Efficiency and Market Structure: Testing for Profit Maximization in African Agriculture

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June, 1996

Marcel Fafchamps, Elaina Rose and John Strauss provided valuable comments and advice on an earlier draft. I thank the International Crop Research Institute for the Semi-Arid Tropics and the International Food Policy Research Institute for making data available. Ellen Payongayong provided vital assistance with the IFPRI Kenya data. Financial assistance from the NSF is gratefully acknowledged. The most current version of this paper is available online at http://www.econ.nwu.edu/faculty/udry/.

1. Introduction

A central question in development economics is the extent to which the rural environment is characterized by competitive markets. The answer has direct implications for the efficiency of the allocation of resources, for the design of economic policy, and for the choice of appropriate analytic methods. Hence, an important task of empirical development economics is to provide a characterization of the market environment in rural areas of poor countries. Much of the relevant literature has been concerned with the existence of well-behaved labor and land markets (e.g., Benjamin, 1992; Collier, 1983; Rosenzweig, 1988; Pitt and Rosenzweig, 1986; Binswanger and Rosenzweig, 1981), but there has also been extensive interest in intertemporal and insurance markets (e.g., Morduch, 1990; Chaudhuri, 1993; Deaton, 1991; Carter, 1994; Townsend, 1994). For historical reasons, the task of an empirical characterization of rural market structure is furthest advanced in Asia and Latin America. Relatively little is known of the extent or characteristics of markets in rural Africa. The goal of this paper is to improve this base of knowledge by using agronomic information to provide evidence on the basic characteristics of rural markets in a variety of African settings.

An implication of the availability of a complete set of competitive markets that greatly simplifies empirical work is separation: the household maximizes profit in its production decisions without regard to its preferences (Krishna, 1964). The null hypothesis of complete markets may seem incredible and thus unworthy of testing. It is true, of course, that nowhere in rural Africa (or anywhere else) does there exist an economy characterized by a complete set of competitive markets. However, a broad variety of spot markets do exist, and in some contexts appear to operate competitively (e.g., Hays, 1975; Jones, 1980; Pingali *et al*, 1987). Informal mechanisms exist which might fill the same functions as other competitive markets (Udry, 1990; Aryeteey, 1993; Guyer, 1981). Moreover, the separation result is robust to the non-existence of some markets (for example, it is retained if there is no market for one of the factors of production). The most practical reason for testing the separation hypothesis, however, is that separation is commonly invoked in empirical studies of agricultural production in poor countries (Singh *et al*, 1986).[1]

The separation theorem, therefore, serves as a simple and useful benchmark for further analysis. In addition, much can be learned from rejections of the exclusion restrictions that are implied by separation. The *pattern* of rejections has implications for the structure of rural markets. This pattern, and its variation over space, can provide useful information about the geography of markets.

The empirical work of this paper consists of a series of tests of separation in a variety of African contexts. The African setting is of interest because the quantitative literature on rural factor markets in Africa remains quite limited, and that which does exist contains arresting suggestions of empirical regularities which look quite different from other parts of the world. The most important example concerns a "stylized fact" of traditional agriculture (Bardhan, 1973): the inverse relationship between farm size and yield. This pattern has been established in a variety of data sets from Asia and Latin America. The limited evidence from Africa, however, looks different. Hill in west Africa and Kevane (1994) in Sudan both show (using small data sets) the opposite relationship - larger farms have higher yields than smaller farms. In contrast, Barrett (1996), Gavian and Fafchamps (1995) and Collier (1983) find that in Madagascar, Niger and

[1]Separation is also invoked, usually without comment or testing, in studies of production in rich countries.

Kenya, respectively, there is evidence of the conventional inverse relationship.

Section 2 describes the separation result, and discusses the exclusion restrictions which it implies. It also raises the most important econometric issue which arises in this context - the possibility that apparent violations of separation are the result of unobserved variation in farm characteristics. Section 3 presents the data from a wide variety of sources which are used to implement the tests. The results are presented, country by country, in section 4.

2. Separation and Profit Maximization

A. A Review of the Separation Result and its Relation to Profit Maximization.

Consider a household with a conventional utility function over vectors of goods (c_{st}) and leisures (l_{st}) in state $s \in S$ of period $t \in T$ (so c_{st} is the vector of goods consumed if state s occurs in period t). For simplicity, assume that both S and T contain finite numbers of elements. This household faces a complete set of competitive markets. Let p_{st} and w_{st} be the price vectors of the state-contingent goods and labor. Let E_{st} be the household's endowment of time in state s and period t, q_{st} be the price of farm output, L_{st} be the labor used on the household's farm, A_{st} be the vector of land inputs and r_{st} is the vector of prices of these land inputs (to simplify notation, I have assumed that there are no inputs other than land and labor - these can be accommodated with no substantive change in the analysis). $F_{st}(L_{st},A_{st})$ is a set of (state-contingent) production functions. Then the household's problem is to

(1) $\underset{c_{st}, l_{st}, L_{st}}{Max}\ U(c_{st}, l_{st})$ subject to

(2) $\sum_{t \in T,\, s \in S} \{w_{st}E_{st} + \Pi_{st} - p_{st}c_{st} - w_{st}l_{st}\} \ \geq\ 0,$

(3) $\Pi_{st} \ =\ q_{st}F_{st}(L_{st}, A_{st}) - w_{st}L_{st} - r_{st}A_{st}, \quad L_{st}, A_{st} \geq 0$ and

(4) $c_{st}, l_{st} \geq 0, \quad l_{st} \leq E_{st}.$

The problem is recursive. With weak conditions on U(.), (2) is binding at the solution and the maximized value of U(.) is increasing in Π_{st}. L_{st} and A_{st} appear only in (3). Hence (1) - (4) can be solved by first maximizing profit Π_{st} with respect to L_{st} and A_{st} and then maximizing utility. That is, the problem (1) - (4) is equivalent to:

(5) $\underset{c_{st}, l_{st}}{Max}\ U(c_{st}, l_{st})$ subject to

(6) $\sum_{t \in T,\, s \in S} \{w_{st}E_{st} + \Pi^{*}_{st}(q_{st}, w_{st}, r_{st}) - p_{st}c_{st} - w_{st}l_{st}\} \ \geq\ 0,$ and

(7) $c_{st}, l_{st} \geq 0, \quad l_{st} \leq E_{st},$

where

(8) $\Pi^{*}_{st}(q_{st}, w_{st}, r_{st}) \ =\ \underset{L_{st}, A_{st}}{Max}\ q_{st}F_{st}(L_{st}, A_{st}) - w_{st}L_{st} - r_{st}A_{st}, \quad L_{st}, A_{st} \geq 0.$

Households maximize profits in each state and on each date and, therefore, production decisions on any plot, depend *only* on prices and the characteristics of that plot.[2] The simplification is extraordinary: from a problem (1-4) of dealing with a (risk averse) household's dynamic behavior in a risky environment we arrive at a very simple static profit-maximization problem.[3]

[2]Note that the choice of the household as the unit of analysis has no effect on this particular result. If markets are complete, separation holds for all standard models of the household - the cooperative bargaining models, the collective model, and even for most non-cooperative models of the household.

[3]It should be noted that (8) does not describe expected profit maximization. Profits are maximized separately in each state of nature. It is unrealistic, of course, to presume that households can adjust labor and land inputs in each state of nature, because some inputs must be committed before the state is realized. To examine the consequences of this fact of life, suppose that in each period t, labor (L_t) and land (A_t) are chosen before the state of nature for that period is realized.

Equation (8) provides the basis of the empirical strategy of the paper. Within any group of plots subject to the same prices, input choices (and outputs) are identical on identical plots. This paper present two series of empirical tests based on this restriction. The first examines the distribution of yields and inputs on similar plots. Since separation implies that output and inputs are identical on identical plots, we examine the dispersion of yields and input intensities on apparently identical plots. Is this dispersion so large that the null hypothesis of separation must be rejected?

The second series of tests is based on the strong exclusion restrictions on input demand and output supply functions which are implied by (8): input demand and output supply functions depend on prices and on plot characteristics but nothing else. Controlling for prices and plot characteristics, is there a strong enough correlation between input use (or output) and other household characteristics that we must reject the null hypothesis of complete markets?

Now consider production on a particular plot i. From (8), yield (output per unit area) on

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Factor prices, therefore, are no longer state-contingent. The budget constraints (2) and (3) now become:

$$(2') \qquad \sum_t \left[w_t E_t + \Pi_t - w_t l_t - \sum_s p_{st} c_{st}\right] \geq 0$$

$$(3') \qquad \Pi_t = \sum_s q_{st} F_{st}(L_t, A_t) - w_t L_t - r_t A_t$$

The problem remains recursive, and (8) becomes

$$(8') \qquad \Pi_t^* = \underset{L_t, A_t}{Max} \sum_s q_{st} F_{st}(L_t, A_t) - w_t L_t - r_t A_t.$$

Production decisions remain a function only of prices and the characteristics of the plot.

that plot (in state s of period t, but I drop those subscripts to simplify notation) depends only on prices and the characteristics of the plot itself:

$$(9) \quad Q^{i} = G(A^{i},w,r,q).$$

Consider a set of plots K, *each of which is subject to the same prices* (w, r, and q). Then a first order Taylor expansion of (9) across plots $i \in K$ implies

$$(10) \quad Q^{i} - \bar{Q} \approx \partial G(A)/\partial A \cdot [A^{i} - \bar{A}] \ \forall i \in K,$$

where $\bar{A}$ is the mean area of the plots planted with the same crop and subject to the same prices. Within groups of plots subject to the same prices (in this paper, I will assume that plots in a particular village face the same prices), the deviation of yield on a plot from the group average yield is a function only of the deviation of the plot's area from the average area of plots in the group. With a flexible specification for the function $\partial G(A)/\partial A$, (10) is an approximation to an arbitrary concave production function. If one assumes that the technology is CES, so that

$A^{i} \cdot Q^{i} = [\delta(A^{i})^{-\rho} + (1-\delta)(L^{i})^{-\rho}]^{-\frac{v}{\rho}}$, then (10) becomes

$$(10') \quad \ln(Q^{i}) - \ln(\bar{Q}) = \frac{\rho \cdot (v-1)}{\rho + v} \cdot [\ln(A^{i}) - \ln(\bar{A})].$$

The first evidence that I examine is extent to which agricultural data from Africa matches the theoretical prediction that yield is identical on identical plots. This evidence is summarized by estimates of the distribution of deviations of actual yield from expected yield. The second type of evidence is drawn from tests of the exclusion restrictions implied by (10): if markets are complete, then yield depends only on prices and plot characteristics, not on other characteristics of the household which cultivates the plot.[4]

B. The Empirical Strategy.

Much of the empirical work of this paper is based on a series of tests of the exclusion restrictions implied by (10) and (10'). Each of the tests has power against different violations of the assumptions which imply separation. The pattern of violations, therefore, can provide information about the structure of rural markets. It is to be expected that the pattern of violations will vary across areas.

Some issues remain before (10) or (10') can be estimated. Contrary to (10) and (10'), of course, A^i is not scalar-valued. Plot i has characteristics in many dimensions - its area, its soil quality, its topography, the particular amount of rain it receives in state s. Moving to a notation more amenable to a discussion of econometric specification, let A^i be composed of two components: X_{vhtci}, which is a vector summarizing the information about plot i (planted to crop c in year t by household h in village v) available to the researcher and ϕ_{vhtci}, a set of unobserved characteristics of the plot (including plot level random shocks as well as more permanent unobserved characteristics), so $G(A) \equiv G(X,\phi)$. Prices are assumed to be the same for all plots in the same village v in a particular year t. Equation (10) becomes:

$$(11) \quad Q_{vhtci} = \bar{Q}_{vtc} + \partial G(X,\phi)/\partial X \cdot [X_{vhtci} - \bar{X}_{vtc}] + \partial G(X,\phi)/\partial\phi \cdot [\phi_{vhtic} - \bar{\phi}_{vtc}].$$

ϕ is unobserved, so the final part of the expression is subsumed in an error term (about which more will be said) and I approximate $\partial G()/\partial X$ with a linear function:

[4]Crop choice, as well as input choice conditional on crop, depends only on prices and plot characteristics if markets are complete. Tests based on this fact would provide another avenue through which agronomic information could be used to test the separation hypothesis.

$$(12) \qquad Q_{vhtci} = \bar{Q}_{vtc} + [X_{vhtci} - \bar{X}_{vtc}]\beta + \epsilon_{vhtci} - \bar{\epsilon}_{vtc}$$
$$= X_{vhtci}\beta + \lambda_{vtc} + \epsilon_{vhtci} \ .$$

(12) is the basic empirical framework of the paper.[5]

It is now possible to define the two series of empirical tests of the paper. First, is output identical on identical plots? This is a question about the characteristics of ϵ. If the null hypothesis of complete markets is correct, then the distribution of ϵ is determined by the distribution of ϕ. Is there a sense in which we can say that in a particular sample, the distribution of estimated residuals is not compatible with the null hypothesis? Such tests can be performed if relatively strong assumptions about ϕ are valid. Second, (8) implies a series of very strong exclusion restrictions in (12). In particular, input demand and output supply depend on prices and plot characteristics and nothing else. Other household characteristics such as farm size, household composition or wealth have no role in (12).

The first series of tests is based on the maintained assumption that the allocation of factors of production across the various plots controlled by an individual is efficient, so that the separation hypothesis is true across these plots. Consider the following pair of regressions:

$$(13) \qquad (a) \quad Q_{vhtci} = X_{vhtci}\beta + \lambda_{vtc} + \epsilon^{v}_{vhtci}$$
$$(b) \quad Q_{vhtci} = X_{vhtci}\delta + \lambda_{vhtc} + \epsilon^{h}_{vhtci} \ .$$

[5] Model specification choices must be made to characterize $\partial G()/\partial X$. The econometric work is cast in per-hectare terms, with log yield and log input intensity as dependant variables. I estimate $\partial G()/\partial X \times X$ as $X\beta$, where X includes log plot area and dummy variables characterizing the plot's topography, location and soil type. In this specification, the coefficient on, say, a dummy variable representing a soil type can be interpreted as the percentage increase in the yield of a plot of that soil type over the base soil type. There is concern about heteroskedasticity and the standard errors are appropriately adjusted.

(13a) is identical to (12), while (13b) replaces the village-year-crop fixed effect with a household-year-crop fixed effect. Attention is restricted to one farmer in each household, so the distribution of ϵ^h reflects the variation in yields across apparently identical plots cultivated by a single individual. The distribution of ϵ^h, therefore, is a function of the distribution of ϕ across plots controlled by an individual. Now consider ϵ^v, the error term defined in (13a). If the distribution of ϕ across plots within a household-year-crop group is the same across plots within a village-year-crop group, then if separation is valid, the distribution of ϵ^v should be the same as that of ϵ^h. The first series of tests, therefore, is based on a comparison of the distributions of ϵ^v and ϵ^h.

The second line of questions is based on the exclusion restrictions implied by (8). (8) implies that γ=0 in the regression

$$(14) \qquad Q_{vhtci} = X_{vhtci}\beta + E_{vhtci}\gamma + \lambda_{vtc} + \epsilon_{vhtci},$$

where E_{vhtci} is the exclusion restriction under consideration. I consider tests based on three sorts of exclusion restrictions: farm size, household demographics, and wealth or cash flow.

The first exclusion restriction is that the total area cultivated by the household should have no effect on output on a particular plot if the null hypothesis is correct. This test is closely related to the large literature which finds an inverse relationship between farm size and yield, or farm size and labor demand.[6] If agricultural production is governed by a CES technology with constant returns to scale, then the log of farm area should have a coefficient of zero in a regression of the log of yield on the log of farm area (see equation (10'), v=1 is the case of constant returns to scale). In fact, it is often found that the coefficient of farm area is negative. The earliest and most popular explanation for this regularity is market failure of some sort - small and large farms face

[6]The most recent paper in this tradition is Barrett (1996).

different opportunity costs and hence optimally choose different mixes of inputs on their farms. This type of explanation is sensible and probably correct in many instances, but the connection between the result and the conclusion is not direct. Bhalla (1988) and Benjamin (1991) argue that unobserved variations in land quality could underlie the oft-observed inverse relationship between farm size and yield - larger farms are less fertile, and thus are optimally farmed less intensively. The analysis in this paper is conducted at the plot level, as specified in (12), with E_{vhtci} defined as the area cultivated by the household on plots other than plot i. I show below that this mitigates the problem of measurement error.

The second series of tests is based on household demographic measures. This is a standard test of the assumptions which imply separation. Do larger households (controlling for land area) farm more intensively? Benjamin (1992), Kevane (1994) and Pitt and Rosenzweig (1986) are key recent papers. The third set of tests is concerned with correlations between input demand and non-farm wealth, income and cash flow (Swamy, 1993; Chaudhuri, 1993; Morduch, 1990; Rosenzweig and Binswanger, 1993).

i. Unobserved Plot Quality Variation and Type I Error.

Each of these tests, however, is subject to a similar important econometric caveat. Under separation, cropping decisions depend only on prices and plot characteristics. I can account for prices through village fixed effects provided that the model is linear. Plot characteristics, however, are problematic. There is undoubtedly unobserved variation in land quality. Therefore, there is a classic omitted variables problem and the bias induced by this problem could lead us to reject the null hypothesis of separation when separation is in fact true.

Consider the relationship between farm size and output. Suppose that in fact F(.) exhibits constant returns to scale and that separation is true. Suppose, however, that there are unobserved (to the analyst) plot characteristics (soil type, weather shocks, etc...), so that $Q_{vhi} = F(L_{vhi},T_{vhi})$, where $T_{vhi} = A_{vhi}(1+\theta_{vhi})$, A_{vhi} is observed plot area and θ_{vhi} is an unobserved land-augmenting plot characteristic (dropping tc subscripts to shorten the notation). A regression of output on T would yield an estimated coefficient of one, given the validity of the separation hypothesis. However, the regression of output on plot area is subject to omitted variables bias because θ_{vhi} is not included in the regression. The sign and size of that bias depends on the covariance of A and θ. If the unobserved variation in land quality is uncorrelated with the area of the plot then the regression is subject to attenuation bias and we will find a less than proportional relationship between output and plot area.

Worse, there is reason to expect that unobserved land quality is worse on larger plots than on smaller plots. Suppose, for example, that all markets exist and operate smoothly except the labor market. If each household has access to one type of land (θ_{vhi}) and cultivates only one plot, then in each state of each period, each household's production problem is to solve:

$$(8'') \qquad \underset{A_{vhi} \geq 0}{Max} \; qF(L_{vh}, A_{vhi}(1+\theta_{vhi})) - r(\theta_{vhi})\,A_{vhi},$$

where L_{vh} is the amount of labor time the household chooses to spend working. Choose units so that for some plot k, $\theta_k=0$. Then define $r = r(\theta_k)$. Competition in the land market ensures that $r_{vhi}=r\cdot(1+\theta_{vhi})$. By the implicit function theorem, $\frac{\delta A}{\delta\theta} = -\frac{A_{vhi}}{(1+\theta_{vhi})} < 0$. Hence plot quality will be negatively correlated with plot size in the cross-section. A regression of yield on T would produce an estimated coefficient of 0. The omission of land quality from the regression of yield on land area, however, will bias the estimated coefficient on land area down from zero because of the negative correlation between unobserved land quality and land area.

It is also true, of course, that if F() has DRTS ($v < 1$ in (10')) then there will be a direct technological explanation for the inverse relationship. In order to eliminate the technological possibility and to attenuate the problem of unobserved land quality, I propose to estimate (14) with E_{vhtci} equal to the area of *other* household plots.[7] Are plots of a given size cultivated differently depending upon the total area on other plots that are cultivated by the same household?

It is clear that this specification eliminates the potential technological explanation for the inverse relationship. It also mitigates, but does *not* eliminate, the problem of omitted variables bias due to unobserved variation in plot quality. Under the null hypothesis of separation, we expect γ in (14) to be zero. Any attenuation bias due to unobserved variation in land quality that is uncorrelated with farm area, therefore, cannot cause a false rejection of the null. However, there is still reason to expect an inverse correlation between the quality of a given plot and the area cultivated by the household on other plots. To see why, consider the household's problem when it cultivates many plots of different qualities:

$$(8''') \qquad \underset{A_{vhi}, L_{vhi} \geq 0}{Max} \sum_{i \in P} \left[F(L_{vhi}, A_{vhi}(1+\theta_{vhi})) - r \cdot (1+\theta_{vhi}) A_{vhi} \right]$$
$$s.t. \ \sum_{i \in P} L_{vhi} \leq E_{vh}$$

If F() is constant returns to scale, *(8''')* implies that $\dfrac{\sum_{i \in P} (A_{vhi} \cdot \theta_{vhi})}{E_{vh}}$ is a constant which depends

[7]Blarel et al. conduct a similar exercise, but don't examine the implications for separation.

only on r. Hence if for a plot i, θ_{vhi} is particularly low, then the household optimally farms that land with relatively low intensity. At the same time (given E and r), the household optimally acquires more land, either on plot i or on other plots. If some of the land acquired is on other plots, there will be a negative correlation between the quality of plot i and the area cultivated by the household on other plots. We would then estimate $\gamma<0$ even if separation is valid.

The tests of exclusion restrictions with respect to demographic variables are also subject to misinterpretation as a consequence of unobserved variation in plot quality. Suppose again that labor markets do not work well, but that land rental markets remain perfect, so that separation still holds. It remains the case that under constant returns to scale the ratio of quality adjusted land holdings to household labor availability is a constant. If households can choose the quality of the land that they cultivate (by choosing which plots to cultivate), then household size will be positively correlated with unobserved land quality. Unobserved land quality is also a potential cause of misinterpretation of tests of exclusion restrictions with respect to cash flow or wealth. Unobserved good quality land can be associated with high income, wealth and cash flow, hence potentially causing γ to appear positive even if separation is true.

There are a variety of avenues for exploring the potential importance of unobserved variation in plot quality beyond the strategy of attenuating the bias by using plot level information.

a. The natural solution, of course, is to use IV estimates. Unfortunately, while there are plenty of variables that are correlated with farm size, plot size, household demographics and non-farm income, it is very difficult to make the case that any of these are uncorrelated with unobserved land quality. I have not, therefore, been able to identify likely instruments in any of the available datasets.

b. Unobserved land quality variation is less of an issue in one of the data sets used in this paper than in most data from developing countries. The ICRISAT Burkina Faso data contains rich information on plot characteristics. For the other data, the use of village-crop-year fixed effects, as well as some plot-specific information, permits a finer degree of control for land quality than has been possible in most previous investigations of related issues (Benjamin, 1992, 1994). In addition, some diagnostic lessons may be drawn from the exercise of conducting tests of the exclusion restrictions with and without a subset of the plot characteristics data. If unobserved land quality is positively correlated with observed land quality, and if inclusion of observed measures of land quality reduces the effect of the test variables, this heightens our concern that unobserved land quality may be causing false rejections of the null of separation.

c. It is possible (though difficult) to trace plots over time in some of these data. This is implemented in the Kenya data set discussed below. Plot fixed effects, then, can control for unobserved land quality. Many observations are lost due to the difficulty of matching plots, and there is heightened concern regarding measurement error in the variables tested for exclusion (Ashenfelter *et al*), but the additional confidence gained with respect to land quality is valuable.

ii. What Causes Rejections of Separation?

Suppose that it is found that output on one plot controlled by a household decreases with the amount of land on other plots cultivated by the household, and increases in the size of the household, and that it is concluded that these correlations are not attributable to specification error. It would seem that the implication is that both labor and land markets in the economy under investigation are imperfect, thus preventing households from realizing the gains which are potentially available from trading land or labor to equalize marginal products across plots controlled by different households. It is true, in fact, that (14) can detect violations of the assumption of perfect labor and/or land markets.[8] However, Srinivasan (1972) (and more recently Feder, 1985; Eswaran and Kotwal, 1986; Carter and Wiebe, 1990; Banerjee and Newman, 1993; Barrett, 1996) show that violations of the assumption of complete insurance or intertemporal markets can also cause rejections of the exclusion restrictions with respect to household demographics or the area of other plots.

To examine the import of this ambiguity, consider the simplest model in which it can arise. There are two states of nature (the probability of state 1 is π) with multiplicative production risk (θ_i). A household with fixed land and labor endowments makes production and labor-leisure decisions before the resolution of output uncertainty. With complete labor and insurance markets, (but no land market) the household's problem is to:

$$\tag{13} \begin{aligned} &\underset{c_1, c_2, l, L^f}{Max} \quad \pi U(c_1, l) \ + \ (1-\pi) U(c_2, l) \\ &s.t. \ \ p_1 c_1 + p_2 c_2 + wl \le (p_1 \theta_1 + p_2 \theta_2) f(L^f) - wL^f + wE \end{aligned}$$

where L^f is the amount of labor used on the farm, and E is the household's labor endowment. Separation holds, and the household maximizes profit on the farm. In contrast, if there are complete insurance markets, but no labor market, then the household solves:

$$\tag{14} \begin{aligned} &\underset{c_1, c_2, l}{Max} \ \ \pi U(c_1, l) \ + \ (1-\pi) U(c_2, l) \\ &s.t. \ \ p_1 c_1 + p_2 c_2 \le (p_1 \theta_1 + p_2 \theta_2) f(E - l). \end{aligned}$$

[8] Benjamin (1992) provides a thorough discussion of the power of a similar test to detect specific violations of the assumption of perfect labor markets when E contains demographic variables. He examines the specific alternative hypotheses that there is a binding constrain on obtaining off-farm employment, a binding constraint on hiring labor, and the more general possibility that the returns to on- and off-farm labor differ. Bardhan (book) offers a similar treatment of the power of the test when E contains farm size.

This is analogous to Sen's (1966) formulation of an autarkic farm household under certainty and separation is violated. Farm output increases in the household's labor endowment.[9]

Finally, if the labor market is complete, but there is no insurance the household solves:

$$(15)\qquad \begin{aligned} &\underset{c_1,c_2,l,L^f}{Max}\ \ \pi U(c_1,l)\ +\ (1-\pi)U(c_2,l) \\ &s.t.\ \ p_1c_1 + wl \le p_1\theta_1 f(L^f) - wL^f + wE \\ &\qquad p_2c_2 + wl \le p_2\theta_2 f(L^f) - wL^f + wE. \end{aligned}$$

The first order conditions of this problem include

$$(16)\qquad 0\ =\ \lambda_1(\theta_1 p_1 f'(L^f) - w) + \lambda_2(\theta_2 p_2 f'(L^f) - w)$$

where λ_i is the marginal utility of income in state i. Separation does not hold because input decisions depend on the ratio of the marginal utility of income in the two states. An increase in the household's endowment of labor will affect this ratio (increasing λ_1 relative to λ_2 if $\theta_1 > \theta_2$ and the household has diminishing absolute risk aversion) and thus change input decisions.

The violation of separation along a particular dimension - in this instance the correlation between household demographics and production - is not conclusive evidence of a particular market failure. However, we can examine the separation hypothesis along various dimensions (in this paper, effects of household demographics, farm size, and non-farm income). Particular configurations of results that are revealed by this series of tests *can* provide evidence of particular

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[9] To be more precise, if derivatives are denoted by subscripts, λ is the lagrange multiplier, and $U_{cl}=0$, then $\frac{dL^f}{dL} = \frac{\pi U^1_{ll} + (1-\pi)U^2_{ll}}{\pi U^1_{ll} + (1-\pi)U^2_{ll} + \lambda f_{LL}}$ which is positive and less than one.

market failures. A complete taxonomy is possible, but it would be lengthy. Instead, I provide this analysis in the discussion of the results of the case studies in Kenya and Burkina Faso (section 4).

3. Data

A. Burkina Faso

The data used for this study are drawn from the Burkina Faso farm household survey conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).[10] The survey was a four year panel study (1981-1985) of 150 households in six villages in three different agro-climatic zones of Burkina Faso. This study uses data from the first three agricultural seasons of the survey (1981-83), during which the most detailed agronomic information was collected. During these three seasons, enumerators visited the sample households approximately every 10 days to collect information on farm operations, inputs and outputs on each of the household's plots since the previous visit. These three seasons of data collection result in 432 household-years of data on agricultural activities, with usable data on a total of 2576 plots cultivated by household heads.[11] An important advantage of these data for this study is the fact that they contain rich descriptive information concerning the area (measured by the enumerators), topography, location and soil characteristics of the plots cultivated by the households.

All of the farmers in the survey are poor, with an average income *per capita* of less than

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[10]See Matlon (1988) for documentation of the survey.

[11]4787 plots were cultivated by the sample households over the three years; 132 of these plots did not have their area measured and so were dropped from the sample. 2079 plots were excluded because they were cultivated by people other than household heads, thus raising complex issues of intrahousehold resource allocation.

$100 (Fafchamps, 1993). The farming system is characteristic of rainfed agriculture in semi-arid Africa: each household simultaneously cultivates multiple plots (10 is the median number of plots per household in any year) and many different crops (a median of 6 different primary crops on the plots farmed by a household in a given year).

B. Kenya

The Kenya data are drawn from a 1985/87 survey of 617 households conducted by IFPRI in South Nyanza, a sugar-growing area of Kenya (see Cogill, 1987 for a description of the survey). Data from two rounds of this survey, covering successive cropping seasons, is used. There is usable data on output on 3194 cultivated plots over these two seasons. These data do not contain as rich information on plot characteristics as do the data from Burkina Faso, but they do have an important advantage. Many of the plots can be traced over the two seasons, permitting the use of fixed effect estimators to mitigate the problem of unobserved plot characteristics. As in Burkina Faso, the Kenyan households are poor, with an income *per-capita* of about $120 (Kennedy, 1989). Households farm multiple plots (an average of 6 plots per household) and many crops (about 8 different crops), though maize is the dominant crop, accounting for between 15 and 30 percent of all farm area, depending on the season (Cogill, 1987). Summary data from both data sets is provided in Table 1.

4. Testing for Profit Maximization

A. Burkina Faso

We begin by examining the characteristics of ϵ^v and ϵ^h in the two regressions (13a) and (13b). X_{vhtci} includes the rich set of plot descriptors discussed in section 3A, and λ_{vtc} and λ_{vhtc} are village-year-crop and household-year-crop fixed effects. The sample is limited to plots cultivated by household heads (rather than all plots within households) because of the evidence presented in Udry (1996) that separation is violated across plots controlled by different individuals within households. I maintain the hypothesis the household head is free to rearrange resources across the plots he controls as an individual, so separation is a maintained hypothesis in (13b). ϵ^h, therefore, is zero in the absence of measurement error in Q, unobserved variation in plot quality, and plot-specific risk (which can be considered a form of unobserved variation in plot quality). In fact, measurement error exists and ϵ^h is not zero: Figure 1 reports a kernel estimate of its distribution. Figure 2 reports the analogous distribution for plot-specific labor demand.

Consider the joint null hypothesis that: (1) separation holds within the village; and (2) the distribution of measurement error in Q and unobserved variation in plot quality is the same across households as it is across plots controlled by an individual household head. Under this null, the distribution of ϵ^v is the same as that of ϵ^h. However, the estimates indicate that ϵ^v has a much more diffuse distribution.[12] There is much more variation in both yield and labor demand per hectare across similar plots controlled by different households within a village than there is across plots controlled by a single individual. Some of this additional variation may be a consequence of greater unobserved plot quality variation across plots controlled by different households than across plots within a household. The force of this plausible explanation is reduced, however, by recognition of the fact that plots controlled by individual household heads are dispersed throughout the village land, probably as one element in an effort to diversify risk. The much larger dispersion of ϵ^v than ϵ^h raises the possibility that the separation hypothesis is violated.

[12] Equivalently, the F(1684,706) test statistic of the hypothesis that $\lambda_{vhtc}=\lambda_{vtc}$ has a value of 1.429 (p=0.00).

Further evidence that separation is violated is provided by the correlations between plot yield or input intensity and a series of variables which should be orthogonal to yield and input intensity (conditional, of course on plot characteristics and prices). Table 2, column 1 reports the results of estimating (14) with E_{vhtci} equal to the log of household size. In apparent violation of profit maximization, plot yield is increasing in household size, conditional on prices and all observed characteristics of the plot. The elasticity is about .2 and is significantly different from zero at any conventional significance level. It is necessary to interpret these results cautiously because, as noted in section 2B, they could be an artifact of a correlation between unobserved plot quality and household size. Turn now to an examination of the relationship between plot yield and the area cultivated by the household on other plots. Again in apparent violation of the separation hypothesis, column 2 of Table 2 reports a highly significant correlation between plot yield and the area cultivated by the household on other plots. In this instance, however, plot yield *increases* with the area cultivated on other plots. This is a striking result, because the implication of conventional land and labor market imperfections would have been a negative correlation between farm size and plot yield; similarly (as shown in section 2Bi) unobserved variation in plot quality would be expected to lead to a negative correlation between farm size and plot yield. This result provides further evidence of violations of the separation hypothesis in Burkina Faso, but broadens the range of potential market failures which should be considered: households with larger farms cultivate their land more intensively than other households, raising the possibility of imperfections in credit or insurance markets.

Following Chaudhuri (1993), I explore the possibility of credit constraints by calculating the correlation between yield (or input intensity) and short-run measures of cash flow. It is possible to use the ICRISAT data to calculate income from non-farm activities and gifts for the four month preceding clearing activities for the single annual crop season. Estimates of (14) with E_{vhtci} equal to the log of these resource inflows are reported in Table 2, column 3 (the results are very similar when non-farm income and gifts are entered separately). Similar plots within village-crop-year groups of plots are cultivated more intensively by households which receive higher short-term resource inflows.

There is a positive correlation between plot yield and household size, area cultivated by the household on other plots, and short term resource inflows conditional on all observable plot characteristics. The results presented in Table 2, column 4, however, indicate that conditional on short-term resource inflows and household size (and plot characteristics), plot yield does not vary with the area cultivated on other plots. On the other hand, plot yield is higher for large households with large short-term inflows of non farm resources, conditional on other household characteristics.

Despite the rich information available in this data set regarding plot characteristics, measurement error induced by unobserved variation in plot quality remains a concern. One possible interpretation of the results revealed in Columns 1-4 of Table 2 is that there are certain wealthy households which cultivate large amounts of land, receive a great deal of nonfarm income, and have many members, and that these households also control land of particularly high (unobserved) quality. The panel nature of the data permits us to mitigate this concern by controlling for the average (over time) quality of each household's land. Column 5 of Table 2, therefore, reports the results of estimating (12) with household fixed effects as well as the village-year-crop fixed effect. The results change in a manner consistent with the interpretation above.

Conditional on the household effect, increases in the area cultivated on other plots are now associated with declines in yield on a given plot. The elasticity is large and statistically significant. Increases in inflows of nonfarm resources remain associated with increases in plot yield - the elasticity is .1 and statistically significant. Changes in household size have no perceptible relationship to plot yield, which may be a consequence of the relative stability of household size over the three years.

Interpretation:

This pattern of results: a negative correlation between yield and the area cultivated on other plots and a positive correlation between yield and short-term inflows of nonfarm resources and (possibly) between yield and household size have strong implications for the structure of rural markets. First, simple labor and land market imperfections would not lead to this pattern of results. If the only market failure is that labor and land cannot be traded, than an increase in nonfarm resources would be associated with an increase in leisure and hence a reduction in yield.[13] However, a combination of financial market and land market failures leads directly to the pattern of correlations observed in the data. Suppose that the labor market operates freely, but that there is a binding cash-in-advance constraint on production in the first period. Increases in nonfarm

[13]Consider the simplest model of a labor market imperfection with smoothly operating credit markets. Production takes time, so labor and land are used in period 1 to produce output in period 2. Consumption of goods occurs in both periods, and there is an inflow of nonfarm resources (G) in period 1. The price vector of the consumption bundle in period t is p_t and the output price is q_2. The household has E units of labor, and T of land. The household solves (suppressing the standard non-negativity constraints):

$$\max_{c_1,\, l_1,\, c_2} \; U(c_1, l_1, c_2)$$
$$s.t. \quad p_1 c_1 + p_2 c_2 \le q_2 F(E - l_1, T) + G,$$

which has a first order condition of $U_l = \lambda q_2 F_l$, where λ is the lagrange multiplier and $\delta\lambda/\delta G<0$. Hence $\delta l_1/\delta G>0$ and yield falls with nonfarm resources.

resource inflows or household size relax this constraint and permit yields to rise, while an increase in area cultivated on other plots dilutes available inputs and lowers yields.[14] The observed pattern of empirical results, therefore, is consistent with imperfections in the financial and land markets, rather than with labor market imperfections.

Turning to data on farm inputs, Table 3 reports estimated demand functions for the two most important farm inputs. Columns 1 and 2 estimate the determinants of log plot labor demand per hectare. In column 1, household effects are omitted and a strong positive correlation is found between plot labor demand and household size, while plot labor demand declines as the area cultivated on other plots increases. When household effects are added to the model, the correlation between household size and plot labor use disappears, but plot labor demand remains strongly decreasing in the area cultivated by the household on other plots. Column 3 reports estimates of the determinants of plot manure demand per hectare. Manure use on a particular plot declines with increases in the area cultivated by the household on other plots. There is no observable effect of inflows of nonfarm resources on either labor or manure demand, despite the strong correlation between such inflows and plot yield. A plausible interpretation of this contrast is that inflows of nonfarm resources affect the timing rather than the level of input application.

There is strong evidence of violations of profit maximization in Burkina Faso associated in

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[14] The utility function is the same as in the previous footnote. The budget constraints now must be met period-by-period:

$$p_1 c_1 + w_1 (L^f - (E - l_1)) \leq G$$
$$p_2 c_2 \leq q_2 F(L^f, T)$$

where L^f is labor demand on the household's farm. The first order conditions include $\lambda_1/\lambda_2 \cdot w_1 = q_2 \cdot \partial F/\partial L^f$, where λ_t is the lagrange multiplier on the period t budget constraint and $\delta(\lambda_1/\lambda_2)/\delta G < 0$. Hence we have $\delta L^f/\delta G = w_1 \cdot \delta L^f/\delta L > 0$. With F() CRTS, after some algebra one can show $0 < \delta L^f/\delta T < 1$, hence yield declines with larger farm size.

particular with changes in the area cultivated by a household on other plots, and with inflows of non-farming resources. Increases in the inflow of resources not directly tied to cultivation are associated with more intensive cultivation, and increases in total farm size are associated with declines in the intensity of cultivation on particular plots. The finding with respect to nonfarm resources complements the work of Savadogo, Reardon and Pietola (1994) and Reardon, Crawford and Kelley (1994), who find in Burkina Faso that households with higher nonfarm income (averaged over a period of years) are more likely to use intensive methods of cultivation (e.g., animal traction). The pattern is strikingly reminiscent of Polly Hill's (1982) argument that poor farming households in the savannah of northern Nigeria are "too poor to farm". She argues that a "householder who has an empty granary at the beginning of the farming season may well have to earn his living every day by means of sundry paid occupations, including farm-labouring, so that he has no time to cultivate on his own account ... [T]here are many other circumstances in which it ['too poor to farm'] applies, such as when manure is lacking" (pp. 69-70).

These results provide some evidence concerning the source of the market failure. Standard models of labor market imperfections obviously could underlie the inverse correlation between farm size and the intensity of cultivation of plots. The same imperfections, however, would induce a negative correlation between inflows of nonfarm resources and cultivation intensity rather than the positive correlation which is observed in the data. An increased inflow of nonfarm resources would relax the household's budget constraint, inducing the household to consume more leisure and thus (with imperfect labor markets) to use less labor on their plots.

In contrast, capital market imperfections could cause both of the correlations observed in the data. With liquidity constraints, an increase in the availability of nonfarm resources permits the household to cultivate more intensively, and an increase in the size of the farm cultivated by the household further dilutes available resources and reduces the intensity of cultivation of a given plot. These results suggest, therefore, that further research on market imperfections in Burkina Faso begin with an examination of financial markets.

B. Kenya

The analysis begins with an examination of the residuals in the regressions (13a) and (13b). In this instance, X_{vhtci} includes a much less rich set of plot characteristics. I maintain the hypothesis that the household is free to allocate factors of production efficiently across its various plots, hence ϵ^h would be zero in the absence of measurement error in plot quality or yield. Figure 3 reports the distribution of ϵ^h and the corresponding distribution of ϵ^v.

Yield is much more dispersed across similar plots cultivated by different households than it is across similar plots cultivated by a single household (the F(1549,128) test statistic of the hypothesis that $\lambda_{htc}=\lambda_{tc}$ has a value of 1.836 (p=0.00)). As was the case in Burkina Faso, the much larger dispersion of ϵ^v raises the possibility that the separation hypothesis is violated at the village level. However, given the limited information available about plot characteristics, there is particular reason to be concerned that these results are contaminated by measurement error. The estimates of β from (13a) and (13b) are presented in columns 1 and 2 of Table 4. If there were no unobserved variations in plot quality, and the production function were CES with CRTS, than the coefficient of the log of plot area would be zero. The fact that this coefficient is so negative is striking, and it is difficult to believe that agricultural production is characterized by such strongly decreasing returns to scale. An inverse correlation between plot size and quality could account for this result. More importantly, the large decline in the coefficient on plot size when moving from the household-crop-season fixed effects to the crop-season fixed effects specification can be interpreted as evidence that the dispersion of these unobserved plot characteristics is larger across plots in the region than it is across plots controlled by individual households. This casts doubt on the interpretation of the larger spread of ϵ^v than ϵ^h as an indicator of non-separation.

It is reasonable, therefore, to treat the tests of exclusion restrictions presented in Table 5 with caution. Column 1 presents the results of the regression testing the exclusion restriction with respect to household size. Plot output is strongly increasing in household size and the coefficient is statistically significant at any conventional level. One interpretation of this result is that with imperfect labor markets, larger households farm their plots more intensively, but other market imperfections and measurement error correlated with household size should also be considered. Column 2 of Table 5 shows that plot output is also increasing with the amount of land cultivated by the household on other plots. As in Burkina Faso, this correlation is opposite of that which would be expected in the presence of conventional land and labor market imperfections or unobserved variation in land quality. Households with larger farms seem to cultivate their land more intensively than other households.

Columns 3 and 4 of Table 5 present exclusion restrictions with respect to short-run measures of cash flow. The log of the sum of non-farm income and gifts and remittances received in the preceding two months is not significantly correlated with plot output, though if attention is restricted to non-farm income the correlation is significant at the 2 percent level (column 4). There is weak evidence, therefore, that short-run resource inflows are positively related to the intensity of cultivation, in violation of separation. Finally, the results in column 5 indicate that plot output increases in both household size and the area cultivated by the household conditional on plot and other household characteristics. As was the case in Burkina Faso, a case could be made that this set of results provides evidence in support of the vision of African rural economies in which poor households are small, have relatively little land, and face resource constraints which prevent them from farming efficiently.

These conclusions, however, have to be drawn with extreme care in this instance. The relatively meager amount of information which is available about plot quality, coupled with the dramatically negative relationship between plot size and plot yield in the data raise serious issues of potential measurement error. It may be that households with large families and large amounts of land have particularly good land (as a consequence, perhaps, of a political process of land allocation), and thus are optimally farming their plots particularly intensively. Fortunately, it seems possible to address this issue decisively with these data, because many plots can be traced over time. Unobserved characteristics of the plot which are constant over the two seasons can be differenced away, so any correlation between such characteristics and household characteristics no longer influences the results.

Table 6 presents a series of simple tests of the exclusion restrictions with plot and crop-season fixed effects. The tests are cross tabulations of changes in plot output (and plot labor use) against changes in household size, area on other plots, and inflows of gifts and nonfarm income (net of crop-season effects). Row 1 indicates that output increases by more on plots controlled by households which grow in size than on plots controlled by households which shrink or remain the same size. The difference is significant only at the 10 percent level. Row 2 provides interesting, but statistically insignificant, evidence that output increases more on plots cultivated by households which increase their cultivated area than on plots controlled by other households.

This would complement the similar striking finding in Burkina Faso, but the evidence in Kenya is quite weak. The third row provides weak evidence that output on plots controlled by households which experience increases in financial inflows declines by more than on plots controlled by other households, but the difference is not significantly different from zero at conventional levels.

Rows 4 through 6 examine labor inputs, and provide striking evidence against separation in the Kenyan data. Labor use grows significantly more on plots controlled by households which grow than on plots controlled by other households. Conversely, labor use diminishes significantly more on plots controlled by households which increase their cultivated area than on plots controlled by other households. Both results accord with conventional models of labor and land market imperfections.

Table 7 presents a multiple regression analysis of the relationship between the growth in plot output and the growth in household size, cultivated area, and financial inflows. The precision of the estimates is quite low, so no conclusions can be drawn from this set of results.

The plot fixed effect analysis presented in this section is a useful response to the most important econometric worry associated with this research program - the possibility that unobserved characteristics of plots are correlated with the household characteristics thus causing false rejections of the profit-maximization hypothesis. The procedure, however, does have significant weaknesses. Eliminating the plot fixed effect also eliminates much potentially useful information, and if there is measurement error in the household characteristics of interest the impact of that measurement error is magnified relative to analysis without fixed effects. In this particular example, the short time period (6 months) between the two rounds is associated with only small changes in the relevant household characteristics and thus tests with relatively low power to detect violations of separation.

Nevertheless, certain patterns do emerge from the data. The intensity of labor use on plots increases with household size, and decreases with the area cultivated on other plots by the household. The overall pattern, therefore, is that there is strong evidence that the separation hypothesis is violated in Kenya, and the pattern (with one exception) corresponds to the relatively simple situation of absent labor and land markets. The exception is that plot output may be increasing in the area cultivated on other plots, which suggests an interesting relationship between nonlabor inputs and household resources. This result however, is statistically significant only at the 20 percent level, and thus must be treated with extreme caution.

5. Profit Maximization in Africa

This paper has provided evidence against the hypothesis that farmers maximize profits in two African settings. In each case, it was shown that plot level production decisions are affected by factors other than prices and the characteristics of the plot itself, and thus that the hypothesis that production decisions are separable from the rest of the households' allocation decisions is not correct.

In Burkina Faso, violations of the separation hypothesis are indicated by correlations between the intensity of cultivation and short-term resource inflows (non-farm income and gifts) over the months preceding planting and between the intensity of cultivation and farm size. The estimates indicate that plot yield increases by 11 percent when non-farm income and gifts double. Plot yield declines by about 15 percent when the area cultivated on other plots doubles. There are strikingly large changes in the allocation of factors of production on a particular plot associated with increases in the area cultivated by the household on other plots. A doubling of farm size leads to a decline of over 15 percent in plot labor use per hectare, while a one standard deviation increase in farm size is associated with a decline in manure use per hectare of over 1000 kilograms (the average manure application per hectare is about 3,250 kg).

In Kenya, the allocation of labor to plots is strongly correlated with household size and farm area. On average, 20 days of labor (the sum of male, female and hired labor) is used on plots in the sample. On plots controlled by households which grew more slowly than average, labor use increased by about 10 days more than on plots controlled by households which grew more slowly than average. Similarly, on plots controlled by households whose overall farm size grew more slowly than average, labor use increased by about 9 days more than on plots controlled by households whose overall farm size grew more quickly than average.

In both Kenya and Burkina Faso, therefore, there are economically large and statistically significant divergences between actual input allocation decisions and those which would be predicted in a simple model of a profit-maximizing farmer. In neither case can the cause of the divergence be determined with certainty using the broad-brush methods of this paper. A rejection of the separation hypothesis can be caused by any number of possible market failures. However, the pattern of results is suggestive: in Burkina Faso the fact that plot output is correlated with nonfarm income and gifts as well as with farm size suggests that further investigation include a close look at capital and insurance markets; in Kenya the fact that plot labor demand is correlated with household and farm size rather than with nonfarm income suggests that future work focus first on possible imperfections in land and labor markets.

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Table 1: Descriptive Statistics

	Median output per ha.	Median labor per ha.	Mean manure per ha.	Mean household Size	Mean Cultivated Area (Ha)	Mean Non-Farm Resource Inflows	Per-capita Land (Ha./Person)	
							33rd %tile	66th %tile
Burkina Faso	36.13 (1000 CFA)	2127 hrs.	3.28 (1000 Kg)	10.17	4.79	93.10 (1000 CFA)	.31	.53
Kenya	0.38 (1000 KSh)	15 days	n.a.	9.59	2.20	2.33 (1000 KSh)	.09	.58

Table 2: Estimates of the Determinants of Log Plot Output per Hectare
ICRISAT Burkina Faso Data

	1 Village-year-crop Fixed Effects		2 Village-year-crop Fixed Effects		3 Village-year-crop Fixed Effects		4 Village-year-crop Fixed Effects		5 Village-year-crop and Household Fixed Effects	
	Estimate	t	Estimate	t	Estimate	t	Estimate	t	Estimate	t
Log Plot Area	-0.240	-10.85	-0.203	-10.00	-0.217	-8.71	-0.241	-9.47	-0.303	-10.64
Log Household Size	0.176	5.98					0.089	2.04	-0.010	-0.07
Log Area on Other Plots			0.068	3.74			0.004	0.11	-0.144	-2.59
Log nonfarm income and gifts					0.070	4.10	0.052	2.54	0.109	2.27
Toposequence:										
Top of Slope	-0.445	-3.37	-0.418	-3.36	-0.477	-3.15	-0.503	-3.28	-0.415	-2.77
Near top	-0.258	-2.25	-0.249	-2.37	-0.369	-2.88	-0.362	-2.76	-0.296	-2.35
Mid Slope	-0.261	-2.31	-0.241	-2.34	-0.308	-2.43	-0.296	-2.27	-0.202	-1.63
Near Bottom	-0.225	-2.00	-0.204	-1.99	-0.371	-2.90	-0.372	-2.81	-0.251	-1.99
Soil Types:										
soil7	-0.163	-1.42	-0.169	-1.46	-0.100	-0.82	-0.115	-0.93	-0.117	-0.83
soil21	0.135	1.00	0.120	1.01	-0.132	-0.63	-0.130	-0.52	-0.249	-1.06
soil31	-0.045	-0.43	-0.065	-0.71	-0.159	-1.33	-0.141	-1.18	-0.101	-0.81
soil32	-0.128	-1.17	-0.131	-1.33	-0.199	-1.61	-0.201	-1.63	-0.156	-1.21
soil33	0.013	0.08	0.058	0.46	0.016	0.10	-0.002	-0.01	0.208	1.05
soil37	0.001	0.01	-0.004	-0.03	0.001	0.01	0.014	0.10	0.125	0.87
soil35	-0.080	-0.45	0.054	0.41	-0.019	-0.10	-0.043	-0.23	0.010	0.05
soil45	-0.081	-0.76	-0.089	-0.89	-0.238	-1.87	-0.233	-1.83	-0.100	-0.76
soil51	0.099	1.22	0.089	1.09	0.173	1.78	0.166	1.71	0.101	0.85
soil1	0.423	3.12	0.412	3.07	0.359	2.49	0.367	2.51	0.380	1.87
soil3	-0.164	-1.78	-0.127	-1.36	-0.147	-1.47	-0.164	-1.65	-0.052	-0.43
soil11	-0.475	-2.19	-0.523	-2.47	-0.792	-2.04	-0.863	-2.17	-1.185	-3.09
soil12	0.082	0.48	0.014	0.09	0.013	0.05	0.125	0.45	0.349	1.17
soil13	0.169	0.71	0.019	0.08	0.097	0.27	0.496	1.20	0.224	0.70
soil34	-0.184	-0.84	-0.226	-1.46	-0.181	-0.82	-0.181	-0.81	-0.108	-0.51
soil46	0.041	0.20	0.003	0.02	-0.046	-0.19	-0.048	-0.21	-0.105	-0.43
soil53	0.265	1.66	0.260	1.60	0.189	1.01	0.180	0.98	0.285	1.57
Compound Plot	0.152	2.55	0.193	3.59	0.174	2.52	0.149	2.13	0.098	1.30
Village Plot	0.122	2.65	0.126	2.92	0.133	2.51	0.144	2.73	0.125	2.21

notes: The dependant variable is the log of the value of all plot output per hectare. These are OLS estimates with village-year-crop fixed effects (in the first four columns) or with village-year-crop and household fixed effects (in the final column). The t-ratios are calculated from heteroskedasticity-consistent standard errors.

Table 3: Estimates of the Determinants of Log Plot Labor Demand and Plot Manure Demand per Hectare
ICRISAT Burkina Faso Data

	Log Plot Labor Demand per Hectare				Plot Manure Demand per Hectare (*1000 kg)	
	1 Village-year-crop Fixed Effects		2 Village-year-crop and Household Fixed Effects		3 Village-year-crop and Household Fixed Effects	
	Estimate	t	Estimate	t	Estimate	t
Log Plot Area	-0.301	-11.84	-0.317	-11.91	-1.980	-5.19
Log Household Size	0.158	4.29	0.097	0.94	-0.452	-0.35
Log Area on Other Plots	-0.059	-2.49	-0.164	-4.19	-1.375	-2.65
Log nonfarm income and gifts	0.012	0.73	-0.036	-0.90	-0.342	-0.63
Toposequence:						
Top of Slope	-0.197	-1.95	-0.179	-1.63	-1.579	-0.86
Near top	-0.274	-3.12	-0.240	-2.48	-2.545	-1.44
Mid Slope	-0.286	-3.36	-0.269	-2.87	-2.589	-1.52
Near Bottom	-0.228	-2.62	-0.165	-1.72	-2.874	-1.61
Soil Types:						
soil7	0.067	0.79	-0.087	-0.76	-0.290	-0.17
soil21	-0.063	-0.39	-0.067	-0.41	0.005	0.00
soil31	0.113	1.13	0.089	0.85	-0.651	-0.50
soil32	0.097	0.91	0.084	0.76	-0.808	-0.56
soil33	0.277	1.94	0.412	2.41	0.146	0.07
soil37	0.329	2.76	0.357	2.88	-1.711	-1.08
soil35	0.058	0.35	0.108	0.58	-0.813	-0.52
soil45	0.095	0.88	0.019	0.17	-0.581	-0.44
soil51	0.201	2.68	0.038	0.40	-1.038	-0.71
soil1	-0.075	-0.27	0.146	0.67	-8.494	-1.86
soil3	-0.041	-0.44	0.063	0.57	-2.407	-1.11
soil11	0.111	0.59	0.117	0.67	2.179	1.32
soil12	-0.163	-0.87	0.217	1.16	1.111	0.64
soil13	0.314	1.41	0.145	0.73	-0.820	-0.67
soil34	-0.098	-0.51	-0.129	-0.66	1.135	0.69
soil46	-0.073	-0.43	-0.027	-0.14	1.032	0.30
soil53	0.333	2.36	0.083	0.53	3.050	0.98
Compound Plot	-0.085	-1.46	-0.119	-1.88	-0.068	-0.08
Village Plot	-0.035	-0.80	-0.003	-0.06	0.590	0.89

notes: The dependant variable is the log of the sum of male, female, and nonhousehold labor per hectare used on the plot. These are OLS estimates with village-year-crop and household fixed effects. The t-ratios are calculated from heteroskedasticity-consistent standard errors.

Table 4: Estimates of the Determinants of Log Plot Output per Hectare
IFPRI Kenya Data

	1 Crop-Season Effects		2 Household-Crop-Season Effects	
	Estimate	t	Estimate	t
Log Plot Size	-0.530	-13.60	-0.334	-3.91
Soil Type:				
Poor	-0.371	-2.98	0.535	0.88
Average	-0.067	-1.28	0.108	1.00
Toposequence:				
topo1	0.023	0.13	0.117	2.69
topo2	0.069	0.39	0.088	0.40
topo3	0.055	0.29	-0.560	-1.73
topo4	0.018	0.07	0.970	1.51

notes: These are OLS estimates. The t-ratios are calculated from heteroskedasticity-consistent standard errors.

Table 5: Estimates of the Determinants of Log Plot Output per Hectare
Crop-Season Fixed Effects
IFPRI Kenya Data

	Specification 1		Specification 2		Specification 3		Specification 4		Specification 5	
	Estimate	t	Estimate	t	Estimate	t	Estimate	t	Estimate	t
Log Plot Size	-0.547	-14.24	-0.563	-14.05	-0.618	-11.67	-0.623	-10.04	-0.673	-10.57
Log Household Size	0.292	5.98							0.292	3.77
Log Area on other Plots			0.022	2.57					0.026	2.00
Log nonfarm income							0.064	2.50	0.032	1.16
Log nonfarm income and Gifts					0.029	1.41				
Soil Type:										
Poor	-0.362	-2.95	-0.365	-2.81	-0.334	-2.07	-0.500	-2.91	-0.559	-3.30
Average	-0.057	-1.10	-0.050	-0.92	-0.081	-1.19	-0.116	-1.40	-0.092	-1.09
Toposequence:										
topo1	0.005	0.03	0.071	0.37	-0.070	-0.34	-0.088	-0.40	-0.026	-0.12
topo2	0.061	0.35	0.114	0.61	-0.084	-0.43	-0.072	-0.34	-0.010	-0.04
topo3	0.057	0.30	0.077	0.38	-0.043	-0.18	0.067	0.25	0.095	0.35
topo4	0.014	0.06	0.021	0.08	-0.081	-0.28	-0.091	-0.30	-0.014	-0.04

notes: These are OLS estimates with season-crop fixed effects. The t-ratios are calculated from heteroskedasticity-consistent standard errors.

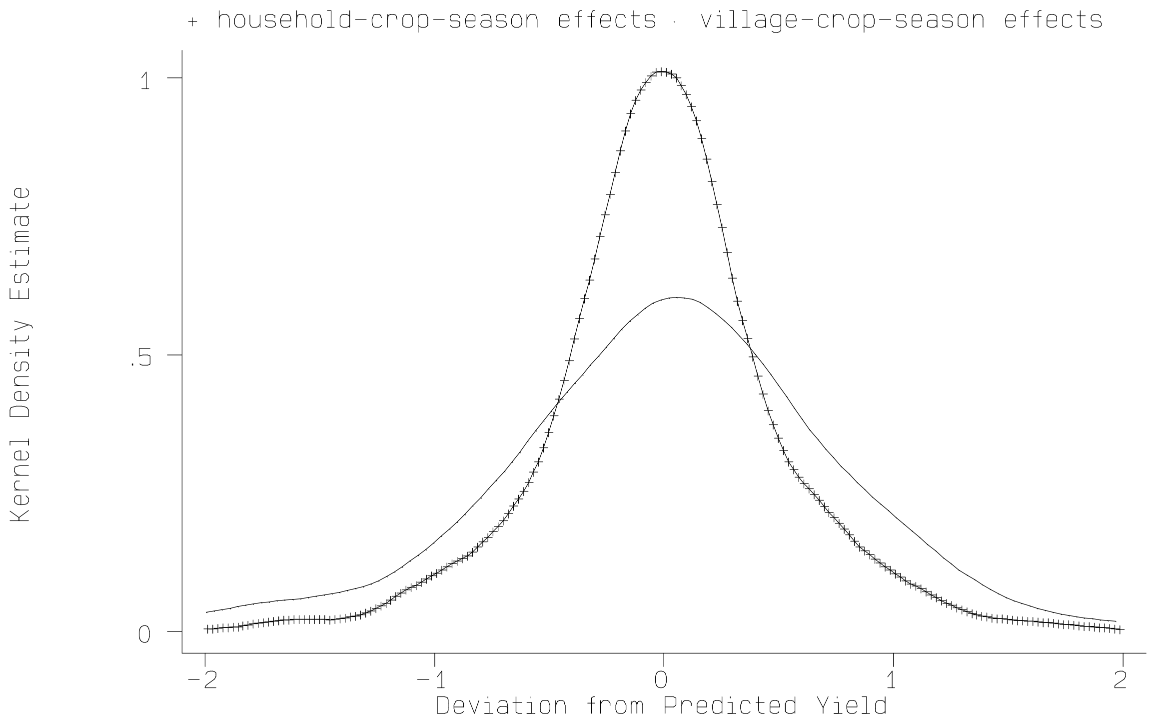
Table 6: Tests of Separation with Plot and Crop-Season Fixed Effects*

	Change in Plot Output		
		Mean Change in Output	t: H_0 is equal means
1	Δhousehold Size > 0	227.1	-1.78
	Δhousehold size ≤ 0	-63.7	
2	Δarea on other plots > 0	109.3	-1.24
	Δarea on other plots ≤ 0	-84.2	
3	Δgifts and nonfarm income > 0	-54.5	1.19
	Δgifts and nonfarm income ≤ 0	119.7	
	Change in Plot Labor Use		
		Mean Change in Labor Use/Ha.	t: H_0 is equal means
4	Δhousehold Size > 0	7.27	-2.09
	Δhousehold size ≤ 0	-2.81	
5	Δarea on other plots > 0	-5.69	2.35
	Δarea on other plots ≤ 0	3.52	
6	Δgifts and nonfarm income > 0	.89	-0.76
	Δgifts and nonfarm income ≤ 0	-2.10	

*Each variable is transformed by subtracting its crop-year mean, and then differencing over time for each plot. That is for each variable A, the transformed variable $\tilde{A} = (A_{pct} - \bar{A}_{ct}) - (A_{pc,t-1} - \bar{A}_{c,t-1})$, where p is the plot, c is the crop, and t is the survey round. The cross-tabulation is calculated over these transformed variables.

Table 7: LAD Estimates of the Determinants of Plot Yield
Plot and Crop-Year Fixed Effects
IFPRI Kenya Data

	Estimate	t
Household Size	22.320	1.23
Area on other Plots	-10.832	-0.58
(Area on other Plots)^2	2.994	0.69
Gifts	-0.016	-1.05
Nonfarm Income	0.001	0.68


+ household-crop-season effects · village-crop-season effects
Kernel Density Estimate
1
.5
0
-2
-1
0
1
2
Deviation from Predicted Yield
Figure 1

+ household-crop-season effects · village-crop-season effects
Kernel Density Estimate
1
.5
0
-2
-1
0
1
2
Deviation from Predicted Labor Demand/Ha.

Figure 2

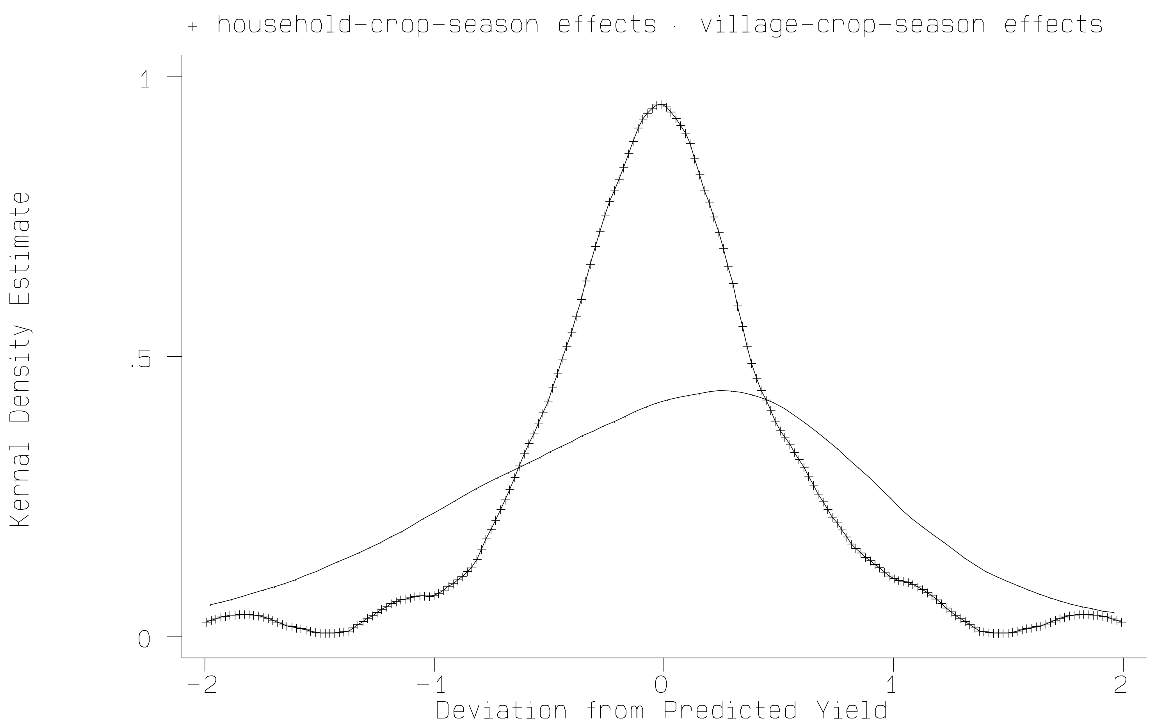

+ household-crop-season effects · village-crop-season effects
Kernal Density Estimate
1
.5
0
-2
-1
0
1
2
Deviation from Predicted Yield

Figure 3