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Why do farmers expand their land into forests? Theories and evidence from Tanzania

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ABSTRACT. This paper examines the causes of agricultural land expansion and deforestation in Tanzania. In the theoretical section, two different—and partly contradicting—sets of hypotheses are outlined. These are based on a subsistence approach, emphasising the food or income requirements of farm households, and a market approach, focussing on the relative profitability of agriculture. The statistical analysis shows that increased agricultural output prices, in particular for annual crops, is a major factor behind agricultural expansion. An increase of 1 per cent in output prices leads to about 1 per cent increase in agricultural area. Other factors such as input prices, technology and economic growth are tested and discussed, but the conclusions are less robust. The controversial role of population growth in explaining deforestation is addressed. Generally the results lend support to the market rather than the subsistence approach.

JEL classification code: Q12, Q23, C23
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1. Introduction

Deforestation has become an issue of global concern, in particular because of the value of tropical forests in biodiversity conservation and limiting the greenhouse effect. To the 80 per cent of the population of Tanzania using land and forest as their main sources of livelihood, however, agricultural expansion into forests is a major strategy to increase agricultural production and income. Even though such expansion may also have harmful environmental consequences at the local level, these may not be con-

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sidered sufficiently in farmers' decisions because of the collective good (or bad) nature of such effects, or because poverty makes short-term survival the overriding objective.

Land does not appear to be a critical constraint in the immediate future in Tanzania. About 6 per cent of total land or 13 per cent of potentially arable land is cultivated. In addition to the 6.8 million ha agricultural land, 10–12 million ha are eminently suitable for maize production, and 3–4 million ha suitable for rice (World Bank, 1994). There is, however, still cause for concern. Shortage of land is a problem in localised areas, especially in the densely populated northern and western highlands regions, and in the arid and semi-arid parts of central Tanzania. Reduction in forest cover is often associated with decreased rainfall infiltration, accelerated soil erosion, and other harmful influences that may contribute to a decline in soil fertility and crop yields.

Data on the extent of deforestation in Tanzania are inadequate and confusing. According to the widely accepted official estimates, deforestation is advancing at an annual rate of about 300,000 to 400,000 ha (United Republic of Tanzania, 1989b, 1994a, 1994b; FAO, 1992, 1997). This compares with a total forest stock in 1990 of about 33.5 million ha (FAO, 1992), making the rate of deforestation about 1 per cent, which is above the average for Sub-Saharan Africa. Other sources, for example Ahlbåck (1988), estimate the rate of deforestation to be as high as 600,000 ha per year.

Most of the deforestation in Tanzania stems from activities related to agricultural expansion and woodfuels consumption (Ahlbåck, 1988; Ramadhani, 1989; United Republic of Tanzania, 1989b; Bagachwa *et al*., 1995). The focus of this study is on agricultural land expansion. The main purpose is to investigate the factors that encourage this expansion.[1] More specifically, the paper intends to empirically examine the role of output and input prices in agriculture, the connection between income and changes in resource use, and the effect of technological change. We also critically discuss the role of population in the analysis of deforestation.

The paper initially provides a brief and critical examination of statistical studies of deforestation. In the second part two different theoretical approaches are outlined: the subsistence and market approaches. Based on this, two sets of—partly contradicting—hypotheses and demand functions for agricultural land are derived. Section 3 discusses data and estimation methods. The analysis is based on panel data from 19 regions for the 1981–91 period. Next we present and interpret the results, which are estimated by the least square dummy variable (LSDV) model. A summary of the main results and some policy implications are found in the concluding section.

Previous studies

There has been a sharp increase in the number of studies attempting to link

[1] Strictly speaking we do not know to what extent agricultural expansion is into forested areas, and not into grassland or savannah. However, as earlier work indicates (see references immediately above), agricultural expansion is the most important source of deforestation in Tanzania. Also, our approach is set within the literature and debate on tropical deforestation.

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deforestation or changes in forest cover to different economic, demographic, and political variables. Kaimowitz and Angelsen (1998) provide a critical review of more than 140 economic models of deforestation. A collection of recent, mainly econometric, studies is found in Brown and Pearce (1994).

The present paper falls within the category of non-spatial regional regression models using panel data, for which there are about a dozen studies available from other (non-African) countries (Kaimowitz and Angelsen, 1998). For example, Barbier and Burgess (1996) estimate agricultural planted area and beef cattle numbers at the state level in Mexico during the period 1970–85 in order to determine the main factors affecting forest land conversion. Similarly, Andersen (1996) uses land survey data in an analysis of 316 counties in Brazil in the same time period, and Cropper *et al*. (1997) analyses information from 58 provinces in Thailand over the period 1976–89 to explore factors that have stimulated forest conversion.

About half of the deforestation models to date are econometric studies. Kummer and Sham (1994), Rudel and Roper (1997), Kaimowitz and Angelsen (1998), and Angelsen and Kaimowitz (1999) argue that a critical assessment of much of the research is necessary for several reasons. Besides the problem of data quality, particularly for deforestation in cross-national (global) regression models, many studies lack an explicit theoretical framework or model, which should guide the empirical analysis in both the selection and interpretation of explanatory variables. Variables at different levels are introduced in the models; the result is confusion about the cause–effect relationships. We believe it is imperative to distinguish between variables at three levels:

1. The *direct sources* of deforestation. Possible variables to be included here are expansion of agricultural area, fuelwood collection, and timber production. The measurement of the relative share of various sources should not, in principle, need to be subject to econometric analysis; simple accounting should be sufficient.
2. The *immediate causes* of deforestation, which are the variables that influence the decisions by the *deforestation agents*. We label these the agents' *decision parameters*. Possible variables, as further discussed in Section 2, include output and input prices, wages, access costs (roads).
3. The *underlying causes*, which are *macro-level variables* that determine deforestation behaviour through their influence on the decision parameters, but do not enter the agents' decision problem directly. Examples here include GDP per capita, economic growth, foreign debt, and population growth/density.

In this hierarchy, the main cause–effect relationship would move from levels 3 to 2, and from 2 to 1. Problems arise when variables at different levels are combined in the same equation, for example, foreign debt, fuelwood collection, and agricultural prices. Some of the explanatory variables will be functions of others, and the interpretation of the causal effects is flawed. Statistically it may result in high levels of multicollinearity. In the present study we limit the analysis mainly to variables at level 2, but include one or two level three variables (e.g., regional GDP per capita) as proxies for those at level 2 (opportunity costs of labour).

Related to this is the issue of which variables are endogenous and which

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are exogenous. The question of using population growth as an explanation for deforestation is highly debatable, an issue elaborated further in Section 2. The correlation between high population density and low forest cover is a well-established fact (e.g., Palo, 1994), but the causal link is far from obvious. It may simply reflect the fact that few people live in the forests. In a more complete model, local/regional population should be considered endogenous due to migration. Agricultural expansion and in-migration could be explained by the same underlying factors, and farm area expansion can attract migrants as more agricultural labour is needed (suggesting a link in the opposite direction).

Cross-national analyses—which form the majority of the econometric studies—tend to focus on variables at level 3. There are several problems with this approach. In order to produce statistically significant results the use of cross-national regression analysis requires that the variables included affect deforestation in roughly the same manner across countries. This is obviously a very strong assumption; indeed studies show that the effect of, for example, economic growth and foreign debt may be very different from country to country.

Since the factors encouraging deforestation are relatively location specific it can be argued that cross-country data are too aggregated for a proper investigation of the causes of deforestation. We should expect to find a much stronger correlation between deforestation and the micro-level decision parameters, than between deforestation and macro-level variables.[2] Bilsborrow and Geores (1994) therefore suggest that sub-national units or even districts are better suited for this kind of methodology. The present study attempts to analyse the problem by using a regional panel data set of mainland Tanzania, and pooling methods which account for location specific (geographical) differences within the country.

The availability and quality of data are a problem in most analyses, including the present one. This strengthens the need for an explicit theoretical framework and careful interpretation of the results. At the same time, there is a strong need for quantitative analysis, which is often necessary to determine the net effects of policies and provide more concrete policy guidelines.

Studies on Tanzania

Few econometric studies on the causes of deforestation in Tanzania are available. Bagachwa *et al*. (1995) look at the likely response of cultivated area and deforestation to economic policies in the country. To capture the environment–policy linkage, they use a range of factors that determine how micro-level actors respond to macro and sectoral policies. The results indicate that deforestation is linked to population increase, and *low* prices of woodfuels and timber. For crops, however, the study reveals that price increases, particularly for annual crops, are a cause of land extensification

[2] The 'decision parameters' are to some extent overlapping with 'sectoral level variables'. Barbier *et al*. (1995: 104) point out that these variables have the most immediate and visible effect on deforestation, which is in line with our claim.

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in the country. The own price elasticity for most crops are found to be in the range of 0.3–1.0.

Two farm household programming models from Tanzania of relevance for the present study are Monela (1995) and Sankhayan (1996). Both studies focus on the effects of population growth and policy changes on cropping area, crop mix, and land clearing. Monela's model suggests higher fertiliser prices have little effect in the short run, but increase deforestation in the long run. The direction of effects is the opposite for other input prices. He finds farmers expand land area when crop prices increase, but the expansion is limited by cash constraints. Sankhayan's model from the Southern Highlands suggests that the structural adjustment programme (SAP) is likely to increase pressure on forest resources, as more wood for curing is required to meet increased tobacco production.

The impact of SAP and economic liberalisation on economic growth, soil erosion, and land expansion is also addressed by Aune *et al*. (1997), using a CGE model. Assuming that farmers respond positively to output price increases, they conclude that export tax reduction and devaluation lead to an expansion of agricultural land. This effect is, however, dampened by a shift towards more land intensive crops, such as cotton and cashews, away from food crops such as cassava and rice. Finally, there are several studies on the determinants of fuelwood consumption, e.g., econometric models by Borberg (1993) and Hosier and Kipondya (1993), and a dynamic simulation model by Hofstad (1997).

2. Theoretical framework and hypotheses

The debate and literature on the causes of tropical deforestation are at times confused because the approach and underlying assumptions are not made explicit. Indeed, many of the controversies can be understood as differences in the approach used, as the hypotheses and policy recommendations may vary widely within the various approaches. In this section we discuss two different models of agricultural land expansion: the subsistence (population) approach (SA), and the market (open economy or profit-maximising) approach (MA). These represent two extremes and are, as such, useful to explore the range of hypotheses for the effect on deforestation of changes in economic parameters. Other approaches, for example, the Chayanovian (a utility-maximising household, balancing leisure and consumption) or a general equilibrium approach could yield hypotheses which are consistent with both approaches presented in this paper. Angelsen (1996) provides a more elaborate comparison of four different approaches, including the two presented here and the Chayanovian.

The SA and MA refer to differing assumptions made about household behaviour and the labour market, the latter being the most important. In the SA no labour market exists, whereas a perfect labour market is assumed in the MA; any amount of labour can be sold and hired at a fixed wage. The relevance of the two models are therefore related to how the economy operates, and also to the time perspective. The MA is more appropriate for the study of long-term effects, in particular because migration will then be important.

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The subsistence approach

The subsistence approach takes as its point of departure the proposition that a person's objective is to satisfy his subsistence requirement, mainly from agricultural production. In its simplest version the subsistence requirement is fixed. The economic problem is to minimise the labour inputs given this constraint. Production is determined by

$$X = Af(L,H,F) \tag{1}$$

where X is production in physical units, A represents the technological level, L is (on-the-field) labour input, H is total land area (land assumed to be of homogenous quality), and F is fertiliser input. The production function (1) is assumed to be concave, with positive but decreasing marginal productivity of all inputs ($f_i > 0; f_{ii} < 0$). All inputs are normal, and any pair of inputs are complementary ($f_{ij} > 0$; $i \neq j$).

There is no market for land, and uncultivated land (forest) can be brought into cultivation on a 'first come first served basis' (open access, where forest clearing gives land rights). There are, however, costs related to the clearing of new land, and also costs from having a large area to cultivate, for example, in terms of walking, transport of inputs and output. These labour costs are in addition to the labour used to cultivate the land (on-the-field labour), and are represented by a convex function $h(H)$.

The Langrangian of this minimisation problem is

$$G = L + h(H) - \lambda[pAf(L,H,F) - qF - sN] \tag{2}$$

where p and q are output and fertiliser prices, respectively. The subsistence requirement is given by subsistence consumption (= income) per capita (s), multiplied by the total population (N). The first-order conditions (FOC) are summarised as:[3]

$$pA = \frac{1}{\lambda f_L} = \frac{h_H}{\lambda f_H} = \frac{q}{f_F} \tag{3}$$

and

$$pAf(L,H,F) - qF = sN. \tag{4}$$

The term $(1/\lambda)$ in equation (3) can be interpreted as the shadow wage of labour in the model. Thus, at the optimum the marginal costs per output unit of the three inputs should equal the price of the output (p), multiplied by the technological level (A).

While not presenting the formal derivation of the comparative status results, the effects of exogenous changes on land area are fairly straightforward in this model. An output price increase or technological progress make it economical for farmers to meet the subsistence target by producing from a smaller land area. Lower fertiliser (or other input) prices will induce the farmers to substitute fertilisers for land (and labour), and thereby reduce the pressure on forests. Improved accessibility (lower costs of bringing new land into cultivation) has the opposite effect. Finally,

[3] Implicitly we are assuming that farmers are not credit constrained or have sufficient cash to purchase the optimal quantity of fertilisers.

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population growth increases the overall consumption (income) requirement, and therefore leads to increased areas of cultivation and deforestation.

The market approach

The market or open economy approach is based on a very different way of reasoning compared to the subsistence approach. The key change in the underlying model assumptions is the introduction of a labour market where labour can be sold or hired at a fixed wage (w). This wage rate gives the opportunity costs of labour used in agriculture. The land expansion decisions can then be studied as a profit(land rent)-maximising problem. This does *not*, however, imply that the household's overall objective is to maximise profit. The perfect labour market assumption implies that production decisions can be separated from the consumption and labour supply decisions of the household.[4] Thus the *production* decisions of a *utility*-maximising household can be analysed as a profit-maximising problem. Confusion is created because this way of modelling is often—and wrongly—associated with profit-minded and commercial farmers, as opposed to highly risk-averse and survival-oriented peasants. The MA does *not* need to introduce any particular behavioural assumption for the farm household.

The production problem is now to maximise total profit or land rent

$$R = pAf(L,H,F) - qF - w[L + h(H)]. \tag{5}$$

The FOC can be summarised as

$$pA = \frac{w}{f_L} = \frac{wh_H}{f_H} = \frac{q}{f_F}. \tag{6}$$

Even though the FOC looks similar in the two versions of the model, the fundamental difference is that whereas the wage rate (w) is exogenous in the latter, the shadow wage (l/λ) is endogenous in the subsistence model. Population, on the other hand, is endogenous in this model whereas it was exogenous in the subsistence one. This makes a crucial difference to the response of exogenous changes. Agricultural production and land use within the MA are determined by the *relative profitability* of agriculture, not any subsistence requirement.

The comparative static results of the market model are summarised in Table 1. Higher output price or technological progress will increase the relative profitability of agriculture, and therefore increase agricultural land. Increased fertiliser prices will, assuming complementarity between fertiliser and land area, reduce the area of cultivation. Better access to the forest margin will, as in the subsistence case, lead to an area expansion. A key variable for the determination of the extent of deforestation is the wage rate; higher opportunity costs of labour will make cultivation on the forest margin unprofitable.

Population does not enter the model explicitly. By extending the approach to include general equilibrium effects in the labour and output markets, population growth may have indirect effects through lower wages and higher food prices. In a regression model where both wages

[4] The standard reference on agricultural household models (and their recursive property) is Singh *et al*. (1986).

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Table 1. *Hypotheses derived from the subsistence and market approaches*

Parameter	*Effect on deforestation of an increase in the parameter*	
	Subsistence approach (SA)	*Market approach (MA)*
Output price (p)	decrease	increase
Technology (A)	decrease	increase
Fertilizer price (q)	increase	decrease[a]
Clearing and access ($h(H)$)	decrease	decrease
Wage (w)	not applicable	decrease
Population (N)	increase	(increase)[b]

Notes: [a] This rests on land and fertiliser being complementary inputs, which seems to be the most realistic assumption. If they are alternative the effect would be an increase.
[b] Whereas population does not enter the model directly, by extending the approach to include general equilibrium effects, a population increase will have indirect effects through lower wages and higher food prices.

and output prices are included, one should nevertheless expect the population effects to be captured directly in these variables.

Both the SA and MA can be extended in several directions. Including the crop choice in the models would enable a discussion of deforestation effects of changes in relative output prices, depending on the land intensity of different crops. Another possible extension would be to include time (dynamics). One important distinction, included in the empirical analysis, is to distinguish between annual and perennial crops. Generally one should expect the response to price changes to be higher for annuals because of their greater flexibility. The (long) gestation period for perennials would increase the importance of factors such as expectations about future prices and availability of credit.

Another important extension would be to include the property rights regime, particularly how rights to new forest land are allocated and the security of such rights. Angelsen (1996) shows that in the situation where land rights are obtained by forest clearing, and farmers expect the land rent to increase over time, the effect of such a property regime is to encourage deforestation. Moreover, in this situation land reforms that aim to strengthen land rights (increasing tenure security) would—contrary to conventionally held views—encourage deforestation. The limited availability of time series and regional quantitative data on property rights has prevented any further analysis of the property issue in this study.

Hypotheses

The hypotheses about the effects on land expansion (deforestation) of changes in economic variables are summarised in Table 1. We note in particular that the hypotheses for the effect of changes in the technological level and the output and fertiliser prices are the opposite in the two approaches. Furthermore, the subsistence approach focuses on the effect of population growth, whereas the market approach highlights the role of alternative employment, as expressed through the wage rate.

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Whereas it is trivial in the two models that an output price increase and (Hicks neutral) technological progress have the same effects, a distinction between these two changes is commonly made in the deforestation literature. A general argument is that whereas a price increase will boost deforestation, improved technology will reduce the pressure on forests. Such a distinction may be due to general equilibrium effects of technological change (see Section 4), but it may also reflect inconsistencies in the arguments as one moves from one approach to the other without any particular justification. Within a partial equilibrium framework technological and price changes will have the same effect.

3. Method and data

Based on the theoretical framework presented in the previous section, the specification of the model for empirical analysis and the data are presented below. This study is based on a panel (longitudinal) data set, in which a given set of cross-sectional units is repeatedly sampled at different points in time.[5] The cross-section and time-series data are pooled using a least square dummy variable (LSDV) model (regional effects only).

In the model with regional effects only, dummy variables are introduced to capture the effects of those omitted variables that are specific to each individual region but stay constant over time. In addition to differences in regional size, they could also include differences in climatic conditions and topography between regions. This fixed effects model is preferred to the random effects model (REM) because panel data are used which are not from a randomly drawn sample, but which comprises all regions except for one[6] in the whole country.[7] Furthermore, since deforestation is location specific, the LSDV model is well suited to capture the regional effects or differences in cross-sectional units. The model is specified as log–log

$$\ln LA_{it} = \alpha_1 D_1 + \ldots + \alpha_{19} D_{19} + \beta_2 \ln PA_t + \beta_3 \ln PI_t + \beta_4 \ln Y_{it} + \beta_5 \ln FE_{it} + \epsilon_{it} \tag{7}$$

where LA_{it} is land area cultivated; α_i is the constant term for the ith cross-sectional unit (region-specific coefficient); D_i are regional dummies; PA_t is the producer price index for agricultural output in year t; PI_t is the real price of agriculture inputs in year t; Y_{it} is real per capita income in region i and year t, which can be interpreted as a proxy for alternative employment opportunities (see discussion later); FE_{it} is per capita fertiliser use in region i and year t, used as a proxy for the technological level. The values for β_k are slope coefficients that are common to all regions.

[5] For details on advantages of panel data, see Hsiao (1992).

[6] We exclude the Dar es Salaam region. The regions included in the panel data set are Mbeya, Kagera, Mtwara, Morogoro, Tabora, Shinyanga, Dodoma, Ruvuma, Kilmanjaro, Iringa, Tanga, Pwani, Arusha, Lindi, Singida, Rukwa, Kigoma, Mwanza, and Mara.

[7] According to Kennedy (1992), if the data encompasses the population, then the LSDW approach which produces results conditional on the data set, is reasonable. If the data are a sample of observations from a large population the LSDV model is no longer reasonable.

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As the model is specified on a log–log form, the coefficients can be interpreted as elasticities; the percentage effect on land area of a 1 per cent increase in the independent variable. ϵ_{it} is a classical disturbance with $E(\epsilon_{it}) = 0$, $E(\epsilon_{it}^2) = E(\epsilon_i \epsilon_i') = \sigma^2_\epsilon$, and $E(\epsilon_i \epsilon_j) = 0$. In this study there are 19 regions ($i = 1, 2, ..., 19$) and 11 years ($t = 1981, 1982, ..., 1991$).

Next we include the population variable in the model such that

$$\ln LA_{it} = \alpha_1 D_1 + ... + \alpha_{19} D_{19} + \beta_2 \ln PA_t + \beta_3 \ln PI_t + \beta_4 \ln Y_{it} + \beta_5 \ln FE_{it} + \beta_6 \ln POP_{it} + \epsilon_{it} \quad (8)$$

where POP_{it} is population in region i and year t.

A priori expectations about the sign of the coefficients depend on the underlying assumptions as discussed in connection with Table 1. That is, under the subsistence approach, coefficients β_2 and β_5 are expected to be negative, β_3 and β_6 are expected to be positive, while the income coefficient β_4 is expected to be either positive or negative, as discussed below. Under the market approach, coefficients β_2, β_5, and β_6 are expected to be positive, while β_3 and β_4 are expected to be negative.

Most of the data for this study were collected by one of the authors in Tanzania from the Bureau of Statistics, the Planning Commission, the Ministry of Agriculture, and the Ministry of Natural Resources, Tourism and Environment. Other consulted sources include various reports from FAO and the World Bank. The data are defined and described below, while details are presented in Shitindi (1996). All price variables are deflated by the GDP deflator for 1985.

Expansion of agricultural land area is used as a proxy for deforestation. Whereas agricultural land expansion is a major source of deforestation, the proxy is not perfect. First, it does not cover all sources of deforestation. Second, some agricultural expansion may not be into forest but, for example, grasslands and savannah. Yet given the limited availability of other data on annual changes in forest cover or deforestation, we think this is the best proxy available at the regional level for an analysis of deforestation.

Land area cultivated annually (LA) is expressed in thousand hectares. Area in region i and year t is computed by adding together the area under the predominant food and export crops. Food crops are maize, paddy, sorghum, millet, cassava, and pulses. Export crops are cotton, sisal, coffee, tea, tobacco, and pyrethrum. All crops except coffee, tea, and sisal are annual.

Producer price indices of agricultural crops are constructed using a Laspeyres base-weighted index, with 1985 as base year. The prices and quantities of ten major crops (maize, paddy, sorghum, cassava, tobacco, coffee, tea, cotton, sisal, and pyrethrum) were used to construct the following indices: price index for agricultural crops (PA); annual crops producer price index (PAA); food crops producer price index (FPA); export crops producer price index (XPA); annual export crops price index (AXPA); and perennial export crops price index (PXPA). There is no regional variation in these indices. Prices used to construct the indices are official producer prices set by the government. Currently, however, the

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official marketing channel of food crops has been largely replaced by an open market system, thus official prices have had limited impact in recent years. Normally, farmers have received somewhat higher prices than those set by the government.[8] For most export crops the position is quite different with most output still being sold through the marketing boards and the unions.

The price index for agricultural inputs (PI), an indicator of costs for inputs employed in agriculture production—also without regional variation—is proxied by annual average price of different kinds of fertiliser in Tanzanian shillings per kilogram, deflated by a GDP 1985 deflator.

The population variable (POP) is for each region for the 11 year period, as recorded by the Bureau of Statistics.

Real GDP per capita (*Y*) by year and region is expressed in 1985 Tanzanian shillings. According to the Bureau of Statistics (1995), income estimates are based on the wage bill as obtained from a labour enumeration survey which gives the wage bill by region. The wage bill ratios have been used to distribute the GDP in each sector by region.

The FE variable is used as a proxy for technology. The variable is computed as annual per capita fertiliser use in each region for the period of study.

4. Empirical results and discussion

We experimented with several combinations of the variables, including different price indices for groups of agricultural crops. The main results of the regression analysis are reported in Table 2 below: equations 1 and 2 are based on (7) and (8) above, whereas equations 3 and 4 use different price indices. The explanatory power of the model is more or less the same across specifications, with the adjusted R^2 ranging between 76 per cent and 77 per cent, indicating a good fit of the estimated model. Using an F-test, the hypothesis that the regional individual effects were collectively the same (testing for homogeneity) was rejected at the 1 per cent level, implying that there is a basis for differentiating the time-series cross-section data.

As can be seen from the correlation matrix presented in the Appendix, multicollinearity between the independent variables appears to be quite low. Tests by the Durbin–Watson statistic and White's test revealed a presence of autocorrelation and heteroscedasticity, respectively. The corrected heteroscedasticity results using White's test proved not to be noticeably different from those before the correction. From this examination, we concluded that autocorrelation was a problem to be eliminated. Thus, all regressions were corrected for autocorrelation using a Cochrane–Orcutt iterative procedure.

Producer prices of agricultural crops

As part of the general liberalisation and market orientation of the Tanzanian economy, starting in the early 1980s, the agricultural sector has gone through substantial reforms (removal of price controls, input subsidies, restructuring of marketing boards, etc.). The response of the sector to

[8] It has not been possible to obtain satisfactory panel data for actual market prices.

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Table 2. *Regression results. T-values in brackets. Dependent variable: Log of cultivated land area of principal crops in thousand hectares*

Independent variable	*Equation 1*	*Equation 2*	*Equation 3*	*Equation 4*
Producer price index, all crops	1.04	0.39		
(LNPA)	(8.54)	(1.99)		
Food crops producer price index			0.73	0.57
(LNFPA)			(5.76)	(3.83)
Export crops producer price index			0.34	
(LNXPA)			(2.37)	
Annual export crops producer price				0.48
index (LNAXPA)				(2.99)
Lagged (4 years) perennial export crops				0.093
producer price index ($LNPXPA_{t-4}$)				(2.48)
Price index agricultural inputs	−0.0087	−0.0088	−0.0058	
(fertiliser) (LNPI)	(−0.13)	(−0.14)	(−0.09)	
Real GNP per capita (LNY)	−0.014	−0.12	−0.031	−0.055
	(−0.23)	(−2.00)	(−0.49)	(−0.96)
Technology proxy (fertiliser use per	0.060	0.069	0.058	0.055
capita) (LNFE)	(2.12)	(2.46)	(2.08)	(1.98)
Population (LNPOP)		0.60		
		(3.94)		
R^2	0.79	0.80	0.79	0.80
ADJ-R^2	0.76	0.77	0.76	0.77
SE	0.24	0.24	0.25	0.25
RSS	11.88	11.01	11.83	11.23
D-W	2.00	2.00	2.00	2.00

these reforms can be characterised as a modest recovery. As in other African countries, higher production has to a large extent been due to expansion of agricultural land rather than yield increases.

The cropping area of Tanzania increased by 38 per cent over the period from 1981 to 1991. The most significant result—both in statistical and economic terms—of the empirical analysis is the importance of agricultural output prices in this process. As regression equation 1 shows, an increase of 1 per cent in the agricultural output price will lead to about 1 per cent increase in agricultural land area. In equations (3)–(4) sub-indices are used, but the combined effect is still around 1 per cent. When population is included, the price elasticity drops to 0.4–0.5, but is still statistically significant at the 5 per cent level (equation 2 and equations not included in Table 2).

The food crops price (FPA) elasticity was estimated to be about 0.7 per cent, and is statistically significant at the 1 per cent level. Note that this is the elasticity of total cropping area, and the high share of food crops (about 80 per cent) makes one expect the elasticity to be relatively high. This result indicates that increasing producer prices for food crops has in part been responsible for the conversion of forests into cropland between 1981 and 1991.

The coefficient of the export crops producer price index (XPA) reported in equation (3) is positive and statistically significant at the 5 per cent level.

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The price elasticity suggests that a 10 per cent increase in the export price will result in about a 3.5 per cent increase in agricultural land. To explore the type of export crops with more impact on land clearing, we replaced the XPA variable with the price index for annual export crops (AXPA), and the price index for perennial export crops (PXPA). The results in equation 4 show that the estimated coefficient for AXPA is positive as expected and somewhat higher than the coefficient for XPA, and statistically significant at the 1 per cent level. Given the fact that annual export crops only constituted about 10 per cent of agricultural land in 1981, an elasticity of 0.4–0.5 is very high. The cultivated area of annual export crops (cotton, tobacco, pyrethrum) increased by 56 per cent over the 11 year period.

The coefficient of perennial export crops (PXPA) was found to be statistically insignificant and 'wrongly' signed (negative) when included in the equation (not reported in Table 2). These results suggest that in the short run, farmers of annual export crops respond to price increases by expanding their farmland, while the area under perennial crops is less likely to be expanded. Since we did not find any proof for agricultural area responding to short-term changes in perennial export crop prices, the index (PXPA) was, after some experimenting, lagged four years ($PXPA_{t-4}$). When lagged prices are introduced (equation 4), the situation changes as the estimated price elasticity of demand for land for perennial crops, although small, is positive and statistically significant. These results indicate that with increasing prices, in the long-run farmers of perennial crops adjust their production by expanding their cultivated land area.

The increase in prices of export crops has been more than twice that of food crops, and more or less the same for annual and perennial export crops. The analysis shows, however, a marked difference in the response for annuals and perennials, with the former offering much higher flexibility. The empirical results show little evidence of farmers responding in the short run to price increases of crops such as coffee, tea and sisal by expanding the cultivated land area. More often, farmers of perennials appear to respond to price incentives in the short-run by intensifying care and improving husbandry (e.g., weeding, pruning, and application of fertiliser) for their existing crops. Also, since perennial export crops are less soil erosive, and productivity can be improved from rehabilitating existing plantations, it is plausible that land expansion would be slower than for annuals. It is easier for farmers to respond quickly to price incentives in the short-run for annuals by expanding the land area. Further, because most annual crops deplete soil fertility faster than perennial crops, they require more new fertile land, especially under low-input extensive farming practices as in Tanzania.

Input prices

The estimated coefficient of the inputs price index (PI), proxied by the real price of fertiliser, is statistically insignificant in all equations tested. Under the subsistence approach it was predicted that increased input costs would discourage the use of modern inputs such as fertilisers. Instead, subsistence farmers expand their area under cultivation in order to compensate for lost output due to reduced fertiliser input. On the other hand, under

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the market approach it was predicted that an increase in fertiliser input price would result in a decrease in the area under cultivation.

The statistically insignificant result could, of course, indicate that the real response of farmers lies somewhere between the two approaches. A number of other reasons may, however, also explain the inconclusive result. Although fertilisers were sold for a long period at subsidised prices, access to these inputs was hindered by inefficient marketing and distribution systems. Frequently, insufficient supplies resulted in aggregate shortages failing to satisfy the farmers' demand at existing prices. Even if prices have increased, the liberalisation of the inputs market and the removal of subsidies have improved the availability of inputs and the supply system in the country. On the other hand, the pan-territorial pricing of inputs before adjustment meant that remote producers were subsidised. Under the market reforms these producers could be the most affected group. Since private traders may prefer to trade in markets that are more profitable, the result may be reduced availability of inputs in more remote areas. In Zambia, a study by Culas (1995) shows that fertiliser use has decreased in the post-adjustment period as pan-territorial pricing was abandoned.

GDP per capita

The estimated coefficient of the GDP per capita variable (Y) was consistently *negative* in all the equations, but statistically significant only in equation 2 where population is included. This result suggests that, despite its general lack of statistical significance, demand for agricultural land tends to *decrease* with increasing real income.

GDP per capita is a level 3 variable, as discussed in Section 1, and is as such not directly included into the farmers' decisions. The variable could be linked to or used as a proxy for several of the decision parameters. One should note that GDP reflects both farm and off-farm income. To the extent it reflects farm income, this should be determined by output prices and production, the latter being a function of land, labour, and other inputs. If farmers are cash constrained, increased income could allow them to spend more on purchasing inputs such as fertilisers. Under the subsistence framework this would lead to reduced pressure on forests, whereas the effect would be the opposite in the market approach.

To the extent that GDP per capita represents off-farm income, it could be a proxy for alternative employment opportunities, i.e., w in the market model in Section 2. The empirical results, even though statistically insignificant, are in line with the hypothesis of reduced deforestation following improved off-farm opportunities. A third effect of GDP growth is to increase the demand for agricultural products. However, this effect should, *in principle*, be reflected in changing output prices.

Population

The population variable (equation 2) coefficient is positive as expected by both approaches, and statistically significant. This indicates that growth in agricultural land is associated with increased population. One should, however, also consider the possibility that the population variable—at

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least to some extent—reflects a general trend variable, as population growth is not changing much from year to year.

The magnitude of the coefficient suggests that an increase of 1 per cent in population will increase land area by approximately 0.6 per cent (the coefficient was lower—about 0.4—in equations which used price indices for sub-sectors of agriculture). When the population variable is introduced into the model, most of the deforestation over the period is explained by population growth. In the models without population, agricultural output prices are the economically most significant factor.

The results lend support to both the SA and MA hypotheses on population. Again, one should be careful when drawing conclusions about the causal relationship between deforestation and population growth. Within a general equilibrium framework, population growth should induce a downward pressure on the wages and an upward pressure on agricultural output prices. The latter effect could be expected to be taken into account by the output prices in the model, whereas the labour market effect is not (sufficiently) included. Thus the labour market effect provides a possible interpretation of the result.

Technology

The coefficient of the technology variable (FE), which is proxied by per capita fertiliser use, is statistically significant but the size of the coefficient (elasticity) is relatively low. The positive sign of the coefficient supports the market approach hypothesis. The results suggest that agricultural land area expands with improved technology, in line with the hypothesis from the market approach.

Some caution regarding the effect of raising agricultural productivity is in order. Other empirical studies to determine the effect on deforestation of technological progress have yielded mixed results (Kaimowitz and Angelsen, 1998). Hicks neutral technological change in a partial equilibrium context (as in Section 2) is the same as an output price increase, but we may arrive at different or at least modified conclusions when considering general equilibrium effects in the labour and output markets. Demand for agricultural products, as demonstrated in a large body of the agricultural economics research, is fairly price inelastic, implying that general productivity gains which increase supply typically lead to sizeable price declines. The key is what happens to farm profitability: if the price decline is sufficiently large it will outweigh the initial productivity gain, and therefore reduce the incentives for forest clearing under the market approach.

In general, technological progress is more likely to lead to agricultural expansion and deforestation when output demand is elastic, there are small opportunities for migration (labour supply inelastic), the technology is labour saving rather than labour intensive, and the new technology is applicable to production systems at the forest frontier (Angelen and Kaimowitz, 1998).

5. Some conclusions and policy implications

This paper has two main objectives. The first is to present two different

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approaches—the subsistence approach and the market approach—to modelling deforestation due to agricultural expansion. The approaches differ both in respect to which variables are important for deforestation and, in the case of productivity or output price increases, the direction of the effect. Because these differences are often not made explicit in the deforestation literature, the intention has been to highlight the differences in assumptions and their consequences for empirical hypotheses.

The policy recommendations depend critically on the approach chosen. The subsistence approach seems to dominate the thinking on the causes of and remedies for deforestation within the development aid community. A main policy recommendation according to this approach is population control and *agricultural intensification*; increased productivity will reduce the deforestation pressure.

Whereas the subsistence approach focuses exclusively on the agricultural sector, the market approach draws attention to the development of the rest of the economy. In particular, it emphasises the importance of alternative employment. It also highlights the counter-productive effect on deforestation of intensification programmes that increase the profitability of agriculture close to forests.

The second objective of the paper is, in the light of the theoretical approaches presented, to examine empirically the possible factors encouraging deforestation and determine which of the approaches is empirically more useful in explaining deforestation caused by agricultural expansion. For this purpose we use a regional panel data set from Tanzania. A general warning about data quality is in order, and the results should be interpreted with great caution.

With this reservation in mind, the major result of the regression analysis is that producer prices, in particular of annual crops, are important factors encouraging expansion of agricultural land.[9] In the light of these findings, the economic behaviour of smallholders in Tanzania seems not to be as disengaged from the market as the subsistence approach may suggest. Instead farmers behave more in line with the market approach, where the production decisions can appropriately be studied as profit-maximising behaviour. One should, nevertheless keep in mind that these models represent extreme cases. A more complex Chayanovian model with subsistence requirements and imperfect labour and credit markets would provide a more realistic description of farm households' behaviour and the constraints they face.

The coefficient for the technology variable, proxied by per capita fertiliser use, was positive and statistically significant, supporting the market approach hypothesis that technological progress leads to agricultural land expansion and deforestation. Indeed, in both versions of the theoretical model technological progress and output price increases are treated in the same way, and the empirical results lend support to the market approach.

The results of the negative effect on deforestation of GDP growth and

[9] In interpreting this result, one should keep in mind that the area for annual crops is far larger than for perennials.

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the positive effect of population growth are open to several interpretations. One plausible hypothesis, in line with the market approach, is that these factors are related to the availability of off-farm jobs. Improved opportunities for income outside agriculture would reduce the pressure on land, whereas population growth depresses off-farm income opportunities.

The result for population is important; higher population is associated with more agricultural land, although the percentage increase in land is only about half of the population increase. One should also question whether regional population can be considered exogenous.

A major conclusion from this study is that increases in productivity and/or output prices in Tanzanian agriculture would most probably result in more forested areas being converted to agricultural land. Recent economic liberalisation has increased agricultural output prices and the response of Tanzanian farmers seems to have been to increase agricultural area and production (cf. Aune *et al*., 1997). These findings indicate a conflict between forest conservation and higher agricultural production and rural income. How to handle this apparent trade-off remains a challenge both for researchers and policy makers. What policy measures can combine multiple objectives related to food security and production, income generation and poverty reduction, and forest conservation? Even though more research is needed, some general guidelines seem to have emerged (Angelsen and Kaimowitz, 1998). Promotion of off-farm employment should combine both the aim of poverty reduction and forest conservation. Labour-intensive technological progress in agriculture should both increase production and wages, and at the same time limit labour available for forest conversion. In addition, technologies which are suitable for land already in cultivation rather than cleared forest land offer win-win-win opportunities.

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Appendix: Correlation matrix of variables (209 observations)

LA	1.000										
PA	0.1120	1.0000									
XPA	0.0873	0.6380	1.0000								
FPA	0.0971	0.9328	0.3176	1.0000							
RPI	0.0716	0.1954	0.3492	0.0777	1.0000						
Y	0.0869	0.2506	0.4481	0.0987	0.0303	1.0000					
AXPA	0.1234	0.6926	0.8273	0.4659	0.4339	0.1897	1.0000				
$PXPA_{t-4}$	−0.0360	−0.5771	−0.2302	−0.6025	0.0904	−0.1752	−0.4512	1.0000			
PXPA	0.0677	0.6012	0.9717	0.2854	0.20328	0.5000	0.6915	−0.1386	1.0000		
POP	0.6911	0.1385	0.2011	0.0763	0.09494	0.1976	0.1555	−0.0014	0.1994	1.0000	
FE	0.0804	0.0529	0.0255	0.0532	0.0022	0.2008	0.0431	−0.0158	0.0244	−0.0747	1.0000
	LA	PA	XPA	FPA	RPI	PCI	AXPA	$PXPA_{t-4}$	PXPA	POP	FE

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