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Extensification of agriculture and deforestation: empirical evidence from Sudan

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Abstract

Extensification of agriculture is one of the major factors contributing to the destruction of forests in Africa. In Sudan, such horizontal expansion comes at the expense of land devoted to trees and other vegetation, thereby inducing conditions that are inimical to sustainable agricultural production. Different factors have contributed to extensification. Although high economic returns from crop (mainly sorghum) production was an important factor encouraging extensification of rainfed mechanized farming, other factors outside agriculture have also contributed to that expansion. This paper uses data from eastern Sudan and an acreage response model, to identify the most important factors influencing acreage expansion. Different measures and forms of risk were used in the acreage response model. The paper shows how policies in the energy sector can indirectly influence acreage expansion in the agricultural sector.

1. Introduction

Degradation of natural resources in the developing countries can be regarded as arising for three primary reasons: (1) explicit government policies to satisfy domestic needs or to increase exports to earn foreign exchange; (2) misguided management policies that have as their intent the actual protection of natural resources; and (3) the interrelations between other economic policies and the natural resource base of a country (Bromley, 1986). In this paper we report on empirical research highlighting the third of these phenomena – the interaction of various economic policies and events that may seem, on the surface, to be unrelated. Specifically, this research illustrates the linkage between energy supply and pricing policy and agricultural extensification – that is, the horizontal expansion of agriculture into forested areas – in eastern Sudan. [1] While

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[1] The impacts of agricultural extensification on forestry and agricultural production have been discussed elsewhere (e.g. Elnagheeb and Bromley, 1992; Ibrahim, 1987).

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the specific venue of the research is Sudan, similar phenomena exist throughout the Sahel.

When imported oil was a cheap source of energy in Sudan, there was scant incentive to clear land for charcoal production. The high cost of land clearing was one of the main factors that protected forested areas against horizontal expansion of rainfed agriculture (Affan, 1984). However, when oil prices began to rise in the 1970's, charcoal suddenly became a competitive energy source for urban dwellers deprived of affordable petroleum products. Moreover, the increase in the population of urban areas from in-migration has led to significant increases in the demand for charcoal. The subsequent increase in charcoal prices soon cast the forest in a new light to farmers and herders who then began to exploit forests to produce charcoal for urban markets. Consequently, the increased revenue potential from clearing land for agriculture has meant that land-clearing costs no longer act as an impediment to accelerated deforestation for creating arable land. Hence, the high returns from charcoal production were hypothesized to be another important factor contributing to the expansion of agriculture into marginal lands at the expense of forested areas. This continued expansion of rainfed agriculture in response to important but *unintended* incentives can be a serious policy problem facing many poor countries.

2. Setting

The rainfed mechanized farming schemes got their start in Sudan in 1944, in an area of about 12 000 feddans, [2] primarily to feed troops stationed in East Africa during World War II. The Government then began to encourage the private sector to participate in these schemes. The high economic returns of early settlers encouraged other participants and so resulted in a fairly rapid expansion of the area cleared for cultivation. By 1985 the total area under rainfed mechanized farming was about 7.4 million feddans (Earl, 1985). While called mechanized farming, in fact only land preparation and sowing are mechanized. Weeding (if any) and harvesting are manual operations. The grain is cut by hand and threshed by stationary harvesters (Ibnouf, 1985). Four crops are grown – dura (sorghum), sesame, millet and cotton. However, dura accounts for 80–90% of the land area (Affan, 1984). Sesame is the second most important crop, while millet and cotton are grown in very limited areas. This trend seems persistent over time.

On the rainfed mechanized schemes, land is leased by the Government to farmers in lots of 1000–2000 feddans for a renewable period of 25 years at a nominal land rent (LS0.05 per feddan per year [3] – approximately \$0.13 per acre – in 1976). These farms are referred to as *demarcated farms*. In addition to the demarcated farms, there are large areas of land that have been cleared without authorization; these areas are referred to as *undemarcated farms*. Whether authorized (demarcated) or not, the typical farming practice is continuous cropping – defined here as putting cleared land under production of the same crop (dura) for successive years without fallowing (or with a very short fallow period). Shifting cultivation to new areas (which are sometimes marginal lands) occurs when yields decline below a profitable level. Although some ecological safeguards – such as shelterbelts and crop rotation – are required by the Mechanized Farming Corporation, these practices are rarely followed. In general, no fertilizers, insecticides or pesticides are applied to these cropped lands and so it comes as no surprise that, over time, productivity declines. [4]

3. Empirical model

An acreage response model was used to study the acreage expansion in the rainfed mechanized

[2] feddan = 1.04 acre ≈ 0.42 ha.

[3] LS, Sudanese pound = \$2.70 in 1976.

[4] Fertilizers, insecticides and pesticides are imported and made available only to irrigated schemes. Following the rotation prescribed by the Mechanized Farming Corporation (MFC) would eliminate (or at least reduce) the need for these chemicals in the rainfed mechanized farms. However, easy access to land and lack of law enforcement discourage farmers to follow the MFC's recommendations.

sector of Sudan. In most of the econometric studies of acreage response it has been recognized that risk with respect to price, yield and income influences farmers' production decisions (Adesina and Brorsen, 1987; Behrman, 1968; Chavas and Holt, 1990; Just, 1974; Ryan, 1977; Trail, 1978; Wilson et al., 1980; Wolgin, 1975). In these studies, risk has been expressed in a 'symmetric' form which considers both very high and very low returns as undesirable (Markowitz, 1970). However, one expects producers to be more concerned about negative than positive deviations from a targeted price, yield or income. Therefore, an 'asymmetric' risk analysis that utilizes only the negative deviations may be preferred to a symmetric risk analysis (Tronstad and McNeill, 1989).

Models estimated in this paper utilize both symmetric and asymmetric forms of risk. Different variables were used to represent riskiness of price or production. These variables range from simple expressions such as a moving range or absolute difference between expected and actual price (Brennan, 1980) to more complicated expressions such as moving standard deviations (Behrman, 1968; Just, 1974).

Dura accounts for 80–90% of the land area under the rainfed mechanized sector (Affan, 1984). Hence, the focus here is on the acreage response for dura only. Millet and cotton are grown on very limited areas. Therefore, variation in prices of millet and cotton can be expected not to affect the acreage response for dura. Sesame is the second crop in rainfed agriculture and shares with millet and cotton the remaining 10–20% of the land area. Therefore, the initial models included sesame price, sesame price risk and the covariance between dura and sesame prices as explanatory variables. However, nested F-tests could not reject the null hypothesis that all coefficients on sesame variables were simultaneously equal to zero. Hence, these variables are not included in the empirical model. The price of charcoal is included because farmers can make use of cleared trees to produce charcoal. This is expected to be an added incentive for farmers to clear more land for cultivation. The revenue from charcoal can offset, or at least reduce, the cost of land clearance (Earl, 1985). The empirical model, based on Behrman (1968), is given by Eq. (1):

$$\ln(A_t) = \beta_0 + \beta_1 \text{EDP}_t + \beta_2 C_t + \beta_3 \text{CP}_t + \beta_4 \text{EDY}_t + \beta_5 \text{ERF}_t + \beta_6 \text{DPR}_t + \beta_7 \text{RFR}_t + e_t \quad (1)$$

where

$e_t = \rho e_{t-1} + u_t$

and

$u_t = N(0, \sigma^2)$

and, for time period t, $\ln(A_t)$ is the natural logarithm of dura-cultivated area in feddan; EDP_t is expected dura real price [5] in 0.01 Sudanese pounds (LS) per kilogram; C_t is cost of dura production in LS per feddan; CP_t is charcoal price in LS per 80-lb sack [6]; EDY_t is expected dura yield in kilogram per feddan; ERF_t is expected rainfall in millimeter; DPR_t is dura price risk; and RFR_t is rainfall risk. Economic theory provides little help in choosing the appropriate functional form and so different functional forms were tried. The form in Eq. (1) gives the best fit of the data.

The data used in this study are limited to the eastern region (Gedarif) which contains the largest area devoted to rainfed mechanized agriculture. The data do not distinguish between demarcated and undemarcated schemes. More complete data were available for the period 1969–1985 and were used for this study. Data sources include different publications. Data on areas cultivated, rainfall and yields are from the Mechanized Farming Corporation (MFC, 1984). The Department of Agricultural Economics and Statistics (1986, 1987, 1989) provided data on areas cultivated, yields and production costs, while the Department of Statistics (undated) is the source of data on prices. Data on consumer price index and charcoal prices are from the National Energy Administration (1987). Charcoal prices for the eastern region were not available. Hence,

[5] The consumer price index was used to deflate dura price and cost of production. While a price index for agricultural inputs would have been a better index for deflating costs of production, lack of data precluded this approach.

[6] lb, pound ≈ 0.454 kg.

we used charcoal prices for the province of Khartoum, a main market for the charcoal produced in Gedarif. Costs of production data are supplemented with data from Thimm (1979) and El Hadari and Suliman (1980). The data are estimates based on cross-section surveys conducted annually by the different government departments.

The expected real price (EDP_t) is assumed to be a linear function of last year's real price (DP_{t-1}) according to the maximum-likelihood-estimated equation: [7]

$$\text{EDP}_t = 0.0763468 + 0.566671\ \text{DP}_{t-1} \qquad R^2 = 0.46$$
$$(2.035) \qquad (3.446) \qquad (2)$$

where t-values are given in parentheses.

Farmers need not form expectations about charcoal price because charcoal making can proceed rapidly. Therefore, the price of charcoal at time t is the observed market price in that year. Land preparation and sowing costs are a major part of production costs and both are known to farmers before land allocation decisions are taken. Hence, production costs are treated as non-stochastic. The expected dura yield and expected rainfall are assumed to be last year's yield and rainfall, respectively. [8]

Two forms of risk analysis (symmetric and asymmetric) are used. Within each form two variables (simple and complex) are used to represent risk. Hereafter, X_t is dura real price or rainfall, while EX_t refers to the expected value. For both price and rainfall risk, the following risk variables are defined. The symmetric-simple measure of risk (SXR_t^s) is the absolute value of the difference between the actual and expected values for the previous year:

$$\text{SXR}_t^s = \text{abs}(X_{t-1} - \text{EX}_{t-1}) \qquad (3)$$

On the other hand, the symmetric-complex measure of risk (SXR_t^c) is a moving standard deviation of X_t over the previous three years (Behrman, 1968):

$$\text{SXR}_t^c = \left[\Sigma_k(X_{t-k} - X_{\text{BAR}_t})^2/2\right]0.5 \qquad (4)$$

where

$$X_{\text{BAR}_t} = (1/3)\ \Sigma_k X_{t-k} \qquad k = 1, 2, 3$$

The asymmetric-simple measure of risk (ASXR_t^s) equals the absolute value of the difference between actual and expected values for the previous year if the expected value exceeds the actual corresponding value and zero otherwise:

$$\text{ASXR}_t^s = \begin{cases} \text{abs}(X_{t-1} - \text{EX}_{t-1}) & \text{if } \text{EX}_{t-1} > X_{t-1} \\ 0 & \text{otherwise} \end{cases} \qquad (5)$$

The asymmetric-complex measure of risk (ASXR_t^c) is given by:

$$\text{ASXR}_t^c = \left[\textstyle\sum_k(\text{XR}_{t-k})^2/2\right]^{0.5} \qquad k = 1, 2, 3 \quad (6)$$

where

$$\text{XR}_{t-k} = \begin{cases} X_{t-k} - X_{\text{BAR}_t} & \text{if } X_{\text{BAR}_t} > X_{t-k} \\ X_{\text{BAR}_t} & \text{otherwise} \end{cases}$$

Economic theory suggests that the supply of a commodity increases as its (expected) price increases ($\beta_1 > 0$). An increase in production costs is expected to decrease the acreage for dura ($\beta_2 < 0$). By converting the cleared trees into charcoal the farmer can make some small profit, or at least reduce the net costs of land clearance. Therefore, we hypothesize that an increase in charcoal price will induce farmers to clear and cultivate more land ($\beta_3 > 0$). An increase in expected yield (EDY) will mean an increase in expected income and so β_4 is expected to be positive. Because we are concerned here with rainfed agriculture, the area cultivated is expected to increase as farmers expect higher rainfall ($\beta_5 > 0$). Assuming that farmers are risk-averse, an increase in perceptions of risk (DPR or RFR) is expected to shift the acreage curve to the left ($\beta_6 < 0$; $\beta_7 < 0$).

[7] A Durbin h-test indicated first-order autocorrelation. The equation was, therefore, estimated by maximum likelihood.

[8] Last year's rainfall gave better statistical results than the average rainfall over the last 2, 3 and 4 years. We also regressed yield on time and experimented with the expected values as a proxy for expected yield. However, yield from the previous year gave better statistical results.

4. Empirical results

Four versions of Eq. (1) were estimated by maximum likelihood procedures (Judge et al., 1982). The four versions differ only in the risk variables (DPR and RFR). Accordingly, these four versions are the symmetric-simple, symmetric-complex, asymmetric-simple and asymmetric-complex risk models. The symmetric form of risk is tested against the asymmetric form, and the simple measure of risk is tested against the complex measure using the non-nested J-test (Davidson and MacKinnon, 1981). The results of the pairwise J-test are presented in Table 1. Generally, Table 1 shows that the asymmetric-risk models were preferred to the symmetric-risk models and the simple measures of risk were preferred to complex measures (for more detail, see Elnagheeb and Bromley, 1991).

Table 1
Results of the non-nested J-test [a]

Tested hypotheses (H_0)	Alternative hypotheses (H_1)			
	SSRM	SCRM	ASRM	ACRM
SSRM		−0.197	1.489 *	
SCRM	2.007 ***			1.690 **
ASRM	0.624			0.900
ACRM		0.181	1.007	

[a] Entries are the values of the t-statistic for testing H_0.
SSRM, symmetric-simple risk model; SCRM, symmetric-complex risk model; ASRM, asymmetric-simple risk model; ACRM, asymmetric-complex risk model.
*, ** and *** indicate statistical significance at the 15%, 10% and 5% level, respectively. A significant t implies the rejection of H_0.

Table 2 presents the maximum likelihood estimates of the four risk models along with the estimates of the conventional non-risk model. In all models, the majority of coefficients (at least five out of seven) are significant at the 5% level of significance. The signs of all significant coefficients conform with a priori expectations. Dura acreage increases with dura's expected price and expected yield and decreases with increases in the cost of production. The insignificance of the expected rainfall coefficient might be due to

Table 2
Maximum likelihood estimates of dura acreage response function

Variable	Model				Non-risk model
	SSRM	SCRM	ASRM	ACRM	
Intercept	6.5383 ***	6.2612 ***	6.8429 ***	6.9837 ***	7.0525 ***
	(17.323)	(13.513)	(18.519)	(17.190)	(16.517)
Expected dura	4.8874 ***	3.9687 ***	1.7706 *	4.0139 ***	3.1177 **
price, EDP	(3.988)	(4.150)	(1.792)	(5.692)	(2.856)
Cost, C	−12.6588 **	−1.6545	−9.5532 **	−13.5655 **	−19.4478 ***
	(−3.230)	(−0.230)	(−1.983)	(−2.388)	(−5.086)
Charcoal	0.06443 ***	0.08236 ***	0.06667 ***	0.079977 ***	0.049006 ***
price, CP	(3.243)	(3.989)	(6.431)	(5.901)	(3.188)
Expected dura	0.001305 **	0.00271 ***	0.0023 ***	0.0030 ***	0.0018 **
yield, EDY	(2.043)	(4.219)	(4.599)	(5.225)	(2.381)
Expected	0.0006	0.0000169	0.0001508	−0.0002421	0.0001961
rainfall, ERF	(1.259)	(0.035)	(0.279)	(−0.582)	(0.334)
Dura price-	−2.51142 **	−2.55884 **	−3.81440 ***	−1.71877 **	
risk, DPR	(−2.235)	(−2.492)	(−3.493)	(−2.796)	
Rainfall	−0.0011524 *	−0.0023291 **	−0.0002945	−0.0004146 *	
risk, RFR	(−1.726)	(−1.982)	(−0.378)	(−1.455)	
Rho, ρ	−0.508720 **	−0.829008 ***	−0.911691 ***	−0.914384 ***	−0.497130 **
	(−2.289)	(−5.741)	(−8.594)	(−8.747)	(−2.219)
Chi-square	43.881 ***	41.284 ***	45.821 ***	45.301 ***	32.480 ***

Numbers in parentheses are the t-values.
*, ** and *** denote significance at the 10%, 5% and 1% level, respectively; one-sided test for all coefficients and two-sided test for chi-square and ρ.

collinearity between expected rainfall and expected yield.

An interesting result is that charcoal price has a positive coefficient which is significant at the 5% level of significance in all models. This finding supports the hypothesis that higher charcoal prices act as an added incentive for farmers to clear land for cultivation. The result may explain, at least partially, why farmers in the rainfed mechanized schemes do not leave a portion of their land in trees for shelterbelts as required by the Mechanized Farming Corporation. The result also illustrates the interrelationships between the energy and agricultural sectors. Policies such as import restrictions on oil products and distorted prices of energy resources, influence charcoal prices and indirectly influence land-clearing costs – and thus influence the total acreage under dura production.

If farmers are risk-responsive (presumably risk-averse), they should cultivate smaller areas as price and rainfall risk increase. This hypothesis is supported by all risk models in Table 2. The coefficients on the price and rainfall risk variables are negative in all models and significantly different from zero except for the asymmetric-simple measure of rainfall risk. Further, a nested F-test rejected, at the 10% level of significance, the null hypothesis that both coefficients on price and rainfall risk variables are simultaneously equal to zero. The hypothesis is rejected in all risk models. The $F(2, 8)$ values are 4.16, 3.72, 7.15 and 6.83 for the symmetric-simple, symmetric-complex, asymmetric-simple and asymmetric-complex risk models, respectively (the tabulated F-value is 3.11). Hence, our results suggest that both price and rainfall risks are important decision variables in the intended level of dura production in the rainfed farming schemes of Sudan.

Table 3
Acreage response elasticities [a] (at the means)

Variable	Model				Non-risk model
	SSRM	SCRM	ASRM	ACRM	
Dura price	0.528	0.429	0.191	0.434	0.337
Cost	−0.503	–	−0.380	−0.539	−0.773
Charcoal price	0.234	0.299	0.242	0.290	0.178
Expected yield	0.359	0.745	0.643	0.829	0.505
Price-risk	−0.130	−0.161	−0.099	−0.316	
Rainfall-risk	−0.164	−0.106	–	−0.195	

[a] Only significant (at the 10% or less level) elasticities are reported.

As expected, omission of the risk variables biased the estimates of the coefficients of the remaining variables and consequently biased the estimates of their respective elasticities. Since the expected dura price (EDP_t) is assumed to be a linear function of last year's price (DP_{t-1}), the elasticity of DP_{t-1} can be obtained from (see Eq. 2):

$$\begin{aligned}\epsilon &= (\partial \ln(A_t)/\partial \text{DP}_{t-1})(\text{DP}^*)\\ &= 0.566671(\partial \ln(A_t)/\partial \text{EDP})(\text{DP}^*) \qquad (7)\end{aligned}$$

where DP^* is the average of DP_{t-1}. The acreage response elasticities for the risk and non-risk models are reported in Table 3.

Table 3 shows that dura acreage response was price-inelastic; a 1% increase in real dura price resulted in about 0.4–0.5% increase in dura acreage. Omission of the risk variables has led to underestimated price elasticity – except for the asymmetric-simple risk model. This result is consistent with results from other research (Adesina and Brorsen, 1987; Hurt and Garcia, 1982; Ryan, 1977). Therefore, any policy decisions related to the price of dura in a non-risk model would likely result in underestimated dura acreage response. Both price-risk and rainfall-risk elasticities from the asymmetric-simple risk model are the least (in absolute value) when compared to those obtained from the other risk models. The acreage response elasticities from the symmetric-complex and asymmetric-complex risk models compare favorably except for the risk variables. The asymmetric-complex risk model gives the highest elasticities, in absolute value, with respect to the risk variables. These results imply that dura acreage seems more responsive to asymmetric than to symmetric price and rainfall risk.

Although price risk is found to be an important decision variable, its elasticity is smaller, in absolute value, than the price elasticity in all risk models. This result accords rather well with that found by Adesina and Brorsen (1987), Winter and Whittaker (1979) and Ryan (1977).

Table 3 also shows that dura acreage was as responsive to cost of production as it was to dura price. This result is important because a good part of the costs of production is the cost of gasoline which is subsidized by the government. Hence, the government can directly influence the dura acreage through controlling both the amount and price of gasoline.

5. Conclusions

Data from the rainfed mechanized farming sector of Sudan were used to estimate an acreage response model for dura (sorghum). Models that utilize symmetric and asymmetric forms of risk using different variables (simple and complex) to measure risk were estimated.

Dura acreage increased with dura's expected price, or expected yield and decreased with costs of production. Sesame prices were not found to influence dura acreage. An increase in charcoal price could be an added incentive for farmers to increase dura acreage. Therefore, policies that directly influence charcoal prices – e.g. oil import restrictions – should consider the impacts of charcoal pricing on acreage expansion. Although production of charcoal will save the country some badly needed foreign exchange, it will have an expansionary effect on the dura acreage. This process of deforestation will eventually have a negative effect on the production of charcoal itself as more trees are destroyed.

Farmers in the rainfed mechanized farming were found to be responsive to risk in prices and rainfall. Omission of risk from acreage response models would likely lead to underestimated price elasticities. Price and rainfall risk negatively influence dura acreage. Hence, policies to reduce dura price variability should consider the likely acreage-increasing effect of such policies. Hence, for any policy that leads to agricultural expansion, the benefits from such an expansion in total dura production should be compared to its costs in terms of the environmental degradation from accelerated deforestation (Simpson, 1978; El Tayeb and Lewandowski, 1983; El Taheir, 1987; Whitney, 1987).

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