grain equivalent value of the same (quantitative) endowment by 15%--in the Sahel the increase is a more modest 5%. Finally, Figures 4 and 5 show the risk management gains made possible by a reciprocity scheme which approximates traditional social structure in the region.[17] In the Sahel, the single year food shortfall probability falls by nearly 33% with reciprocity (though it remains a forbidding 15%). In the Transition Zone, reciprocity nearly eliminates the probability of a food shortfall.

While interesting as indicators of the functionality of non-market insurance substitutes, these estimates also help organize and bracket discussion about the impact of risk on agricultural development trajectories in West Africa. As should now be apparent, that discussion cannot take place without specification of the social and institutional environment within which development takes place. One possibility is that agrarian development takes off within an environment in which:

1. Capital and insurance markets remain thin and absent; and,
2. Communal tenure rules and supporting social structure have dissolved.

While other institutional configurations are possible, this "*laissez faire* counterfactual" is made compelling by its likelihood and by its consistency with a *laissez faire* approach to development. Its assumption of imperfect markets is straightforwardly defensible in terms of the sorts of information economics articulated by Binswanger and McIntire. The second assumption, and its significance, warrants greater elaboration.

As noted earlier, both conditional self-insurance and reciprocity have been embedded in traditional West African social structure: Self-Insurance because non-exclusive rights of ownership permit elastic redistribution of land to guarantee individuals access to the quantities and qualities of land needed to pursue self-insurance; Reciprocity because extended family structures empower compound and lineage heads to mobilize land and labor to produce for a granary against which indemnification may be sought by subordinates. However, a strong case can be made that for both exogenous and endogenous reasons, this traditional structure is disappearing.[18]

The dissolution of traditional communal tenure structure is likely to affect risk management along two dimensions. The first is the *Rights Reassignment* inherent in the assignment to individuals of exclusive rights to particular pieces of land. While concentrating land-embodied investment incentives in a single individual, Rights Reassignment exposes individuals to losing flexible access to the land needed for subsistence. Absent insurance contracts or buoyant reciprocity arrangements, liquidation of assets (including land) becomes a primary means by which individuals deal with shocks that overwhelm their self-insurance (see Watts). Lacking rights to a subsistence endowment following Rights Reassignment, individuals would be able to regain liquidated land can only by repurchase--a feat which would become more difficult as the endowment base and self-insurance capacity shrink, shifting the distribution of returns to the northwest in Figures 4 and 5. The sustainability of the land quantities and quantities needed to pursue self-insurance becomes an economic issue, not a social guarantee.

The dissolution of communal tenure is also likely to undermine what have here been called exogenously enforced and vertical forms of reciprocity. In other historical contexts at least, the elimination of reciprocity, patron-client obligations and the like, has appeared as a *Rights Extinction*, with subordinate units loosing all claim to those resources on which they used to have at least a conditional claim (for example, see Scott and Kerkleviet 1973). It is this rights extinction, or shift from conditional to unconditional inequality which "fundamentally changes the nature of inequality" as traditional social structure dissolves, to use Michael Watts' language.

The impact of risk on the agricultural development from a production-minded perspective can now be examined with Figures 4 and 5. Under the *laissez faire* counterfactual, the average, or representative production unit, would be confined to an agricultural portfolio with returns given by the self-insurance density functions. Over time, there might be some drift toward the monoculture cdf's if production units find it expensive to maintain diversity within the context of interim asset transactions needed to smooth consumption. On the other hand, endogenous reciprocity schemes could, if implemented, modestly improve the risk profile.

Would the self-insuring representative production unit be positioned to adopt a yield-enhancing technology? Such technologies are unlikely to stochastically dominate the self-insurance portfolio at least because they imply increased cash exposure. Without greater specificity about the new technology, and a behavioral model with which to examine the relevant tradeoffs, the growth potential of the representative production unit cannot be fully judged. The magnitudes of risk under self-insurance are informative, however. As noted, self-insurance prospects are weak in the Sahel, and the riskiness and instability of the representative production units' agricultural portfolio are extraordinarily high, making substantial additional risk-taking difficult to imagine. In the Transition Zone, self-insurance is much more effective, but it is also vulnerable in the sense that the loss of self-insurance capacity would move the production units to the risk levels characteristic of the Sahel.

To consider the distribution or class differentiation concerns articulated in the introduction to this paper, Figures 4 and 5 display cumulative density functions for the agricultural portfolios of relatively land scarce and relatively land abundant production units under the *laissez faire* counterfactual. Both land scarce and abundant units are assumed to have the endowments and to employ the currently observed patterns of self-insurance described in Section 3.3 above. The difference in risk exposure for the two groups, both of which comprise about a quarter of the population, is startling. The land abundant cdf's are relatively immune from risk. The land scarce units would almost be immune from survival if dependent on solely on their agricultural returns under the laissez faire institutional counterfactual. (Disturbingly, the analysis of Reardon *et al.* shows that these less well-endowed households are the ones with *least* well diversified income sources.) Remarkable in Figures 4 and 5 is how the fairly narrow range of observed asset inequality translates into a wide range of risk exposure under the *laissez faire* counterfactual. In the spirit of the Eswaran and Kotwal work discussed in the introduction, this wide range of risk would almost surely provide the objective basis for an incipient process of class formation. Empirically, Raynaut (1988) and Watts (1983) document a dynamic of landlessness and social differentiation based on the inability of less well endowed agents to achieve adequate levels of self-insurance.

To link together the production-minded and differentiation concerns, it is useful to think of an *endowment-risk correspondence*. Arrayed in order of increasing endowments, self-insuring production units under the *laissez faire* counterfactual would map to a sequence of cdfs bracketed by the land scarce and land abundant functions in Figures 4 and 5. Given the magnitudes of risk along this sequence, there is bound to be some critical density function "northwest" of which risk becomes so large that it inhibits technological change. Also within that range of risk, it seems reasonable to hypothesize a second critical level northwest of which the corresponding asset base cannot be maintained over time. The number of units which lay beyond these critical levels would determine the impact of risk on the agrarian development trajectory.

In summary, agro-climatic risk is high in the semi-arid regions of West Africa examined here. Reciprocity and conditional self-insurance, rooted in communal tenure structures, play an important risk management role--a role which information-constrained markets seem ill-positioned to fulfill. However, the historical fragility of communal tenure opens the way to development within an institutional environment of greater individual vulnerability, and along a socially problematic, risk-constrained trajectory. The presumptive case for public intervention in the sphere of risk management--as articulated by Platteau and Bromley and Chavas--is strongly supported by the results here. Clearly more work is needed to tighten the arguments made here. The time for such work, however, is now, rather then in some future moment when problematic aspects of risk have emerged in the form of a stunted or socially unsteady growth trajectory.

TABLE 1
CROPPING PATTERNS AND TECHNOLOGIES

	Sahel			Transition Zone		
	Millet	Sorghum	Maize	Millet	Sorghum	Maize
Yield (kg/ha)	381	412	405	480	609	1458
Labor (hours/ha)	331	583	4414	955	907	1106
Fert. (kg/ha)	0.15	0	1.1	8.6	15.4	19.6
Intercrop (%)	38%	42%	34%	67%	83%	56%
Toposequence	2.0	2.3	1.85	2.0	2.0	2.0
"Ring" Location	2.2	2.3	1.7	2.0	2.3	1.5
# Fields	2.1	0.4	1.2	2.1	4.6	1.5
Has. in Crop (% of cult.area)	6.1 (93%)	0.27 (4)	0.07 (1)	1.2 (31)	2.5 (59)	0.07 (2)

TABLE 2
YIELD AND RAINFALL VARIABILITY, 1981-1983

	Sahel			Transition Zone		
	1981	1982	1983	1981	1982	1983
Crop Season Rainfall (mm)	329	276	388	506	422	539
Millet (kg/ha)	504 (312)	205 (194)	439 (258)	599 (453)	438 (482)	467 (448)
Sorghum (kg/ha)	731 (168)	256 (381)	365 (199)	847 (755)	585 (400)	625 (461)
Maize (kg/ha)	577 (855)	154 (736)	707 (1967)	1761 (1269)	1392 (966)	1589 (1530)

Figures in Parentheses are estimated standard deviations.

TABLE 3
MAXIMUM LIKELIHOOD ESTIMATES OF
RAINFALL PROBABILITY DENSITY FUNCTIONS

	Sahel Millet	**Transition Zone** Millet
α_0	10.3 (1.48)	4.3 (1.1)
α_1	2.1 (0.035)	-0.43 (0.37)
β_0	1.94 (0.30)	6.79 (1.4)
β_1	-1.1 (0.16)	0.65 (0.42)

Figures in parenthesis are estimated asymptotic standard errors.

TABLE 4
MEAN ANNUAL YIELD FUNCTIONS ESTIMATES

Variables	Millet	Sorghum	Maize
Endowment			
Simp Index	-127 (226)	-143.	-583 (560)
Field			
Plant Date	0.07 (0.62)	-1.1	-2.7 (1.7)
Topo 1	-6.4 (185)	-78	99 (431)
Topo 2-4	-40 (171)	37	0.6 (393)
Place 1	125 (45)	198	-48 (171)
Place 2	72 (39)	121	-64 (166)
Intercrop	-313 (1309)	3429	-5409 (4748)
Environment			
Rain	-2.8 (4.9)	11.9	-5.6 (12)
Rain^2	0.01 (0.01)	-0.02	0.02 (0.03)
Rain^3	-9E-6 (7.6E-6)	1.6E-5	1.2E-5 (2E-5)
Ic*Rain	3.2 (9.0)	-22	49 (32)
Ic*rain^2	-.008 (-0.02)	0.04	-0.12 (0.07)
Ic*rain^3	6E-6 (1.3E-5)	-2.6E-5	1E-4 (5E-5)
R^2	0.26	--	0.13
Std Error	332	--	1721
Number Obs.	740	1162	528

TABLE 5
SIMULATED INTER-TEMPORAL VARIANCE COMPONENTS

	Rain	Yields		Inter-Temporal Correlation		
	Mean	Mean	σ^c	Millet	Sorghum	Maize
Sahel						
Millet	344	373	164	1.0	0.96	0.95
Sorghum	344	277	80	-	1.0	0.99
Maize	332	499	226	-	-	1.0
Transition Zone						
Millet	678	662	88	1.0	0.18	-0.26
Sorghum	678	743	174	-	1.0	0.85
Maize	634	2756	1443	-	-	1.0

TABLE 6
GLS PRODUCTION FUNCTION ESTIMATES OF SPECIFIC RISK

	Millet	Sorghum	Maize
Production Function Regression			
R^2	0.504	0549	0.677
Heterosedasticity Regression			
Constant	102 (25)	-47 (38)	-23 (63)
Field Size	-13 (1.2)	-9.6 (3.5)	-67 (172)
Intercrop	43 (13)	-17 (19)	224 (56)
Rainfall	0.15 (0.05)	0.68 (0.07)	1.32 (0.21)
Simulated Mean Specific Risk, σ^s			
Sahel Full Resid. Var. "1/2 Variance"	 130 95	 163 115	 276 195
Transition Zone Full Resid. Var. "1/2 Variance"	 193 136	 448 317	 820 580

TABLE 7
CONDITIONAL SELF-INSURANCE AND RECIPROCITY

	E[Food Availa-bility] (kg/con.)	Objective. Risk Ex-posure (%)	Certain Grain Equivalent (kg/con.)	Private Benefit/ Social Cost
SAHELIAN ZONE				
Monoculture				
Millet	337	24	274	--
Sorgum	251	39	194	< 0
Self-Insurance				
Activity Divers.	297	27	255	< 0
Enviorn. Divers.	337	20	293	19/0
Mix & Scatter	293	25	262	< 0
Obs. Self-Insur.	333	21	290	16/4
Reciprocity				
Endog. Horizontal	334	20	291	17/4
Exog. Horizontal	334	16	292	18/4
Vertical	337	15	296	--
TRANSITIONAL ZONE				
Monoculture				
Millet	287	10	272	5/32
Sorgum	320	24	267	--
Self-Insurance				
Activity Divers.	305	16	283	15/15
Environ. Divers.	320	13	296	29/0
Mix & Scatter	303	11	290	23/17
Obs. Self-Insurance	317	4	309	42/3
Reciprocity				
Endog. Horizontal	317	3	310	43/3
Exog. Horizontal	317	2	310	43/3
Vertical	318	1	310	--

Figure 1: Yield Risk in the Sahel

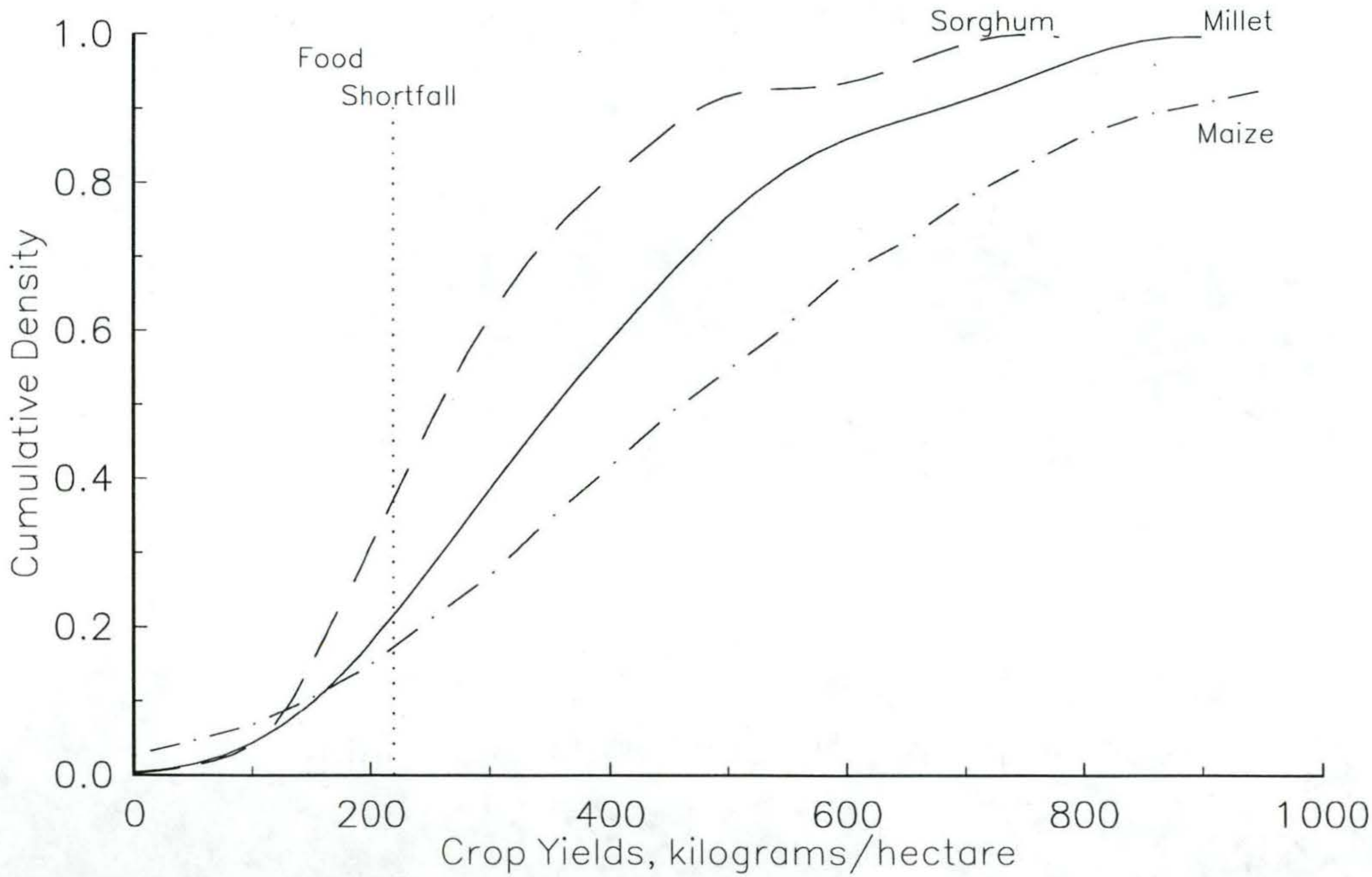


Figure 2: Yield Risk in the Transition Zone

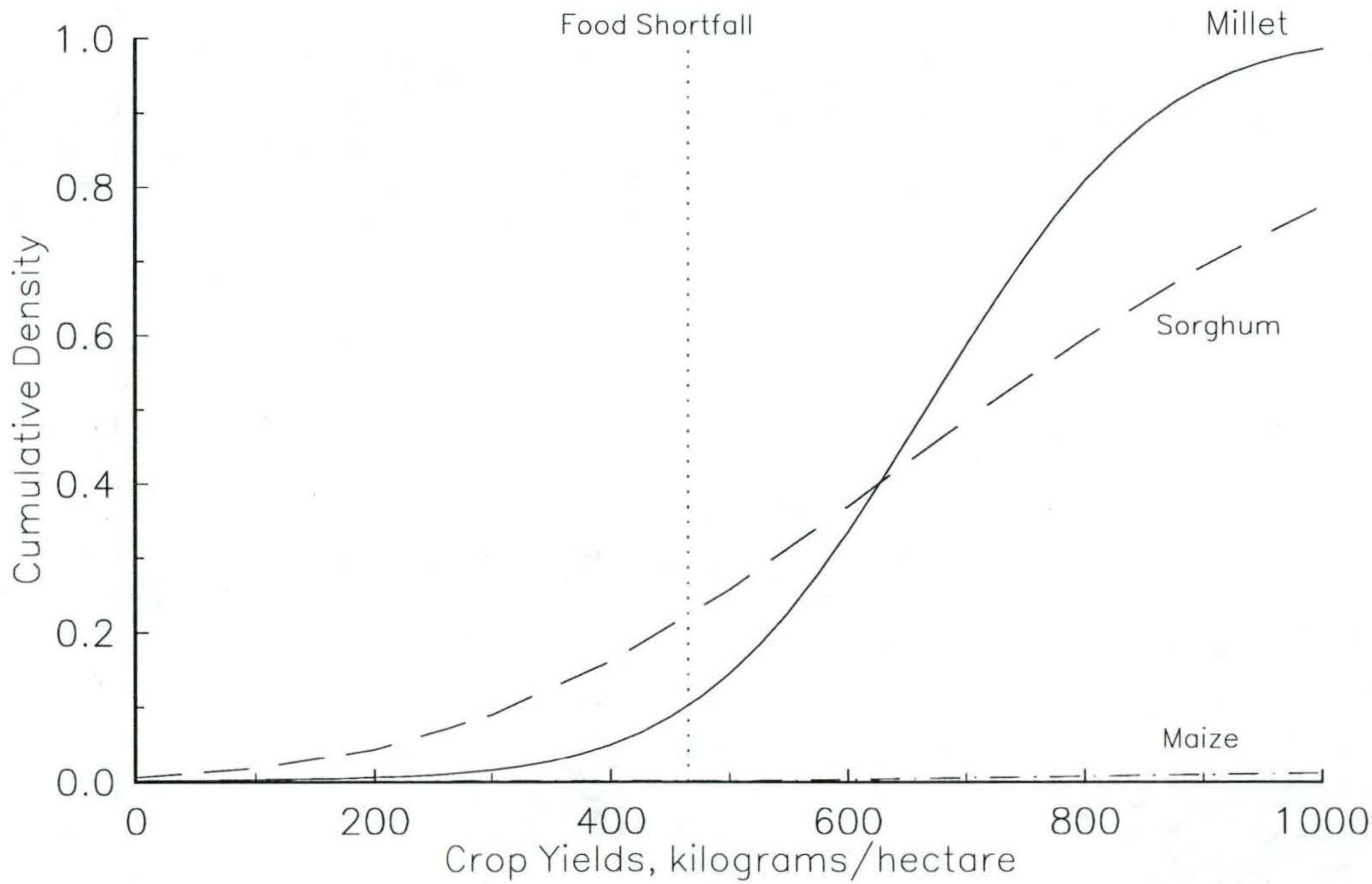


Figure 3: Mean Annual Yield Functions and Rainfall PDF's

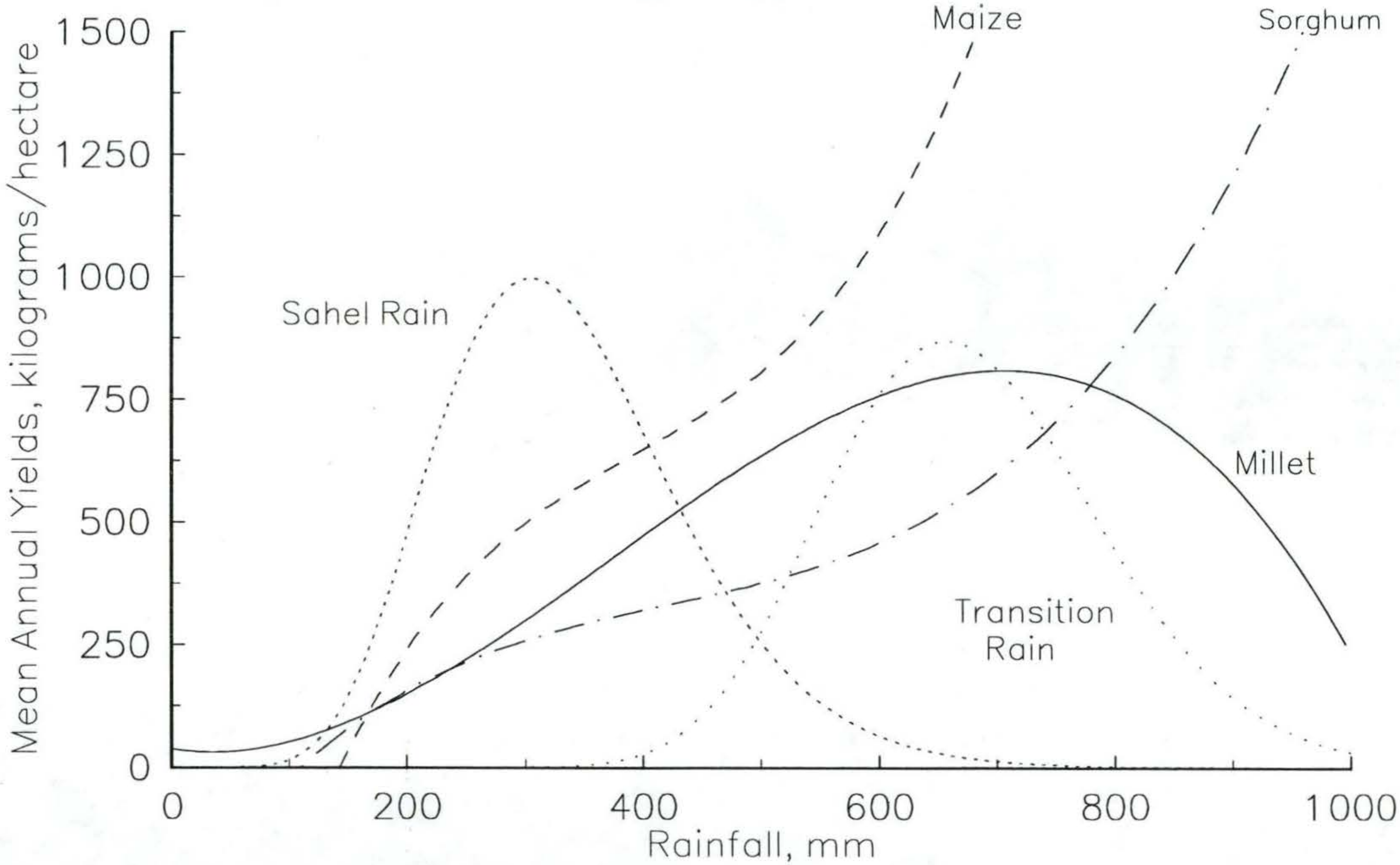


Figure 4: Reciprocity and Conditional Self Insurance in the Sahel

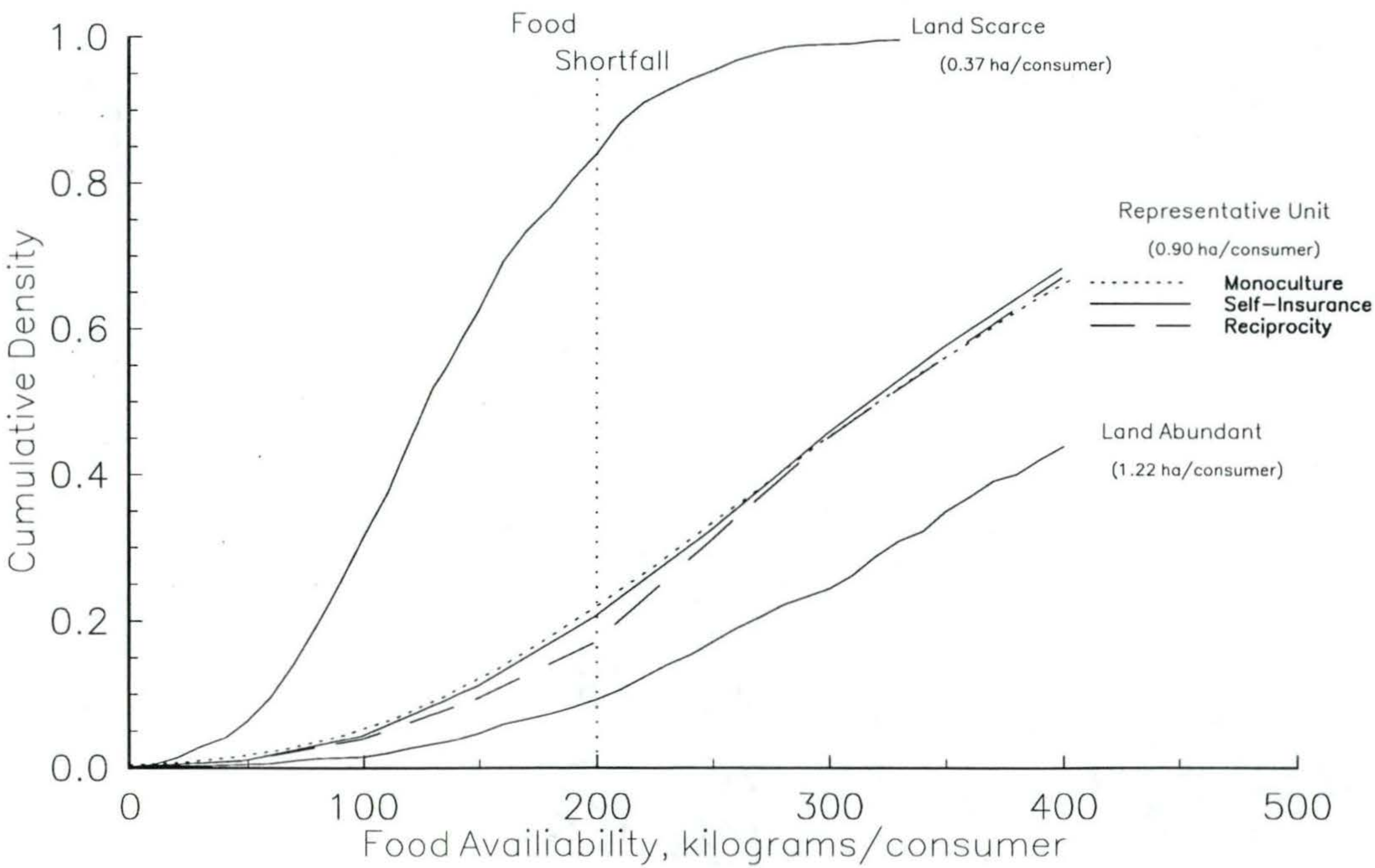
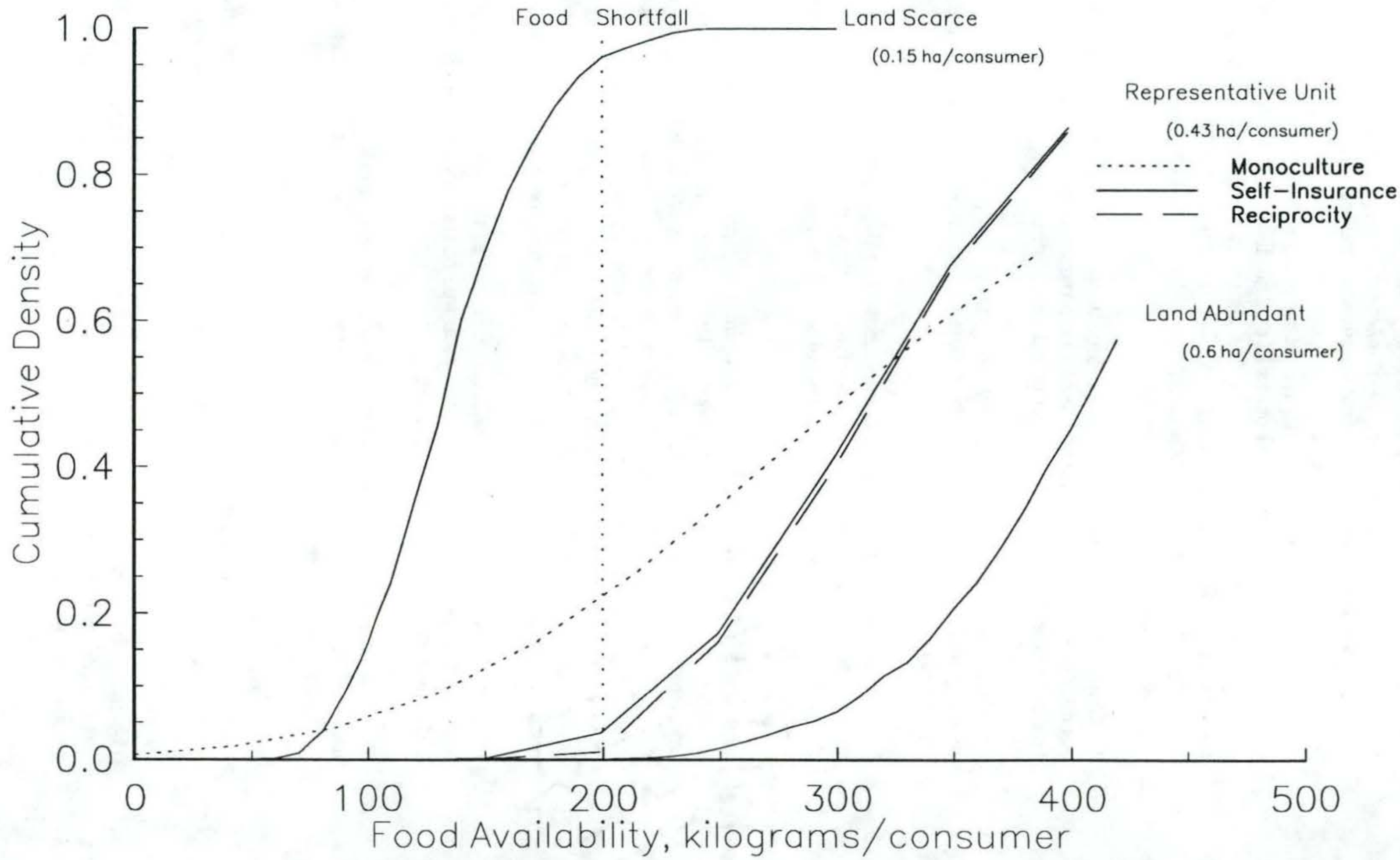


Figure 5: Reciprocity and Conditional Self Insurance in the Transition Zone



ENDNOTES

1. Rosenzweig (1988), Rosenzweig and Wolpin (1989), Udry (1990) and Reardon *et al.* respectively analyze the risk management potential of marriage, bullock investment, informal loans and off-farm income. Mellisoux's work is a classic statement of the logic of family structure.

2. This focus on objective risk matches the reconsideration expressed by Binswanger and Sillers about efforts by Binswanger (1981) and others to explain differences in individual economic strategy in terms of different subjective risk preferences. The above cited papers by Eswaran and Kotwal are a similarly self-conscious effort to explain class formation in terms of objective differentiation rather than Knightian subjective differentiation in which entrepreneurial emerges from those most subjectively willingly, as opposed to objectively able, to bear risk.

3. M. Carter and F. Zimmerman "Paths of Growth and Transformation in African Agriculture: Solving the Food Crisis?" formulate a dynamic stochastic programming model of individual behavior which they propose to use to examine the impact of risk on agrarian development.

4. The data collection was undertaken by the West African program of ICRISAT. For discussion of sampling methodology, see the Guide to Data Collection and Encoding Procedures, ICRISAT, West African Economics Program, 1986.

5. The villages were purposefully selected according to the criterion of percent of households possessing animal traction for cultivation purposes. Particularly in the Sahelian zone, this was a very demanding criterion and the Sahelian villages surveyed should probably be understood as relatively privileged and wealthy villages.

6. Note that the data have a basic panel structure with repeated observations on cross-sectional production units over a three year time series period. Unlike conventional panel data, the multiple fields cultivated by a single production unit create multiple observations for a single cross-sectional unit within a single year. This data structure suggests a triple subscripting of observations (production unit "i", field "j", and year "t"). However, field coding was not consistent across years, making it impossible to determine if there were multiple observations on a single field. Reflecting this reality, and to simplify notation, observations will be simply double subscripted by production unit and year. The reader should bear in mind, however, that in general there are more than three observations for any given production unit.

7. Here and throughout this study, rainfall is measured as the rain which falls between planting and harvesting dates. Within the same year, measured rainfall can thus be different across fields which have different planting dates or cycle lengths.

8. The indicators of a field's quality are its topographical position and its distance from the production unit's residence (or its position in what Jaeger (1985) calls the "ring management" sequence). In Table 1, the former is measured by a toposequence variable takes the value of "1" for low-lying fields which tend to collect moisture, "2" for mid-slope fields, and "3" for up slope fields which typically are the driest and least prone to flooding. Following Jaeger (who explores how cultivation becomes less-intensive as one moves further out through the concentric circles which ring the household), field position is measured as a ring location variable takes the value of "1" for close-in household garden plots, "2" for nearby compound fields, and "3" for distant bush fields.

9. The endogenous reactions production units make to rainfall reactions should flatten the sensitivity of yields to rainfall. Chavas and Kristjanson (1990) discuss in detail endogenous reactions to realized weather information.

10. Following the suggestion of Judge *et al.*, OLS estimates of (10) were used to calculate residuals for use in the heteroscedasticity regression, (11'). Because the residual for (11') is itself heteroscedastic, OLS estimates of the heteroscedasticity parameters ($c\gamma$) were used as the basis for a GLS re-estimation of (11'). These GLS estimates of γ were then used as the basis for GLS estimates of the MAY function parameters. To reduce the dimensionality of the problem of estimating the MAY function parameters--given that the fixed effect specification introduced approximately 75 dummy variables--a standard fixed effects transformation was imposed. For the first round OLS estimates, the data were deviated from their respective production unit means, where these means are just the fitted values of the auxiliary regressions of left and right hand side variables on the matrix of production unit dummies. For the GLS estimates, the GLS-transformed data were deviated from the fitted values obtained from the auxiliary regressions on the GLS-transformed production unit dummies. These "double residual" regression procedure gives the same point parameter estimates as if the full set of production unit dummies were included. Degrees of freedom and reported standard errors were adjusted to account for the implicit estimation of the household fixed effects.

11. Judge *et al.* suggest an iterative, weighted least squares procedure in which observations are given the following weights:

$$w_{it} = 1 \quad \text{if } |e_{it}| < c1;$$
$$w_{it} = c1/|e_{it}| \quad \text{if } c1 < |e_{it}| < c2;$$
$$w_{it} = 0 \quad \text{if } |e_{it}| > c2,$$

where e_{it} is the residual defined by the previous round estimates of the MAY function parameters. Starting from mean absolute deviation estimates,the procedure is continued until the parameter estimates converge. The results reported in the text used critical values c1=75 and c2=150. In the final round estimates, 702 observations were dropped (zero-weighted) with these critical values, 286 were given full weight, and 174 were given an intermediate weight.

12. Similar efforts to see if the yield-rainfall relationship is different for different toposequence positions yielded even less precise results then the reported inter-cropping specification.

13. The failure to find a significant negative impact of field scattering on yields is not necessarily surprising since, given the extremely low levels of fertilizer use, the major problem implied by field scattering is likely to be labor time lost to travel.

14. Note that Figure 3 graphs the fitted MAY regression functions for the Sahel. The functions fitted for the Transition Zone (primarily the fixed effects are different) are similar in appearance, but the sorghum function is shifted relatively higher than the millet function.

15. Using data drawn from the same villages studied here, Reardon *et al.* find that own-farm agricultural income comprises only 50% to 60% of total household income. Other income sources are not well diversified, however, in the sense that they depend on the same risk components which affect own-farm production.

16. Rather than analytically calculate density functions for increasingly complex portfolios, mean utility values for long simulation series were used to approximate expected utility.

17. The cdf's correspond to the case of endogenously enforced vertical reciprocity discussed in Section 3.4 above.

18. The seeming inevitability of the dissolution of the traditional social system is predicated on the "natural" force of population pressure (Vierich and Stoop 1985, Feeney 1989) and on the land reform interest of policy makers in eliminating communal tenure in order to sharpen agricultural investment incentives (Platteau 1990 and Feder and Noronha 1987).

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