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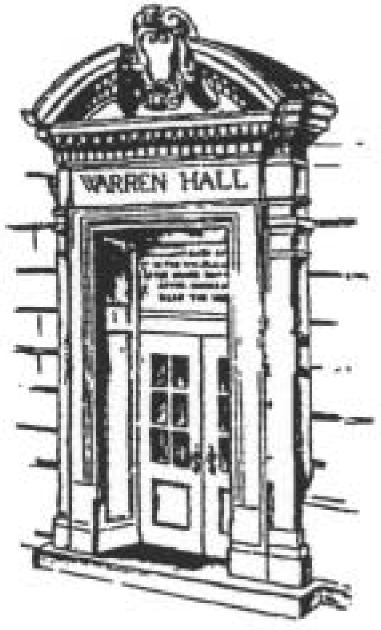

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Macroeconomic shocks, human capital and productive efficiency: Evidence from West African farmers

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Macroeconomic shocks, human capital and productive efficiency: Evidence from West African rice farmers

Abstract: Little empirical work has quantified the transitory effects of macroeconomic shocks on farm-level production behavior. We develop a simple analytical model to explain how macroeconomic shocks might temporarily divert managerial attention, thereby affecting farm-level productivity, but perhaps to different degrees and for different durations across production units. We then successfully test hypotheses from that model using panel data bracketing massive currency devaluation in the west African nation of Côte d'Ivoire. We find a transitory increase in mean plot-level technical inefficiency among Ivorien rice producers and considerable variation in the magnitude and persistence of this effect, attributable largely to *ex ante* complexity of operations, and the educational attainment and off-farm employment status of the plot manager.

I. Introduction

Although economies do not move instantly from one long-term equilibrium to another, most empirical and theoretical analysis focuses on comparative statics and the long-term general equilibrium effects of macroeconomic shocks. Relatively little attention has been paid to the response paths followed by individual producers as they adjust from one equilibrium to another, and particularly not to empirical assessment of the dynamic response of small farmers responding to major policy shocks in low-income economies. Yet smallholders' response to potentially long periods of disequilibrium may have important aggregate effects on output and rural poverty in low-income agrarian economies undertaking major macroeconomic reforms.

There may also be predictable variation in dynamic responses across individuals. Schultz (1964, 1975) hypothesized that the ability to deal with disequilibrium induced by economic shocks is largely a function of education, with better educated individuals adjusting more successfully than less educated agents. The basic idea is simple and intuitive; appropriate adjustment to shocks requires the collection and processing of new information, and better educated individuals would be expected, on average, to excel at such tasks. Schultz's primary interest was technological shocks, but his point applies more broadly. Yet, despite the plethora of macroeconomic adjustment programs in low- and middle-income economies over the past two decades, we are unaware of any studies of interhousehold differences in the rate or extent of recovery from producer-level disequilibria potentially induced by macroeconomic shocks.

An obvious reason for the dearth of empirical testing of the Schultzian hypothesis, or of the effects of macro shocks on producer behavior more broadly, has been a lack of panel production data straddling a major shock. One must be able to identify cross-sectional differences in observational units' intertemporal changes in behavior and performance. In this paper we use a 1993-95 panel data set of rice farmers in the west African nation of Côte d'Ivoire, straddling the massive devaluation of that country's currency in 1994, to test (i) whether the macroeconomic shock is manifest at the microeconomic level in the plot-level technical efficiency of producers, (ii) whether there exist identifiable cross-sectional differences in the immediate impact of the shock, and (iii) whether the Schultzian hypothesis holds, that education is an important determinant of cross-sectional differences in subsequent recovery.

Our strategy in this paper is to start, in section II, by building a simple analytical model wherein a sharp change in the external economic environment (e.g., product and factor price ratios) diverts managerial attention from directly productive tasks in order to make sense of changes in the broader economic environment. We hypothesize that this diversion may have a measurable effect on productivity that could vary predictably across farmers. Section III then introduces the data we use to test these hypotheses. We show that currency devaluation caused sharp changes in relative prices and price variability in rural Côte d'Ivoire, proving stimulative in aggregate to the nation's rice sector, although yields per hectare fell. Section IV then introduces the original econometric method we use to implement the analytical model, estimating a time-invariant rice production frontier jointly with the correlates of plot-specific technical inefficiency, specified so as to enable us to test directly for intertemporal changes in technical inefficiency in the wake of the macroeconomic shock. Section V reports our estimation results. We find that technical inefficiency increased immediately following the shock, then recovered somewhat the subsequent year. There exists significant cross-sectional variation in estimated technical inefficiency changes, for example with respect to farmer educational attainment and off-farm employment status, and the complexity of the farming operation. Section V concludes with some thoughts on the micro-level dynamics of adjustment to macro-level policy reforms, how those dynamics may vary across households and the implications for the design of policy reforms.

II. A Model of Farm Manager Response to Macroeconomic Shock

First we construct a simple reduced form model of producer behavior in which exogenous shocks may temporarily divert managerial attention, thereby reducing unobservable labor quality and yielding an increase in estimated technical inefficiency on the farm. The shock's immediate impact and intertemporal propagation is conditional on individuals' exposure to the shock and on their capacity to deal with disequilibrium, hence the possibility of cross-sectional differences in the initial impact of the shock and in the rate of recovery from any shock-induced effects. The analytical model yields testable hypotheses with respect to (i) the effects of a uniform exogenous (e.g., macroeconomic or technological) shock on mean producer technical inefficiency, as commonly estimated using labor allocation (i.e., time) data that cannot control for unobservable managerial attention (i.e., labor quality), (ii) characteristics that will cause cross-sectional variation in the extent of the disruptions manifest as increased estimated technical inefficiency, and (iii) the effects of human capital, education in particular, on the extent and pace of recovery from temporary efficiency disruptions. We will test those hypotheses econometrically in the subsequent section.

We start with a standard, basic model of a household that maximizes utility subject to a budget constraint, a time availability constraint, and a technology constraint. The latter is the focus of attention in this paper.[1] Let the variables y, a, l, and x represent output, area, labor, and variable non-labor inputs, respectively, with the function f(.) mapping the latter three into the former such that y. f(a,l,x) with f(.) monotone in each argument. In theory, this constraint binds at all optima, so that in long-run equilibrium, optimizing producers should exhibit perfect technical efficiency, $y = f(a,l,x)$. Nonetheless, most empirical studies find evidence of technical inefficiency, i.e., that $y_i = f(a_i, l_i, x_i) - u_i$ with u_i a non-negative, plot-specific technical inefficiency parameter, strictly positive for most plots (Ali and Byerlee 1991).[2]

In distinguishing between managers and manual laborers, economists have long

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[1] In the interests of brevity, we do not present a fully specified household behavioral model of constrained utility maximization. The results of the simpler, reduced form model we present follow directly from such a model under the assumption that the returns to spending a unit of scarce time collecting and processing information in the wake of a macroeconomic shock is at least equal to the opportunity cost of labor, equal to roughly US$0.60/day at prevailing unskilled agricultural wages. Given how pervasive long discussions about the consequences of FCFA devaluation were in rural Côte d'Ivoire following the shock, this seems a very mild assumption.

[2] There is some reason to suspect that econometric error may substantially overstate smallholder technical inefficiency in much of the literature (Ali and Byerlee 1991, Barrett 1997, Sherlund et al. 2002). The problem of interpreting estimated technical inefficiency parameters lies at the heart of this paper since our model ultimately revolves around the unobservability of managerial attention.

implicitly recognized that effective labor is effectively a composite of two distinct inputs: time spent in physical work (w) and managerial attention to that work (m). Let us represent this relationship by the function l(w,m), which is strictly monotonically increasing in both arguments, reflecting the basic idea that work on which one is concentrating is more productive than either thought without physical effort or thoughtless activity. The physical and the cognitive dimensions of labor can be pursued simultaneously. While undertaking the physical work required on a plot, a farmer may concentrate on the tasks at hand and get them done efficiently. Or he may spend some of his measurable labor time thinking about things other than the current task, including matters that affect the farm, such as the effects of changing relative prices on input procurement and output sales patterns, next period's crop choice, etc. The (partial) diversion of managerial attention away from the immediate, menial task at hand might affect the quality of the manual labor undertaken and thereby productivity.

The imperfect relationship between time expended in physical work, w, and effective labor effort, l, underpins the vast literature on moral hazard in agricultural labor markets, in which hired workers are understood as able to reduce their effective labor effort without reducing the time they spend working, i.e., to shirk. Here we apply the same basic concept with a somewhat different twist. Rather than shirking as hired laborers might, owner-managers may have their attention temporarily diverted by exogenous events that require concentrated thought that can nonetheless be undertaken, perhaps at an efficiency cost, while performing other, more menial tasks. Such exogenous events might include macroeconomic or sectoral reforms that cause substantial swings in relative price ratios.

This issue of partial diversion of attention becomes important because only the physical work time of the farmer is directly measurable. Empirical studies inevitably use w to proxy for l. Since w and m are highly correlated with one another in owner-operated businesses like smallholder agriculture, and since both increase effective labor power, econometric estimates of the parameters of the production frontier estimated using w in place of l(w,m) will be susceptible to omitted relevant variables bias. For present purposes, however, the point on which we wish to focus is that when economic policy shocks distract managerial attention, effective labor input may decrease, yielding lower output for the same time spent in physical work. When w proxies for l(w,m), this reduction in output will appear as a deviation from the production frontier, i.e., as an increase in estimated technical inefficiency, u_i. Given inability to measure directly m or its effect on output, we can understand u(m) as a weakly monotonically decreasing function of m.[3]

If exogenous shocks divert decision-makers' attention from directly productive activities as they collect and process information, weigh alternative courses of action, search for new buyers or suppliers, or some combination of these, then shocks may have transitorily adverse effects on productivity.[4] We can formalize this idea by representing the farm-level supply of managerial attention by the function $m(\varphi_{it}, c_{it}, o_{it}, h_{it})$. The individual-specific shock effect felt by decision-maker i at time t, φ_{it}, is nonnegative. The nonnegativity of φ_{it} is arbitrary; one could equally make it nonpositive. The key is that the measure allows for no effect and that any environmental or exogenous shock, whether it increases or decreases welfare, requires some attention. It is important not to confuse welfare effects with the shock's inducement of behavioral response. The variable c is a nonnegative measure of the complexity of the manager's operations (e.g., the number of crops grown or the share of area planted in improved cultivars requiring careful management), o measures the off-farm work responsibilities of the decision-maker, and h is a measure of the manager's human capital endowment. Assume managerial attention is increasing in h and decreasing in the other three arguments.

The magnitude of the unobservable, individual-specific shock, φ_{it}, is itself a function of the complexity of the operation being managed and of the human capital of the manager. In the case of agriculture, for example, as the share of area under modern varieties dependent on

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[3] u(m) is weakly monotone because u is bounded from below at zero.

[4] Because the data we use are not well suited to investigating questions of allocative efficiency (for reasons we explain later), we ignore the question of changes in allocative efficiency in response to policy shocks. One could understand the phenomenon of transitory technical inefficiency due to the diversion of managerial attention as the short-term price managers pay for subsequent gains in allocative efficiency that result from managers having thought through the implications of changes in their environment while doing their menial work.

purchased inputs (e.g., seed, fertilizer, pesticides) increases, so does the dimensionality of the information collection and processing and contracting tasks faced by the smallholder, so a shock should have greater effect on those managing more complex enterprises. The effect of human capital, especially education, is qualitatively different in that it doesn't affect the magnitude of the immediate shock but rather the rate at which the shock's effects dissipate. Literacy, numeracy, and logical abilities are no shield against disruption, but they certainly help individuals respond quickly and effectively to shocks by gathering and processing information efficiently and accurately (Huffman 2002).

These relationships can be captured in the linear state equation,

$$\varphi_{it} = \rho\varphi_{it-1} + \alpha h_{it}\varphi_{it-1} + c_{it}\varepsilon_t \qquad (1)$$

where ρ is a positive first-order autoregressive parameter capturing the intertemporal propagation of the shock conditional on i's human capital endowment, α captures the effect of human capital on the shock's propagation, and $\varepsilon_t \geq 0$ is a cross-sectionally uniform exogenous shock, like a macroeconomic policy reform or the introduction of a new production technology. The Schultzian hypothesis suggests $\alpha<0$, that human capital accelerates recovery from the distraction caused by an exogenous shock. In this framework, $\rho+\alpha h_{it}=0$ implies full recovery after only one period.

The effects of a common shock,$_{.t}$, on the managerial attention of the ith operator at time t, m_{it}, may therefore vary over time. The effects may emerge through any of several parallel transmission channels:

$$\partial m_{it}/\partial\varepsilon_t = \partial m/\partial\varphi_{it}\cdot c_{it} + \partial m/\partial c_{it}\cdot\partial c_{it}/\partial\varepsilon_{.t} + \partial m/\partial o_{it}\cdot\partial o_{it}/\partial\varepsilon_{.t} + \partial m/\partial h_{it}\cdot\partial h_{it}/\partial\varepsilon_t \qquad (2)$$

$$\partial m_{it+1}/\partial\varepsilon_t = \partial m/\partial\varphi_{it}\cdot c_{it}(\rho+\alpha h_{it})+\partial m/\partial c_{it}\cdot\partial c_{it+1}/\partial\varepsilon_t+\partial m/\partial o_{it}\cdot\partial o_{it+1}/\partial\varepsilon_t+\partial m/\partial h_{it}\cdot\partial h_{it+1}/\partial\varepsilon_t \qquad (3)$$

By the weak monotonicity of u in m, the effect of a common shock,$_{.t}$, on plot- and period-specific technical inefficiency will vary across individual operators and time periods:

$$\partial u_{it}/\partial\varepsilon_{.t} = \partial u/\partial m \left[\partial m/\partial\varphi_{it}\cdot c_{it} + \partial m/\partial c_{it}\cdot\partial c_{it}/\partial\varepsilon_t + \partial m/\partial o_{it}\cdot\partial o_{it}/\partial\varepsilon_t + \partial m/\partial h_{it}\cdot\partial h_{it}/\partial\varepsilon_t\right] \qquad (4)$$

$$\partial u_{it+1}/\partial\varepsilon_t = \partial u/\partial m\left[\partial m/\partial\varphi\cdot c_{it}(\rho+\alpha h_{it})+ \partial m/\partial c_{it}\cdot\partial c_{it+1}/\partial\varepsilon_t+\partial m/\partial o_{it}\cdot\partial o_{it+1}/\partial\varepsilon_t +\partial m/\partial h_{it}\cdot\partial h_{it+1}/\partial\varepsilon_t\right](5)$$

Under the assumptions that $\partial h_{it}/\partial \varepsilon_t = \partial c_{it}/\partial \varepsilon_t = \partial o_{it}/\partial \varepsilon_t = 0$, i.e., that neither the manager's stock of human capital, nor the complexity of her operations nor off-farm employment responsibilities change instantaneously, the effect of a uniform common shock, ε_t, on contemporaneous estimated technical inefficiency should be positive because it reduces managerial attention and therefore labor productivity. The induced increase in technical inefficiency should be greater for managers overseeing more complex operations and somewhat less for those who reduce off-farm employment (e.g., in the nontradable service sector) in response to real exchange rate depreciation.

The difference of equations (5)-(4) identifies the factors affecting plot-level recovery in technical inefficiency (i.e., in output or yields, *ceteris paribus*):

$$(\partial u_{it+1}/\partial \varepsilon_t - \partial u_{it}/\partial \varepsilon_t) = \partial u/\partial m\, [\partial m/\partial \varphi_{it} \cdot c_{it}\, (\rho + \alpha h_{it} - 1) + \partial m/\partial c_{it}(\partial c_{it+1}/\partial \varepsilon_t - \partial c_{it}/\partial \varepsilon_t) +$$
$$\partial m/\partial o_{it}(\partial o_{it+1}/\partial \varepsilon_t - \partial o_{it}/\partial \varepsilon_t) + \partial m/\partial h_{it}(\partial h_{it+1}/\partial \varepsilon_t - \partial h_{it}/\partial \varepsilon_t)] \quad (6)$$

Assume the shock has no effect on human capital, so the last parenthetical expression in (6) equals zero, and that is negative, as predicted by Schultz. Then recovery in technical inefficiency is greatest (i.e., the value of (6) is lower) for managers with more human capital or who reallocate time from off-farm obligations in response to the shock, as reflected in the first and third parenthetical expressions, respectively, on the righthand side of equation (6). If the shock induces an increase (decrease) in the complexity of the operation, technical inefficiency will increase (decrease). This simple analytical model yields several hypotheses which we test in section III.

To summarize graphically, we hypothesize that devaluation induces a sharp adjustment in relative prices, depicted in stylized form in Figure 1 as a pivoting of the price line about the production frontier. But the diversion of managerial attention may cause producers to move from the old equilibrium at E^0 to a new long-run equilibrium at E^L in two or more steps. Omitting, for the sake of brevity, the possibility of temporary allocative inefficiency,[5] the

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[5] In Figure 1, allocative inefficiency would appear as selection of a point on the production frontier other than the

response path of our stylized producer to the common exogenous shock, may involve an intermediate step to a point of disequilibrium within the production frontier, such as D^1. The location of D^1 relative to the production frontier and the rate at which the producer thereafter approaches E^L – in other words the magnitude and persistence of induced transitory technical inefficiency – depend on the characteristics just discussed: the manager's human capital and off-farm employment responsibilities and the complexity of the operation. The implication is that output will steadily increase as the producer moves from Y^0 to Y^L, but yield (reflected in the slope of the line segment connecting the origin to the production point) initially falls before recovering. As the next section describes, this is precisely the pattern we observe in the rice sector of Côte d'Ivoire following the 1994 currency devaluation.

This line of reasoning builds on a literature on the "human capital approach to allocative efficiency" that emerged in the 1970s among Chicago students of Becker, Griliches and Schultz. That literature emphasized the central role of education in achieving allocative efficiency, above all in agriculture (Griliches 1963, Welch 1970, 1978; Fane 1975; Huffman 2002; Ram 1980). Its focus was on the role of education in an environment of technological change, as was appropriate in post-war United States agriculture and during the Green Revolution abroad. More recently, technology shocks have been less common than policy shocks in low-income agriculture, so our focus differs because the context of disequilibrium has changed. The earlier literature also generally assumed perfect technical efficiency and introduced education directly into the production function as an input. Our approach accommodates the empirical regularity of estimated technical inefficiency. More importantly, it allows us to identify education's period-specific value in helping producers adjust to shocks. As Schultz (1964, 1975) famously posited, human capital probably matters little to stable, traditional production, but becomes valuable to those dealing with disequilibrium. So we opt to estimate instead producers' technical inefficiency and then check whether human capital has an effect on the magnitude of the initial

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point of tangency with the relative price line.

shock, the recovery from the shock, or both.

III. Data and the FCFA Devaluation

We use data from the farm management and household survey (FMHS) fielded by the West Africa Rice Development Association (WARDA) to test the hypotheses developed in section II. The WARDA FMHS tracked 120 randomly selected rice-producing households in Côte d'Ivoire, 1993-95, yielding 464 different rice plot observations. Surveys consisting of 22 different questionnaire modules were administered annually and are described in detail in WARDA (1997).

The WARDA FMHS data set is uniquely suited to this question of the micro-level responses to macro-level shocks. After 46 years' unchanged 50:1 parity against the French franc, the 14 members of the Communauté Financière Africaine devalued their common currency, the CFA franc (FCFA), by 100 percent in January 1994, between the first and second years of this survey. While devaluation was widely anticipated, the extent and timing of the event were nonetheless a substantial shock to residents of the FCFA economies. For some months thereafter, there was considerable uncertainty, discussion and reflection as to how prices would change and what implications this had for farmers' livelihood strategies.

The FCFA devaluation aimed to correct price distortions caused by an overvalued currency and thereby to induce change in input and output choices and to stimulate tradables sectors such as rice. In the FMHS survey regions, the nominal local market price of local variety rice increased 47.9 percent from 1993 to 1995 (Table 1). This reflected a real increase in the rice price, as manifest by a 49.2 percent increase in the ratio of the rice price to the price of yams, a locally nontradable food. Since nontradable labor and land are the major costs of rice production in Côte d'Ivoire, devaluation increased incentives for producers to bring additional inputs into rice cultivation in spite of increased real prices for tradable inputs (e.g., chemicals). Good standardized input price series are not available in the FMHS data, but using labor markets transactions data we estimate that the ratio of the rice price to the adult male wage rate increased significantly (16.8 percent) from 1993 to 1995. Predictably, area under rice cultivation, the size of rice plots, the amount of labor used, and even chemical use were significantly higher in 1995 as compared to 1993.[6] Nationally, rice output increased 17.5 percent between 1993 and 1995 in Côte d'Ivoire (FAO 1999). Devaluation plainly stimulated rice production in Côte d'Ivoire.

Although rice output increased in response to devaluation, yields among traditional Ivorien rice farmers declined sharply after the devaluation, from a mean (median) of 2.16 metric tons/hectare (1.86 t/ha) in 1993 to 1.75 t/ha (1.66 t/ha) in 1994. Yields recovered somewhat in 1995, to a mean of 1.99 t/ha (and a median of 1.95 t/ha). Parts of the country experienced significantly lower rainfall in 1994 than in either 1993 or 1995, so natural, rather than policy shocks are surely at least partly responsible for the lower yields. But when we control for rainfall and other time-varying natural variables (pest abundance, plant disease, etc.), there remain statistically significant, year-specific yield effects (Sherlund et al. 2002). This paper explores whether the apparent transitory yield shocks might reflect micro-level disequilibrium dynamics of the sort posited in the preceding section.

Knowing that area under cultivation increased following devaluation, it is plausible that a yield decline could be attributable to extensification onto less fertile land. But the FMHS includes detailed biophysical information on plots – soil fertility, slope, etc. – enabling us to control for any such change in the subsequent frontier estimation. Moreover, extensification would be inconsistent with the transitory nature of observed yield declines.[7]

The price data support the claim that exchange rate devaluation can induce temporary uncertainty that might divert managerial attention. Figure 2 shows the evolution of 13-month centered moving average prices for locally produced rice, as well as the time path of the

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[6] We compare 1995 against 1993 because stickiness in price adjustments and asynchronous agricultural calendars – some farms made irreversible production decisions before the price effects of devaluation had played out fully – make comparison of 1994 to 1993 less informative than 1993-1995 comparisons. That said, the qualitative result holds for the 1993-1994 comparison as well: nominal and real rice prices and input application rates increased.

[7] It could be consistent with the transitory drop in yields if land expansion preceded the observed increase in application of other (yield-increasing) inputs. But that was not the case. The data show the pace of input expansion was roughly equiproportional across measured inputs 1993-94 and 1994-95.

coefficient of variation of those prices.[8] One sees a clear shock to the relative (much less absolute) variation of the rice price series, beginning with devaluation in early 1994. The coefficient of variation in rice prices increased sharply for a period of almost a year before settling down at a new, higher level.[9] Our own casual conversations with Ivorien smallholders reveal that they indeed spent much time mulling over the implications of this shock and the resulting uncertainty. So while it cannot be directly corroborated empirically, the sort of managerial attention diversion that we model in the abstract indeed appears plausible.

By way of a brief tangent, we note that this model also offers an alternative way to understand the empirical regularity of short-run price elasticities of crop supply that are significantly lower than the corresponding long-run price elasticities (Askari and Cummings 1976, Rao 1989). Typically, the deviation of short-run from long-run elasticities is attributed to quasi-fixed factors of production (e.g., land), adaptive expectations formation, or unspecified convex adjustment costs. We do not challenge these other, quite sensible explanations. Because it explicitly introduces adjustment dynamics, however, the present model offers another, complementary explanation of the oft-observed phenomenon.[10] In our model, there are no expectations, no quasi-fixed factors, and convexity is not imposed on the explicitly identified source of the adjustment costs.

IV. Estimation Methods

In order to test the hypotheses developed earlier, we jointly estimate a stochastic

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[8] The underlying data are series for each of the three survey regions (Boundiali, Gagnoa, and Waninou). The figure depicts the unweighted, arithmetic average of the series. The qualitative point holds for the series individually, as well.

[9] This pattern is consistent with theory and empirical evidence that devaluation increases the variance of stochastic price series more than the mean when devaluation induces a shift in the underlying market equilibrium condition from an importable to a nontradable (Barrett 1999).

[10] One could presumably test this new explanation by checking the symmetry of the short-run/long-run differential to positive and negative price shocks. Conventional models would predict symmetric differentials, while ours would predict asymmetric differentials, with output overshooting the downward adjustment in response to a fall in relative output prices. Since the FMHS data include only price increases, we cannot explore this issue further in these data.

production frontier and correlates of technical inefficiency in Ivorien rice production. As a result, we also derive plot-specific estimates of technical inefficiency. Correlates of technical inefficiency include farmer-specific characteristics hypothesized to affect the extent and persistence of transitory technical inefficiency.[11] Since there is no reason to believe that a discrete change to relative prices would fundamentally change a traditional production technology over a year or two, and because the intertemporal comparisons on which we focus require a common reference point, we estimate a time-invariant production frontier.

The empirical production frontier literature generally follows one of two methods. The preponderance of the published literature follows the stochastic production frontier (SPF) approach independently pioneered by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977). In this approach, one specifies *a priori* a functional form for the production frontier (e.g., Cobb-Douglas or translog) defining output (Y) as a function of variable (X) and fixed or exogenous (W) variables and probability density functions for the asymmetric technical inefficiency parameter, u (typically the half-normal or truncated normal), and the symmetric statistical error parameter, v (usually the normal). Letting i index plots and t index growing seasons, the SPF specification is thus $Y_{it} = f(X_{it}, W_{it}) - u_{it} + v_{it}$. Then the (log-) likelihood function may be written out and maximum likelihood used to estimate the parameters of interest.

The second approach uses nonparametric, data envelopment analysis (DEA) methods to impose monotonicity and concavity properties on the estimated frontier and otherwise make no functional form or distributional assumptions about the shape of the production frontier. This flexibility comes at the considerable cost, however, of an assumed absence of measurement or

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[11] Because managers may be aware of their technical inefficiency and adjust input applications accordingly, estimating the primal production function may introduce simultaneity bias. However, if the market level price data available are weakly related to the true shadow prices guiding farmer decisions in an environment of considerable transactions costs, risk, quality variation, etc., then price observations will introduce errors in variables problems in estimation of dual cost or profit functions. Since price recordation occurred only at regional level in the FMHS data set and many plots' inputs (e.g., child labor, adult family labor, land, animal traction, soil quality, slope) were not purchased and so have no observed prices associated with them, we opt for the primal method in the present analysis based on the belief that with adequate controls for farm-level production conditions, endogeneity bias related to inputs is likely considerably less than errors in variables bias related to prices in these data.

sampling error (Färe et al. 1994).[12] We focus on the former, stochastic parametric approach, although an earlier version of this paper included DEA results that were qualitatively similar, indeed, even more striking in magnitude and statistical significance. In short, our findings appear robust to the technical inefficiency estimation method employed.

Jondrow et al. (1982) show how to estimate the conditional expectation of the plot-specific technical efficiency parameter (conditional upon the composed error term, $v_i - u_i$) in stochastic parametric frontier estimation. One problem with this approach, however, is that the technical inefficiency parameter is assumed to be independently and identically distributed. This clearly is not the case if we suspect (and find) that the technical inefficiency parameter is related to variables such as managerial characteristics and practices that vary across firms.

To combat this potential problem, some studies suggest estimating the production frontier and the relationship between technical inefficiency and the sources of inefficiency jointly, rather than in a two-step procedure. Kumbhakar et al. (1991) generalize the stochastic production frontier model of Aigner, et al. by specifying that the distribution of the technical inefficiency parameter be the positive truncation of a normal distribution with variable mean $Z_i\delta$, i.e., $u_i \sim N^+(Z_i\delta, \sigma^2_u)$, where δ is a vector of parameters to be estimated. Reifschneider and Stevenson (1991) instead propose that $u_i = Z_i\delta + \xi_{i.} \geq 0$, where $\xi_i \sim N^+(0, \sigma^2_\xi)$. But the latter method does not guarantee that $u_{i.} \geq 0$. Huang and Liu (1994) take a slightly different approach. They specify $\xi_i \sim N(0, \sigma^2_\xi)$ and truncate this from below at the variable truncation point, $-Z_i\delta$. Huang and Liu also allow for interactions between the productive inputs and the managerial variables in the technical inefficiency relationship.

Other studies have concentrated on the panel data aspects of production frontier estimation. Pitt and Lee (1981) implement a random effects treatment to estimate a stochastic

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[12] The output-oriented, variable returns to scale, strong disposability DEA model may be written: $2*(X_i,Y_i$ |VRS,SD) = $\text{Max}_{2,z}$ 2, subject to $2Y_i$ #zY, zX # X_i, 3_i z_i = 1, and z 0 R^N_+, where i = 1,...,N and z is the activity vector indicating to which plots the ith plot is being compared. The resulting output measure of technical efficiency is bounded from below at one, 2 $ 1, and represents the multiple by which output may be expanded, holding the input bundle constant, had the ith plot been fully efficient.

production frontier. Cornwell, Schmidt, and Sickles (1990), Kumbhakar (1990, 1991), Battese and Coelli (1992), and Lee and Schmidt (1993) allow the technical efficiency parameter to vary across time via time-specific dummy variables or according to a specified functional form. But in these models, the technical inefficiency parameter is assumed to follow the same pattern over time for all firms. Battese and Coelli (1995) generalize the model of Huang and Liu to allow for panel data, though not explicitly allowing for interactions between the inputs and managerial variables in the technical inefficiency relationship. This model allows the technical inefficiency parameter, and hence technical efficiency, to vary across time in a potentially different, but predictable, manner across firms.

We implement Battese and Coelli's model, wherein the technical inefficiency parameter is related to a vector of farmer-specific managerial variables subject to statistical error, so that $u_{it} = Z_{it}\delta + \xi_{it} \geq 0$, where $\xi_{it} \sim N(0, \sigma^2_\xi)$, i indexes firms, and t indexes time. But since $u_{it} \geq 0$, $\xi_{it} \geq -Z_{it}\delta$ so that the distribution of ξ_{it} is truncated from below at the variable truncation point, $-Z_{it}\delta$.. The statistical error of the production frontier is assumed to be mean-zero, normally distributed with variance σ^2_v. Then the log-likelihood function for the i^th^ firm at time t takes the form

$$\ln L_{it} = -\tfrac{1}{2}\,[\ln(2\pi) + \ln(\sigma^2)] - 1/2\sigma^2[Y_{it} - f(X_{it}, W_{it}; \beta, \theta) + Z_{it}\delta]^2 - \ln[\Phi(d_{it})] + \ln[\Phi(d_{it}^*)] \qquad (7)$$

where $f(X_{it}, W_{it}; \beta, \theta)$ is the production frontier, β, θ, δ, γ and σ^2 are the parameters to be estimated, $d_{it} = Z_{it}\delta/(\gamma\sigma^2)^{1/2}$, $d_{it}^* = \{(1-\gamma)\, Z_{it}\delta - \gamma[y_{it} - f(X_{it}, W_{it}; \beta, \theta)]\} / [\gamma(1-\gamma)\,\sigma^2]^{1/2}$, and $\Phi(\cdot)$ denotes the standard normal cumulative distribution function. Note that, under this parameterization, $\gamma = \sigma^2_u / (\sigma^2_u + \sigma^2_v)$ and $\sigma^2 = \sigma^2_u + \sigma^2_v$.

We use a translog specification for the production frontier, imposing separability between the X and W variables in order to conserve degrees of freedom:[13]

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[13] The presence of many zero-valued observations is troublesome. The convention in much literature is to set ln(0) = 0. However, due to observations taking on values in the range (0,1], setting ln(0) = 0 implicitly reorders observations with respect to that subspace. So instead, we set ln(0) = ln (./10), where . is the smallest strictly positive observation in the sample. We tried to address the problem of zero-valued observations instead through the use of other flexible functional forms, e.g., generalized Leontief, CES-CT-GL, and symmetric generalized McFadden, but all failed diagnostic tests for satisfaction of regularity conditions (Waldman 1982).

$$\ln(Y_{it}) = \beta_0 + \sum_{k=1}^{K} \beta_k \ln(X_{ikt}) + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{J} \gamma_{jk} \ln(X_{ijt}) \ln(X_{ikt}) + W_{it}\theta - u_{it} + v_{it} \qquad (8)$$

Rice production (Y_{it}) is measured in kilograms. The variable inputs (X_{it}) consist of land (in ares), various measures of labor (in hours) and chemical fertilizer (in kilograms), while W_{it}, includes the categorical variables for soil erosivity, soil fertility, soil aptitude, topographic location dummies and region-specific dummies, as well as continuous variables reflecting plot slope, pest infestation, weed density, weed height, plant disease, rainy days, and rainfall. Because both rainfall measures are common to all plots in a region, they also capture some year-and-region-specific unobserved heterogeneity and should therefore be interpreted with care.

Since our inquiry focuses on the intertemporal response of plot-level technical inefficiency to a macroeconomic shock, we specify the technical inefficiency equation as:

$$u_{it} = Z_{it}\delta_1 + I_{93}Z_{it}\delta_2 + I_{95}Z_{it}\delta_3 + \xi_{it} \qquad (9)$$

where the indicator variables I_{93} and I_{95} equal one for 1993 and 1995 observations, respectively, and zero otherwise. The vector of characteristics (Z_{it}) affecting technical inefficiency include the proportion of area planted in modern rice varieties, years of rice cropping experience, the number of total crops cultivated, and dummy variables for completion of elementary school or secondary or tertiary education, married women, unmarried women,[14] off-farm work in agriculture, off-farm work outside of the agricultural sector, year and geographic region. This specification permits interpretation of the δ_2 and δ_3 estimates from equation (2) as year-on-year differences in technical inefficiency since $u_{i94} - u_{i93} = -I_{93}Z_{it}\delta_2$ and $u_{i95} - u_{i94} = I_{95}Z_{it}\delta_3$. Based on the analytical

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[14] One needs to control for gender and marital status because rural Ivorien women are less educated than men. Absent control for gender, one could easily conflate gender bias among married adults (i.e., wives disproportionately bearing the adjustment costs of shocks) with the effects of educational attainment. Only 4.6 percent of the women in our sample had even elementary school education, while almost 18 percent of the men had secondary level education or beyond. Partly as a consequence, women rice farmers are far less likely to speak French, the language of the national market information service. So when price shocks come along, women may have to invest more effort in acquiring and processing information not directly accessible to them, especially because the extension system in Côte d'Ivoire exhibits considerable bias against women (Adesina and Djato 1997). If married women in Ivorien society disproportionately bear the adjustment costs of shocks and women are also less educated on average, then failure to control for the gender could cause upward bias in the estimated effects of education on farmer performance. Indeed, when we dropped the gender dummy from our regressions, the coefficient estimate on the education variable increased significantly in each of the regressions.

model advanced in section II, we would expect the estimates of δ_2 to include negative coefficient estimates on the complexity of the farming operation (share in modern varieties, number of crops). We would likewise expect the δ_3 estimates to include negative coefficients on educational attainment and experience, reflecting the salutary effects of human capital in dealing with disequilibrium, and on the off-farm non-agricultural employment dummy, since Ivorien farmers with jobs in the (largely nontradable) tertiary sector generally reallocated time from off-farm employment towards farming, albeit while still maintaining off-farm employment for financial liquidity and risk management purposes (Barrett et al. 2001).

V. Transitory Technical Inefficiency in Ivorien Rice Production

In the interests of brevity, we do not dwell on the full set of production frontier coefficient estimates, which are discussed in detail in Sherlund et al. (2002). The results are intuitive and standard. For example, plot-level output is strongly increasing in land, labor and chemical fertilizer, with hired labor and chemicals appearing to be substitutes. Environmental conditions matter a great deal to rice output as well, with expected output decreasing in plant disease and pest incidence, weed density and height, and plot slope, and increasing in days of rain and rainfall volume, as well as in more favorable agroecological regions. Instead, we move directly to explore the intertemporal patterns of technical inefficiency evident in these data and to test the hypotheses posed by the model of section II.

The first question concerns the evolution of plot-specific technical inefficiency in the wake of massive currency devaluation. As hypothesized, inefficiency increased from 1993 to 1994 and recovered slightly in 1995. Across the unbalanced panel of plots, mean output in 1993 was 82.4 percent of the estimated plot-specific production frontier, but fell to 73.3 percent in 1994 before partly recovering to 76.3 percent in 1995. However, because some plots are put into or brought out of fallow or are combined or subdivided across years, we do not have an even panel at plot level. Looking only at plots for which we have three consecutive annual observations, 65.3 suffered an increase in technical inefficiency between 1993 and 1994, and

67.7 percent enjoyed reduced technical inefficiency in 1995, relative to 1994. Half the plots exhibited the three-year fall-recovery pattern hypothesized in section II, while only 17 percent had the opposite pattern. Although nearly two-thirds of sample plots suffered increased technical inefficiency in 1994, immediately following the FCFA devaluation, almost eighty percent of those plots' efficiency improved the following year. The general hypothesized pattern of a transitory increase in technical inefficiency in response to a macroeconomic shock seems supported by these data.

Our model not only predicts a temporary increase (decrease) in estimated technical inefficiency (output) on average, it also hypothesizes predictable cross-sectional differences in changes in inefficiency. In particular, the initial, adverse managerial diversion effects of the shock should be felt most acutely on plots managed by operators who supervise relatively more complex operations or who have off-farm employment that gives them a place to collect information on changing market conditions and to reflect on the implications of these changes for their farming practices (rather than doing this only while farming). We use the number of different crops under the control of the plot manager (crops) and the proportion of the plot planted in modern rice varieties (modern) to capture operational complexity. Most operators did not change the complexity of their operations during the survey period. So although our model suggests that the effect of the shock on complexity should itself affect the magnitude of the common shock's effect on plot-and-period-specific technical inefficiency, we omit the change in complexity variable because it is clearly endogenous and we haven't suitable instruments for predicting such changes.[15] Similarly, we do not include changes in off-farm employment status since this is plainly endogenous and because change in off-farm employment was almost entirely infra-marginal, enjoying adjustments in hours worked rather than cessation or commencement of employment (Barrett et al. 2001).

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[15] As a check, we also ran regressions including change in crops, in plots, and in the proportion planted in modern varieties as regressors. This specification, which likely suffers endogeneity bias, returned qualitatively identical results as the specification we report, which may suffer (modest) omitted relevant variables bias from the omission of these change variables. The consistency of the results suggests the qualitative findings are robust.

Although our model posits that human capital does not prevent farmers suffering the effects of shocks initially, it predicts that higher levels of human capital should lead to faster recovery in technical inefficiency in the subsequent recovery period, from 1994 to 1995. We use the operator's rice farming experience (measured in years) and highest level of schooling completed (captured by dummy variables for elementary school or for secondary or higher education) to proxy for human capital, and assume no change in these adults' education levels in the wake of FCFA devaluation.[16]

Table 2 reports the technical inefficiency equation estimates. Note that, even though we report the estimates separately, the stochastic production frontier and technical inefficiency equations are indeed estimated jointly. Across all three years, those with little or no education and off-farm employment in agriculture have significantly lower technical inefficiency -- likely because of reciprocal labor sharing arrangements and learning from others on whose farms they work -- while the relatively well-educated who also work off-farm in the nonagricultural sector likewise exhibit greater technical efficiency. There are significant differences in technical inefficiency across the three agroecological regions spanned by these data. Farmers in the more humid forest and forest-savannah transition zones appear more efficient than those in the drier savannah zone.

The estimates reported in Table 2 largely confirm our hypotheses regarding the effects of the macroeconomic shock on plot-level technical inefficiency. Education doesn't shield people from the shock, as is apparent in the statistically insignificant estimates for the education variables and for the regressors interacting education and complexity. The sole exception arises from the positive coefficient estimate on the interaction term for those with secondary school

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[16] In these data, almost 80 percent of plots were operated by farmers who had not completed elementary school. Only 15 percent had completed secondary school, and fewer than 2 percent had completed college. If higher education leads to self-selection out of agriculture, so that farmers with higher educational attainment may actually possess below-average ability or work ethic for individuals of their education level, then there may be some bias in the estimated effect of education on technical inefficiency, although we can control for this somewhat by including off-farm employment status among the regressors. Our results may therefore err somewhat on the conservative side in making our point.

education and nonagricultural off-farm employment, a small subsample who have superior access to market information from their largely salaried jobs in the main market towns. So that one exception to the general point makes sense. Moreover, jointly, the education variables have no statistically significant effect on technical inefficiency in the immediate aftermath of the shock, as evidenced by a Wald test statistic (p-value) of 13.93 (0.2371), as reported in Table 3.

Subsequent recovery nonetheless appears greater for more experienced and educated operators, and the estimation results support this Schultzian hypothesis. The human capital variables are jointly significant in the recovery phase -- Table 3 reports a Wald test statistic (p-value) of 27.15 (0.0044) for the human capital variables in the 1994-1995 change in technical inefficiency -- where they were insignificant in the initial response to the devaluation shock. Technical inefficiency decreases significantly in farmer experience and sharply and significantly for those who have completed at least elementary education, with the effects greatest for those who also work off-farm. Education appears most valuable for those with more complex operations, as indicated by the statistically significant, negative estimate for interaction term between secondary education and share of farm in modern varieties, although none of the other education-complexity interaction terms are statistically significantly different from zero. Both the magnitude and sign of the point estimates and the statistical significance of these estimates support the Schultzian claim that education facilitates more rapid and substantial recovery.

Estimated inefficiency increases with operational complexity in the immediate aftermath of the shock, as reflected by negative and strongly statistically significant point estimates on the modern and crop-secondary education interaction terms. Although they are jointly significant in the initial effects of the shock (Wald test statistic (p-value) of 20.65 (0.0021)), the complexity variables are jointly statistically insignificant in the second stage recovery (Wald test statistic (p-value) of 8.92 (0.1784)), suggesting that farm complexity basically conditions one's initial exposure to a shock, but has little effect on the time path of recovery. Relatively simple farms operated by relatively well-educated farmers therefore both suffer smaller technical inefficiency shocks in macroeconomic disequilibrium and recover from them more quickly, giving them a significant competitive advantage in periods of macroeconomic disequilibrium.

Off-farm employment plainly matters to patterns of farm efficiency response to macroeconomic shocks, although the coefficient estimates in Table 2 suggest a pattern more complicated than we can fully explain here with these data. Unlike the education or farm complexity variables, the off-farm employment variables have jointly statistically significant effects on both the 1993-1994 and 1994-1995 technical inefficiency changes. Initial change in technical inefficiency was lower for those with off-farm agricultural employment and for well-educated farmers with nonagricultural off-farm employment, as reflected in positive and sizeable coefficient estimates. Those with off-farm agricultural employment had less improvement in 1995, with the two effects almost perfectly offsetting each other, implying that farm workers have enjoyed a very transitory efficiency advantage over those who only work their own farm. Those with nonagricultural off-farm work, however, not only suffered smaller adverse initial inefficiency effects, but they also improved further in 1995, as reflected in a negative and statistically significant estimated effect among those with at least elementary education. Future research might usefully explore these seemingly heterogeneous effects of off-farm employment on farm productivity, in order to establish to what extent these might relate to informational, financial liquidity, or labor timing differences across different types of off-farm employment.

Overall, the estimation results support the hypotheses advanced by our simple model. The macroeconomic shock of currency devaluation appears to have had a significant transitory effect on technical inefficiency felt most acutely among smallholders managing relatively complex operations. The rate and extent of recovery, however, depends primarily on operator human capital, in the form of experience and education, on the complexity of the farming operation, and, in a complicated way, on off-farm employment status.

The point that education hastens one’s response to shocks but doesn’t shield one from them is a more nuanced finding than appears in the existing literature. For example, Glewwe and Hall (1998), using 1985 and 1990 panel data from Peru, found that households with better educated heads were less vulnerable to the adverse effects of macroeconomic shocks. But their data did not permit them to establish whether it was the relatively more rapid speed of *ex post* adaptation or less initial exposure to the shock that accounted for the superior performance over five years among households with better educated heads. Similarly, the "human capital approach to allocative efficiency" literature consistently found that education positively affects agricultural output, the allocative efficiency of farmers, or both (Griliches 1963, Welch 1970, 1978; Fane 1975; Huffman 2002; Ram 1980). But that literature failed to identify the context-dependent returns to education. Education seems to pay off most in the wake of substantial disruptions to the economic environment and when the operation managed is relatively more complex. Our analysis brings out these important refinements, offering empirical support to Schultz's seminal claim that human capital enhances one's ability to adapt to changing economic circumstances (Schultz 1964, 1975). Of course we cannot tell in these data whether people who go far in school are inherently more adaptable or whether they learned something there that helps them adapt. So while our results suggest education is important, one must keep in mind that education might merely proxy for unobserved human capital more generally.

VI. Conclusions

Macroeconomic shocks affect microeconomic decision-makers. The short-run burden of collecting and processing information on which operators base resource reallocation decisions, and of finding new trading partners and negotiating new contracts may divert managerial attention from directly productive activities, leading to transitory increases in technical inefficiency and therefore to (perhaps temporary) deviations of output below its potential. The disruption of the shock costs the economy aggregate output, but the effect is not uniformly experienced.

Rather, there are predictable cross-sectional differences across operators in the extent to which the shock diverts managerial attention and therefore in induced transitory inefficiency. Although education is no shield against the initial adverse effects of a shock, the pace and extent of subsequent recovery depends heavily on managerial human capital. Managers with greater experience and cognitive abilities process information more quickly and more accurately, enabling faster recovery from the initial impact of a shock. So investment in universal education might bear dividends in the form of reduced foregone output in the wake of disruptive shocks, reinforcing the Schultzian argument that the returns to education increase as dynamic changes in the economy become greater or more frequent.

The magnitude of the technical inefficiency increases resulting from macroeconomic shocks appears greatest for those managing more complex operations and somewhat less for those who couple farming with off-farm employment. This underscores the need for extension assistance to more complex, commercialized farms in times of sharp macroeconomic adjustment. It also reinforces previous findings on the importance of rural non-farm economy to performance in the agricultural sector and the need for policymakers to devote more time to understanding the complex farm-nonfarm relationship in rural communities (Reardon et al. 1992, 1998).

The literature on producer response to macroeconomic and sectoral shocks has yet to address these issues although they surely matter to short-run sectoral and macroeconomic performance and to the welfare of poor smallholder subpopulations. Less well-educated smallholders and those who bear the domestic burdens of disequilibrium, chiefly women, fall behind their better-educated and less-encumbered counterparts. These effects may help explain the sluggish response of agricultural output to policy shocks over the past two decades in much of the low-income world (Barrett and Carter 1999).

Table 1: Observed Changes in Prices and Input Applications

(Percent change, 1993 to 1995)	
Prices (FMHS survey regions monthly average series)	
Nominal local rice variety price	47.9
Local rice/yam price ratio	49.2
Local rice price/wage ratio	16.8
Input volumes (FMHS survey households)	
Area in rice	39.7
Average plot size	12.8
Adult family labor hours	28.0
Hired labor hours	21.1
Child labor hours	54.8
Chemical inputs	5.0

Table 2: Technical Inefficiency Estimation Results

	Unconditional		1993 Interactions		1995 Interactions	
Variable	Coefficient	Std.Error	Coefficient	Std.Error	Coefficient	Std.Error
Constant	0.8743	0.5639	-0.0167	0.5584	-0.4897	0.6150
Modern (Mod)	0.2724	0.2688	-1.5735***	0.6112	0.0397	0.3331
Experience	-0.0056	0.0185	-0.0333	0.0324	-0.0606**	0.0303
Married woman	-0.0892	0.2560	-0.5761	0.7783	-0.1019	0.3439
Unmarried woman	0.4505	0.3443	-0.9456	0.9282	-0.6412	0.8355
Elementary edu. (Ele)	2.1209**	1.0621	-1.6600	1.0877	-2.4726*	1.2962
Secondary edu. + (Sec)	0.2128	0.6733	-0.8758	0.8554	-0.3876	0.9038
Crops (Crp)	-0.0222	0.0876	0.1309	0.1341	0.1024	0.1134
Off-farm, non-ag work (Nag)	0.0884	0.2511	0.2367	0.3968	-0.3534	0.4688
Off-farm, ag work (Agw)	-0.7268***	0.3130	1.0879**	0.5123	1.0165*	0.5190
Mod x Ele	0.1496	0.6542	0.6859	1.0038	0.6896	0.8514
Crp x Ele	-0.4347*	0.2619	0.4901	0.3840	0.5101	0.3642
Nag x Ele	-0.2829	0.7799	0.2968	0.9795	-2.0355**	0.9282
Agw x Ele	-1.2992	0.8850	0.2207	1.0233	3.0524***	1.3039
Mod x Sec	-0.0392	0.4469	0.0189	0.9336	-1.7961*	0.9502
Crp x Sec	-0.1490	0.2177	-0.6929***	0.2687	0.1848	0.3409
Nag x Sec	-1.2367***	0.5160	2.8514***	0.6666	1.2352	0.7614
Agw x Sec	2.0102***	0.6224	-0.1344	0.6858	-1.5815**	0.7997
Transition zone	-1.4929***	0.4366				
EqForest zone	-1.3595***	0.3918				
σ^2	0.2116***	0.0223				
γ	0.8931***	0.0289				
Log-likelihood	-10.6831					
No. observations	464					

*, **, *** indicate statistical significance at the ten, five and one percent levels, respectively.

Table 3: Wald Tests of Parameter Restrictions
(p-value in parentheses)

Null hypothesis	degrees of freedom	1993-1994	1995-1994
Complexity variables = 0	6	20.65	8.92
		(0.0021)	(0.1784)
Human capital variables = 0	11	13.93	27.15
		(0.2371)	(0.0044)

Figure 1: Hypothesized Response Path to a Discrete Relative Price Shock

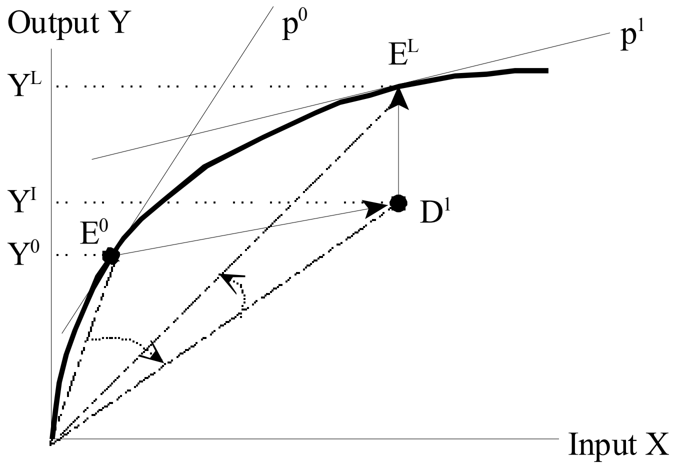
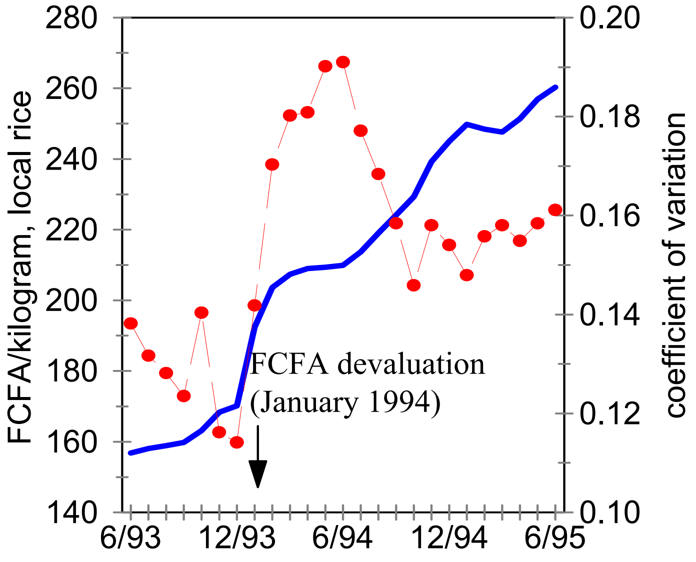


Figure 2 : Evolution of stochastic rice prices

(13-month centered moving average of regional series)



Mean price in solid, measured against left axis. C.v. in bulleted dashes, measured against right axis.

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