The Effects of the Structural Adjustment Program on Deforestation in Ghana

J.K.A. Benhin and E.B. Barbier

This paper is a theoretical and empirical investigation into the impact of the structural adjustment program (SAP) on forest loss in Ghana between the period 1965–95. An optimal control model is used to derive estimable reduced form equations for forest loss, cocoa land, maize land and timber production, which are in turn functions of mainly input and output prices. Piecewise linear and switching regression approaches are used to distinguish between the influence of the post from the pre-adjustment policy impacts on forest land use. The overall results show that cocoa land expansion and timber production, but not maize land expansion, are significant causes of forest loss in Ghana. However, the impact on forest loss in the post-adjustment period was reduced. Changes in the relative output and input prices due to the SAP may have played a significant role in the reduced impact of agricultural and timber related deforestation in the post-adjustment period.

According to the FAO (1993 and 1997), Africa has the second largest annual deforestation rate in the world. West Africa has experienced the most rapid and recent deforestation of all regions, and Ghana has one of the highest rates of deforestation in West Africa. Increased timber production and agricultural expanison are considered to be the main causes of this forest loss. However, what is less clear is whether recent deforestation trends have been affected by the sectoral and macroeconomic policies associated with Structural Adjustment Programs (SAP).[1] Among the SAP policies that may have influenced forest loss are liberalized markets, higher producer prices, reduced subsidies, and devaluation. This, however, need not be the case if the increased returns from these activities, due to the SAP, increase the incentives of producers to adopt efficient methods of production.

Given the uncertain impact of SAP reforms on forest loss, it is important to investigate this potential relationship on a case-by-case basis. A number of recent studies have analyzed the relative importance of various economic activities, including timber extraction and agriculture expansion, in causing tropical deforestation (see Amelung and Diehl 1992; Barbier et al. 1994; Brown and Pearce 1994; Kaimowitz and Angelsen 1998 for a review). A few studies have further looked into how the SAP reforms, through their impacts on either timber extraction or agriculture expansion, have affected the problem of deforestation in the tropics. However, very few of these studies have been undertaken in West Africa, where most of the countries have experienced high forest loss and have also embarked upon Structural Adjustment Programs since the early 1980s.[2]

The following paper aims to make a contribution to this literature by investigating the impacts of the

E.B. Barbier is the John S. Bugas Professor of Natural Resource and Environmental Economics with the Department of Economics and Finance at the University of Wyoming. J.K.A. Benhin is a postgraduate student in the Environment Department, University of York. This paper is based on a study undertaken in Ghana and Cameroon that was funded by the Center for International Forestry Research (CIFOR), UK Darwin Initiative, Central African Program for the Environment (CARPE), and the African Economic Research Consortium (AERC) for which we are very grateful. In particular, we acknowledge the support and helpful comments of David Kaimowitz, Jon Lovett, William Lyakurwa, Charles Perrings and William Sunderlin and two anonymous referees. A version of this paper was presented at the World Congress of Environmental and Resource Economists held in Venice, Italy, Isola di San Giorgio, June 25–27, 1998.

[1] Structural Adjustment Programs (SAP) are the macroeconomic and sectoral reforms, consisting of fiscal, monetary, trade, pricing and exchange rate policies, which most developing countries including Ghana have undertaken since the early 1980s in order to eliminate supply-demand imbalances, resulting from distorted prices and overvalued currencies, and to achieve a sustainable economic growth (Khan 1987). See Benhin and Barbier (1999), Munasinghe (1999) and Deacon (1995) for further discussion of the links between macroeconomic policies, SAP and forest loss.

[2] Ehui et al. (1989) analysed the impacts of agricultural expansion on the long run forest stock in Côte d'Ivoire. However, the authors did not look at the impacts of SAP reforms on deforestation in their study.

Agricultural and Resource Economics Review 30/1 (April 2001) 66–80

SAP on deforestation in Ghana between the period 1965–95. In Ghana, food crops such as maize and cocoa production and timber extraction have been identified as the main proximate causes of forest loss.[3] The expected net benefits from these proximate causes of forest loss are in turn influenced by underlying factors, such as input and output prices. Macroeconomic policies, such as those undertaken under the SAP introduced in Ghana in April 1983 (ISSER 1992), which include fiscal, monetary, trade and exchange rate policies, work through these underlying causes and other sector-specific policies to either mitigate or aggravate the influence of agriculture and timber extraction on deforestation.

In the light of this, two main hypotheses are examined in this paper. First, we explore whether expansion of the land cultivated for cocoa and maize, and greater timber extraction, have been the proximate causes of deforestation in Ghana in recent decades. Second, since prices and other economic factors determining the expansion of these activities have been influenced by the introduction of Structural Adjustment policies in Ghana in the early 1980s, these policies may have also influenced deforestation significantly.

In examining these hypotheses, the paper develops a model based on a dynamic optimal control problem of renewable resource exploitation. The model is comprised of a three-sector approach to forest land use in Ghana. The model is used to derive a recursive relationship for forest land conversion to cocoa land, maize land and timber extraction as functions of sectoral output and input prices and other factors, and a forest loss equation. The hypothesized relationship between deforestation in Ghana and its proximate and underlying causes is examined through estimating the recursive model for the 1965–95 period. The possible influence of the SAP on these relationships is analyzed through employing linear piecewise and switching regression approaches to distinguish the influence of the post (1983–95) from the pre-adjustment (1965–82) period.

The rest of the paper is organized as follows. The next section discusses briefly Ghana's timber and agricultural sectors and their influences on forest loss. The following section develops the theoretical analysis, whilst the results of the empirical analysis are presented in the section following that. The expected impacts of policy induced price changes on forest loss are examined next, and a summary of the main results and some policy implications are found in the concluding section.

SAP, Agriculture, Timber Extraction and Forest Loss in Ghana

Forest loss in Ghana has been so extensive and rapid that it is becoming increasingly difficult to get precise figures for the country's present forest cover and rates of deforestation. Repetto (1988) estimated the annual rate of deforestation during the period 1981–85 to be 1.3% while the FAO (1993 and 1997) has estimates of 1.5% for 1980–90 and 1.3% for 1990–95. The forest reserves now contain most of the country's remaining tropical moist forest, most of which even exist in isolated fragments.

Forest loss in Ghana has been caused by the interaction of different factors: social, cultural, political and economic. The main proximate (direct) causes of forest loss, include fire, mining, quarrying, plantation strategy, but more importantly logging and farming (ITTO 1993).

Studies show that 'salvage felling' which allowed unlimited felling of the largest or 'over mature' trees and the 'creaming' of high value species in the 1970s took a devastating toll on total forest cover and quality. This has been exacerbated by high levels of waste in timber extraction estimated to be as high as 50% (Nash 1990; Chachu 1989). Logging also makes the forest more susceptible to fire, and accessible to farmers (Hawthorne 1989; Martin 1991). Moreover, commercially exploited areas have been repeatedly re-logged instead of being allowed to recover which leads to further forest loss and degradation.

Low timber royalties and subsidized costs of extraction in the pre-adjustment period may have been an incentive for increased logging. In the Structural Adjustment period, macroeconomic policies leading to devalued exchange rates have increased the domestic returns from logging and therefore may have also increased the incentive for indiscriminate and destructive logging activities. However, there is the possibility that the higher returns may increase efficiency in timber extraction and thereby reduce timber-related deforestation in Ghana. Policies that raised the costs of logging, such as the imposition of higher royalties may also help reduce logging activities and their related deforestation (Richards 1995).

Agriculture is the largest and most important sector in Ghana (ISSER 1992 and 1997). It employs about 60% of the population, with land and

[3] Maize is an important staple food crop in Ghana, and more importantly, like cocoa, the crop is also grown in the high forest zone of Ghana (Bateman et al. 1989).

the forest as the main input in production. About 13.6 million ha., representing 57% of the country's land area, are classified as suitable for agricultural purposes, of which about one-third was cultivated in 1990. Thus there is not yet a shortage of available land for agricultural production in Ghana (Ministry of Agriculture 1991). The main problem is the opening up and conversion of marginal forested lands for cultivating some crops. Expansion of agricultural land is expected to proceed at a rate of 2.5% annually, mainly for the production of tree crops, such as cocoa, and food crops, such as maize (Ministry of Agriculture 1991). The productivity of land and labor in agriculture is very low due largely to the extensive use of traditional methods of cultivation, such as slashing and burning the vegetation, which also leads to widespread forest destruction.

Under the SAP, improved prices for cocoa and maize and improved credit facilities have been an incentive to expand production (ISSER 1992 and 1997). The removal of subsidies on inputs like insecticides, and ammonium sulphate discourages the use of these inputs and therefore may have increased the use of land in agricultural production. These two policies point to a higher incentive to use more land, and therefore forest land, in production. However, as stated earlier, it is possible that this may not be the case. This is because the increased crop prices, together with the availability of agricultural inputs and high yielding seeds may induce an increased substitution of these inputs for land. The pressure on land and therefore forest land may fall. In the next two sections, we develop a model which we use to empirically investigate the impacts of these prices and policy change on the demand for cocoa and maize land and timber production and therefore the forest in Ghana over the SAP period, 1983–1995.

Theoretical Framework

The following model assumes three sectors: cocoa production, maize production and timber extraction. The production function for each sector is assumed to be a single-valued continuous function with continuous first and second order partial derivatives, and also increasing and strictly concave.[4] The production functions for the cocoa, maize and timber sectors are defined respectively as

(1) $$C(t) = C(L^c(t), X^c(t))$$

(2) $$M(t) = M(L^m(t), X^m(t))$$

(3) $$H(t) = H(F(t), X^h(t))$$

$C(t)$ is the output of cocoa in each time period, t, $L^c(t)$ is the total land input use in cocoa production, measured in hectares and and $X^c(t)$ represent other inputs used in cocoa production. $M(t)$ is the output of maize in number of bags in each time period, t, $L^m(t)$ is the total land input use in maize production and $X^m(t)$ represents other inputs used in maize production. The production of timber, $H(t)$, is assumed to depend on the stock of forest land, $F(t)$, and other inputs used in timber extraction, $X^h(t)$.

The net benefits from cocoa, maize and timber production, in each time t, are defined respectively by the difference between the total revenue and the total cost:

(4) $$P^c(t)[C(L^c(t), X^c(t)] - W^c(t)X^c(t)$$

(5) $$P^m(t)[M(L^m(t), X^m(t)] - W^m(t)X^m(t)$$

(6) $$P^h(t)[H(F(t), X^h(t)] - W^h(t)X^h(t)$$

where $P^i(t)$, $i = c, m, h$ is the per unit output price for each respective sector, and $W^i(t)$, $i = c, m, h$ is the per unit input price. The output and input prices are assumed to be exogenously determined.

Higher net benefits in each of the three sectors are the incentives to used more of the stock of forest land. As the net benefits increase, either through output price increasing and/or input price falling, it becomes more profitable to use more of the stock of forest land for the three activities.[5] It is further assumed that the stock of forest land provides other environmental benefits, $B(F(t))$, apart from its use for timber production. These include maintaining local climates, watershed protection, non-timber products and the preservation of natural habitats:

(7) $$B = B(F(t)), \quad B_F > 0 \; and \; B_{FF} < 0$$

However, the total stock of forest land, F, is not

[4] The model is similar to that of Ehui and Hertel (1989), although it differs from their model in some important aspects. First, Ehui and Hertel are concerned with deriving the long run optimal forest stock through estimating a quadratic functional form of the aggregate agricultural yield function. In contrast, here we are interested in deriving demand functions for various forest land uses from the analytical model, following an approach similar to Barbier and Burgess (1997). Moreover, in this model no steady state results or comparative statics are derived, since the focus is on assessing how a structural change due to the SAP may have influenced forest land uses through changing input and output prices.

[5] Note that the cost of the stock forest land, either in terms of conversion to cocoa or maize land, or exploited for timber, is not included in the output decisions of the three sectors. This is because, in general, there is no market price for forest land as such, and any existing price is not an adequate reflection of the costs of this input. However, later we introduce these costs through 'shadow prices' for converted and existing forested land.

static but is linked to agricultural land expansion and timber production. Increases in land under cocoa production ($\dot{L}^c$) and maize production ($\dot{L}^m$) are assumed to be due to the conversion of forest land to cocoa land, $\ell^c(t)$, and to maize land, $\ell^m(t)$. Such conversions of forest land are assumed to be irreversible

$$(8) \qquad \dot{L}^c = \ell^c(t), \quad \ell^c(t) \geq 0, L^c(0) = L_0{}^c.$$

$$(9) \qquad \dot{L}^m = \ell^m(t), \quad \ell^m(t) \geq 0, L^m(0) = L_0{}^m.$$

It is also assumed that timber extraction leads to a fixed amount of stock of forest land loss, given by a timber-related conversion factor, α. However, forest land extracted for timber can be regenerated by an amount given by k. Therefore extraction of timber in any time t leads to the stock of forest land changing by $-(k - \alpha)H(F(t), X^h(t))$. The change in the stock forest land, F, or the amount of deforestation, D, is defined by

$$(10) \qquad \dot{F} = - D(t) = -\ell^c(t) - \ell^m(t) - (\alpha - K)H(F(t),X^h(t)), \quad H(t) \geq 0, F(0) = F_0$$

Given these assumptions, the social objective function is to maximize the discounted stream of net benefits, Π, from the uses of the stock of forest land, (4)–(7)

$$(11) \qquad Max \prod(t) = \int_0^\infty e^{-\delta t}[B(F(t)) + P^c(t)(C(L^c(t),X^c(t)) - W^c(t)X^c(t) + P^m(t)(M(L^m(t),X^m(t)) - W^m(t)X^m(t) + P^h(t)H(F(t),X^h(t)) - W^h(t)X^h(t)]dt$$

subject to (8), (9) and (10) and utilizing the social discount rate, δ. The control variables in the model are X^c, X^m, X^h, ℓ^c, and ℓ^m, and the state variables are F, L^c, and L^m.

The current value Hamiltonian for the above optimal control problem is[6]

$$(12) \qquad \mathcal{H} = [B(F) + (P^cC(L^c, X^c) - W^cX^c) + (P^mM(L^m, X^m) - W^mX^m) + (P^hH(F, X^h) - W^hX^h)] - \lambda((\alpha - k)H(F, X^h) - \ell^c - \ell^m) - \psi\,\ell^c - \mu\,\ell^m$$

where λ, is the costate variable or shadow price of the forest, and ψ and μ, are also the costate variables for forest land converted to cocoa and maize land respectively. Assuming an interior solution, the first order conditions for maximizing (12) are equations (8), (9) and (10) plus

$$(13) \qquad P^cC_x(X^c,L^c) = W^c$$

$$(14) \qquad P^cM_x(X^m,L^m) = W^m$$

$$(15) \qquad P^hH_x(X^h,F) = W^h + \lambda(\alpha - k)H_x(X^h,F)$$

$$(16) \qquad \lambda = \psi = \mu$$

$$(17) \qquad \dot{\lambda} + B_F(F) + P^hH_F(F,X^h) = \delta\lambda + \lambda(\alpha - k)H_F(F,X^h)$$

$$(18) \qquad \dot{\psi} + P^cC_L(X^c,L^c) = \delta\psi$$

$$(19) \qquad \dot{\mu} + P^mM_L(X^m,L^m) = \delta\mu$$

$$(20) \qquad \lim_{t\to\infty} e^{\delta t}\lambda(t)F(t) = 0, \ \lim_{t\to\infty} e^{\delta t}\psi(t)L^c(t) = 0, \ \lim_{t\to\infty} e^{\delta t}\mu(t)L^m(t) = 0$$

Equations (13) and (14) indicate that, at any point along the optimal path, the value of marginal products of inputs used in cocoa and maize productions are equal to their respective input prices. For timber, along the optimal path, equation (15) shows that the cost of the net timber-related deforestation, $\lambda(\alpha - k)H_x(X^h,F)$, must equal the net marginal returns to timber operations, $P^hH_x(X^h,F) - W^h$. Equation (16) implies that, along the optimal path, the shadow price of forest land must be equal across all uses, i.e. the marginal value of the stock forest land converted to cocoa, ψ, and maize, μ, should be equal to the cost or 'shadow price' of forest land, λ. Equation (17) indicates that the stock of forest land should be employed in timber production and other environmental purposes up to the point where the benefits are equal to its social cost. The benefits include non-market environmental values, $B_F(F)$, the gross returns to timber extraction, $P^hH_F(F,X^h)$, and a capital gains term, $\dot{\lambda}$. The costs comprise the social cost of net timber related deforestation, $\lambda((\alpha - k)H_F(F,X^h))$, and an interest charge, δλ, for the use of the forest as capital. Similarly, equations (18) and (19) both imply that forest will be converted to cocoa or maize land until the value of the marginal product of the converted stock of forest ($P^cC_L(X^c,L^c)$ or $P^mM_L(X^m,L^m)$) plus any capital gains ($\dot{\psi}$ or $\dot{\mu}$) equal the opportunity cost of "investing in" converted land (δψ or δμ). Finally, equations (20) are the transversality conditions of the optimization problem.

From combining equation (16) to (19) we obtain

$$(21) \qquad B_F(F) + (P^h + \lambda(\alpha - k))H_F(X^h,F) = P^cC_L(X^c,L^c) = P^mM_L(X^m,L^m)$$

[6] Note that from this point onwards notation is simplified by omitting the argument of time-dependent variables and partial derivatives are represented by subscripts.

Equation (21) indicates that along the optimal path, the stock of forest land should be allocated up to the point where the marginal returns are equal across all uses—forest land, cocoa land and maize land. Note that the above equation is similar to a result obtained by Barbier and Burgess (1997). Following the latter's approach, a useful interpretation of (21) is that the opportunity cost, or 'price' of using the stock of forest land for one land use is the forgone benefits of other uses. Thus each land use has a 'price,' which can be denoted by $V^i(t)$, $i = h, c, m$.

Through utilizing $V(t)$ for each land use in (21), and substituting for λ, we obtain

$$(22)\quad B_F + (P^h H_F) + \frac{P^h H_x(X^h,F) - W^h}{H_x(X^h,F)} H_F(X^h,F) = V(t) \Rightarrow V^h(F,X^h,W^h) = V^h(t)$$

$$(23)\quad P^c C_L(X^c L^c) = V(t) \Rightarrow V^c(L^c,X^c,P^c) = V^c(t)$$

$$(24)\quad P^m M_L(X^m,L^m) = V(t) \Rightarrow V^m(L^m,X^m,P^m) = V^m(t)$$

In equation (22) the opportunity cost or 'price' of maintaining an additional stock of forest land for environmental benefits plus timber production is forgoing other marginal benefits from converting the stock of forest land to either cocoa land or maize land. As this 'price,' $V^h(t)$, increases (which means it will be more beneficial to convert to either of the alternative two uses), less and less stock of forest land is maintained. Similarly, in (23) and (24), the opportunity cost or 'price' of converting an additional stock of forest land to cocoa or maize land is, either the foregone benefits from maintaining the given stock of forest land or conversion to the alternative agricultural land use. As this 'price' ($V^c(t)$ or $V^m(t)$) increases, conversion of forest (to cocoa or maize land) declines. These three equations (22–24) therefore form the optimal implicit demand for L^c, L^m and H. Consequently, substituting for the endogenous terms in (22)–(24) and utilizing the fact that $V^h = V^c = V^m$, then the optimal stock of timber production, cocoa land and maize land in the model can be represented by the following reduced form system of equations, which are a function of the price parameters of the model[7]

$$(25)\quad L_t^c = c(P_t^h,P_t^c,P_t^m,W_t^h,W_t^c,W_t^m)$$

$$(26)\quad L_t^m = m(P_t^h,P_t^c,P_t^m,W_t^h,W_t^c,W_t^m)$$

$$(27)\quad H_t = h(P_t^h,P_t^c,P_t^m,W_t^h,W_t^c,W_t^m)$$

The final equation in our system is equation (10) determining an optimal forest loss or deforestation. Using discrete notation ($\dot{F} = F_t - F_{t-1}$), we write this equation as

$$(28)\quad -(F_t - F_{t-1}) = (L_t^c - L_{t-1}^c) + (L_t^m - L_{t-1}^m) + (k - \alpha)H_t = f(\ell_t^c,\ell_t^m,H_t)$$

In sum, we have demonstrated that if the most important determinants of forest land allocation are the net benefits derived from the various uses of the forest stock, then conversion and use of this stock will be determined in turn by the input and output prices of the relevant economic activities (equations (13)–(15) and (21)–(24)). We have used this model to derive demand equations for optimal timber harvesting, cocoa land and maize land that are a function of the price parameters of the model ((25)–(27)). As deforestation in the model is a function of the change in land use and timber production, equation (28) will also by definition be a function of these price parameters. In the next section, we attempt to estimate the reduced form demand equations (25) to (27) and deforestation equation (28), and use them to explore the hypothesis that the Structural Adjustment Program implemented in Ghana in the 1980s influenced these relationships.

Estimation Procedure and Discussion of Empirical Analysis

The hypothesized relationship between deforestation in Ghana and its proximate and underlying causes is examined through estimating for the 1965–95 period a modified form of equations (25)–(28) above. We assumed that these relationships are also affected by income or GDP per capital (Y_p) and population density (*popd*).[8] The possible influence of structural adjustment on these relationships is analyzed through employing a piecewise linear and switching regressions to distinguish the influences of the post from the pre-adjustment period.[9] Secondary data, collected mainly, from the

[7] For example, from (13) to (15), X^c and L^c are a function of P^c and W^c; X^m and L^m are a function of P^m and W^m; and X^h, and F is a function of P^h, W^h and λ. Note that $\lambda(t)$, which is the marginal value of forest land, is essentially endogenous, and depends on the optimal solution of the value function, $\Pi(t)$. That is, at any time t

$$\gamma(t) = \frac{\partial \Pi(t)}{\partial F} = \max \int_t^\infty [B_F(F) + P^h H_F(F,X^h)]e^{-\delta t} dt$$

It follows that $\lambda(t) = \partial \Pi(t)/\partial F$ is a function of X^h and F, and in turn, from (10), (15) and (17) the latter are both a function of P^h and W^h respectively.

[8] This is a common assumption in other empirical estimations. See (Barbier and Burgess 1997; Cropper and Griffiths 1994; Capistrano 1994; Reis and Margulis 1991; and Southgate et al. 1991).

[9] The piecewise linear regression assumes that the true model being estimated is continuuous, with a structural break. The switching regres-

Table 1. Definitions and Sources of Data

Variable	Definition and Data Sources
F	Total closed forest area (national level, '000 km^2). Total closed forest area, for 1965–91, collected from the Forestry Department, Accra; Estimations for 1992–95 using a rate of change of −1.3% as given by the FAO (State of the World's Forest, 1997).
L^c	Cocoa land area harvested (national level, '000 ha). Data from the Ghana Cocoa Board, Accra, and FAOSTAT database, FAO.
L^m	Maize land area harvested (national level, '000 ha). Data from Policy Planning, Monitoring and Evaluation Department (PPMED), Ministry of Agriculture, Accra, and FAOSTAT database, FAO.
H	Industrial roundwood production (national level, '000 CUM). Data from the Forest Products Inspection Bureau (FPIB), Timber Exports Development Board (TEDB), and Forestry Department, Accra.
P^c	Real producer price of cocoa (national level, constant 1990 prices, '000 Cedis/tonne). Producer price of cocoa data from the Ghana Cocoa Board, Accra.
P^m	Real average price of maize (national level, constant 1990 prices, '000 Cedis/100kg). Maize price data from PPMED, Accra.
P^h	Real average price of exported industrial roundwood (constant 1990 prices, '000 Cedis/CUM). Average price of exported industrial roundwood data from FPIB and TEDB.
W^c	Real price of insecticides (national level, '000 Cedis/liter). Price of insecticides data for 1965–81, derived from Stryker, J.D. et al. (1990), 1982–1995 from ISSER, 1993 and 1996.
W^m	Real price of ammonium sulphate (national level, '000 cedis/liter). Price of ammonium sulphate data for 1965–81, derived from Stryker, J.D. et al. (1990), 1982–1995 from ISSER, 1993 and 1996.
W^h	Real average logging costs (national level, '000 cedis/CUM). Data from FPIB and TEDB. Estimations done for 1991–95 using the annual national rate of inflation.
Y_p	Real per capita GDP (national level, GDP in constant 1990 values/population). GDP and population (millions) data derived from the IMF's International Financial Statistics.
$Popd$	Population density (national level, population/total land area ('000 ha)). Total land area data from FAOSTAT database, FAO.

Note: The consumer price index (CPI) for 1990 was used to estimate the real prices.

Ministry of Agriculture, the Forestry Department of Ghana and the Food and Agriculture Organization (FAO) were used in the estimations (see table 1).[10]

The equations to be estimated for timber production, cocoa land, maize land and forest loss, respectively, are stated as follows

$$(29)\quad H_t = \beta_{01} + \beta_{11}P_t^h + \beta_{21}P_t^c + \beta_{31}P_{t-1}^m + \beta_{41}W_t^h + \beta_{51}W_t^c + \beta_{61}W_t^m + \beta_{71}Yp_t + \beta_{81}popd_t + \mu_{1t}$$

$$(30)\quad L_t^c = \beta_{02} + \beta_{12}P_t^h + \beta_{22}P_t^c + \beta_{32}P_{t-1}^m + \beta_{42}W_t^h + \beta_{52}W_t^c + \beta_{62}W_t^m + \beta_{72}Yp_t + \beta_{82}popd_t + \mu_{2t}$$

$$(31)\quad L_t^m = \beta_{03} + \beta_{13}P_t^h + \beta_{23}P_t^c + \beta_{33}P_{t-1}^m + \beta_{43}W_t^h + \beta_{53}W_t^c + \beta_{63}W_t^m + \beta_{73}Yp_t + \beta_{83}popd_t + \mu_{3t}$$

$$(32)\quad -(F_t - F_{t-1}) = \beta_{04} + \beta_{14}(L_t^c - L_{t-1}^c) + \beta_{24}(L_t^m - L_{t-1}^m) + \beta_{34}H_t + \mu_{4t}$$

Table 1 provides definitions of the variables used in (29)–(32).[11] All price variables and GDP per capita are in constant 1990 values. Given that all the explanatory variables in equations (29)–(32) are exogenous, the model is recursive, and so Ordinary Least Squares (OLS) is a reasonable procedure for the time series analysis.[12] A Cochrane-Orcutt iterative approach was adopted for the estimation to correct for autocorrelation where it was detected. The first step in the estimation procedure

sion also assumes that the true model has a structural break, but the regression relationship is not continuous (see Pindyck and Rubinfeld 1991, p 117–20).

[10] Thus unreliability of the data should be considered in interpreting the estimated model. The use of forestry data, especially from the FAO, for deforestation analysis has been criticized because of its reliance on population density in its indirect estimation methodology. In recent times, however, remote sensing approaches have been used to give a more accurate estimate (Rudel and Roper 1997). Ghana is among the countries that is yet to fully use this new estimation approach. The FAO data is therefore the best available data for such a study.

[11] Current years' prices are used for timber and cocoa, because timber prices are based on current years' contracted price and, cocoa prices are government determined. However, for maize, farmers do not know how much they would receive for their produce, since the eventual price depends on how much is produced in the current year. Therefore, decisions on maize land in the current year depend more on what prices were in the previous year.

[12] The model is recursive because it displays a zero contemporaneous correlation between the disturbance terms and the matrix of the coefficients of the endogenous variable is triangular (see Gujarati 1995, pp. 680–682). In addition, the Hausman specification error test was used to test for the simultaneity/exogeneity of per capita GDP (Y_p) in the estimated harvested cocoa land equation (45) and the timber production equation (47) (see Gujarati 1995, pp. 669–673). The test showed that per capita GDP (Y_p) is exogenous and there is no simultaneity bias in our system of equations. This further substantiates the recursivity of the model and the use of OLS for estimating each equation.

was to determine whether there is any significant difference in the functional forms (linear and log-log) of the estimated equations. This was done by the use of the Mackinon, White and Davidson (MWD) test (Gujarati 1995).

The next step was to determine whether the piecewise linear (PW) or the switching (SW) regression approaches allowing for the influence of structural adjustment is preferred to the continuous regression of the entire 1965–95 period. First, the data were separated into pre-adjustment (1965–82) and post-adjustment (1983–95) periods. Estimations were conducted for the two separate periods and a Chow test was applied to determine whether the two regressions were significantly different. Where the Chow test showed a significant difference, the appropriate structural adjustment dummy variables (*DP* for the PW and *DS* for the SW) were included in the model for the estimation of the piecewise linear or the switching regressions.

The final step was to determine whether the piecewise linear or the switching regression was the best approach for capturing any influence of the structural adjustment 'break' in the estimated relationships. This was done in three ways: First, by comparing the adjusted R-squares of the two types regressions; second, by comparing the level of significance of the coefficients of the dummy explanatory variables in the respective regressions; and third, by comparing the joint significance of their dummy explanatory variables using the F-test (Gujarati 1995).

Implementing the above procedures led to the following results for the overall model. The MWD test showed that, the linear functional form was preferred to the log-log functional form in all the four equations. The piecewise linear regression allowing for the influence of the SAP was preferred in the demand for land for cocoa production, and for the forest loss equations, while the switching regression was preferred in the equation for maize land. In the timber equation, however, the linear estimation without the structural change influence was preferred. In all the estimations, except for the forest loss equation, the Cochrane-Orcutt iterative procedure was used to correct for the presence of autocorrelation.[13] The following discusses each of the estimated equations, starting with forest loss (32), then cocoa land (30), maize land (31) and finally timber production (29).

[13] The nature of the forest loss equation itself (the first differencing of some of the variables in the equation) removed the presence of autocorrelation.

Forest Loss Results

A Chow test performed on equation (32) confirmed a significant difference between the pre and post adjustment period. The estimated piecewise linear regression results for the forest loss equation are presented in table 2.[14] In the pre-adjustment period there was a positive relationship between the change in harvested cocoa land expansion and forest loss. A 1000 ha increase in change in cocoa land led to about 0.95 km^2 increase in closed forest area loss. Total timber production also led to an increase in forest loss. Total timber production also led to an increase in forest loss. A 1000 cum increase in total industrial roundwood production led to about 0.2 km^2 increases in closed forest area loss (table 2). The hypothesis that cocoa land expansion and timber production are important proximate factors in forest loss in Ghana is therefore supported by the model in the pre-adjustment period.

There is a significant difference in the impacts of forest loss due to a change in cocoa land in the pre and post-adjustment period. Table 2 shows that in the post-adjustment period, cocoa land expansion reduces the rate of forest loss. A 1000 ha increase in harvested cocoa land expansion leads to a reduction in forest loss by 0.35 km^2. The elasticity shows that a 1% increase in cocoa land expansion leads to the rate of forest loss or the rate of deforestation falling by about 0.2%. There is however, not much significant difference between the impact of industrial roundwood production in the pre and post-adjustment period. Even though the estimated marginal value is negative, with the elasticity portraying that a 1% increase in industrial roundwood leads to a 2.4% fall in the rate forest loss or the rate of deforestation, the post-adjustment dummy coefficient (β_{54}) is not very significant. It can therefore, be stated that timber production still has a negative impact on the forest in Ghana. To some extent, however, this impact has reduced although the coefficient of the post-adjustment timber production dummy is not fully significant.

[14] The change in maize land ($L^m_t - L^m_{t-1}$) variable was dropped from the estimated forest loss equation because it was not statistically significant and its inclusion did not also improve upon the significance of the whole model. *D1* is a dummy to capture the increase in total forest area in 1968, due to the re-demarcation of more forest lands as reserve forests in Ghana. The dummy variable is negative and very significant as expected, indicating that the re-demarcation of new forest reserves led to increased total closed forest area and helped reduce the total amount of forest loss.

Table 2. Ordinary Least Squares Estimation of the Forest Loss Equation Dependent Variable = $-(F_t - F_{t-1})$: Change in Total Closed Forest Area in '000 km²

Estimated piecewise linear regression

$$-(F_t - F_{t-1}) = \beta_{04} + \beta_{14}(L_t^c - L_{t-1}^c) + \beta_{24}H_t + \beta_{34}D1 + \beta_{44}((L_t^{cs} - L_{t-1}^{cs})DP + \beta_{54}(H_t^s)DP + \mu_{4t}$$

where:

$L_t^{cs} - L_{t-1}^{cs} = (L_t^c - L_{t-1}^c) - (L_{t_0}^c - L_{t_0-1}^c);\ t_0 = 1983$
$H_t^s = H_t - H_{t_0};\ t_0 = 1983$
$D1 = dummy\ for\ 1968$
$DP = dummy\ for\ the\ structural\ adjustment\ period\ in\ Ghana;\ DP = \begin{cases} 1\ if\ t > year\ 1983 \\ 0\ if\ t \leq year\ 1983 \end{cases}$

	Estimated Results			Pre-adjustment			Post-adjustment		
Variable		Coefficients	t-Values		Marginal Values	Est. Elast.[1]		Marginal Values	Est. Elast.[a]
Constant	β_{04}	53.75	0.275	β_{04}	53.75		β_{04}	53.75	
$(L_t^c - L_{t-1}^c)$	β_{14}	0.95***	2.231	β_{14}	0.95	−0.157	$\beta_{14}+\beta_{44}$	0.345	−0.19
H_t	β_{24}	0.21*	1.783	β_{24}	0.21	1.069	$\beta_{24}+\beta_{54}$	−0.121	−2.39
$D1$	β_{34}	−606.02**	−2.368	β_{34}	−606		β_{34}	−606	
$(L_t^{cs} - L_{t-1}^{cs})DP$	β_{44}	−1.29*	−1.936						
$(H_t^s)DP$	β_{54}	−0.33	−1.667						
R-square = 0.493		F = 4.671			DW statistic = 2.24			No. of observations = 30	

Note: The dependent variable is positive, therefore a positive coefficient means increasing levels of the explanatory variable leads to increasing levels of forest loss whereas a negative coefficient means increasing levels of the explanatory variable leads to falling levels of forest loss.
[a]Elasticities were calculated by using the means in the respective periods.
***Coefficients statistically significant at 1% level. **Coefficients statistically significant at 5% level.
*Coefficients statistically significant at 10% level.

These results support the hypothesis that, in the post-adjustment period timber production but not cocoa land expansion is an important proximate factor determining forest loss in Ghana. Policies with respect to cocoa in the adjustment period, such as higher producer prices for cocoa in Ghana (see table 3) may have helped reduce the impact of cocoa land expansion on forest loss. It is also possible that the negative influence of cocoa land expansion on forest loss in the post-adjustment period may be explained by the increased rehabilitation of old cocoa lands which were destroyed in the 1982/83 bush fires. However, timber related policies have not had a very significant impact in reducing the impact of timber production on deforestation.

One factor explaining this latter regression result is that industrial roundwood production might have captured most of the effects of changes in both cocoa and maize land of deforestation. Amelung and Diehl (1992), have stated that more than 70% of the primary forest areas brought under cultivation are first degraded by commercial logging and according to the FAO, deforestation rates due to agricultural conversion are eight times greater in logged-over forests than undisturbed forests (Sun 1995). Barbier (1994) also reports that in many African countries, around half of the area that is initially logged is subsequently deforested, while there is little if any deforestation of previously unlogged forest lands.

Another explanation is that cocoa and especially maize farmers may be shifting production from existing land to either new forest land or fallow land, or to old cocoa farms in the case of maize. Thus when the total harvested area of cocoa or maize land is estimated, it might appear to be constant, but the proportion of the total harvested land from forest area, may be higher or lower. The fact is that it is difficult to estimate how much of the newly harvested area in each period is from converted forest land. It follows also that even though the maize land variable was not important in the estimated regression, given the reasons stated

Table 3. Ordinary Least Squares Estimation of the Cocoa Land Equation Dependent Variable = (L^c) (Harvested Cocoa Land in '000 ha.)

Estimated piecewise linear regression:

$$L^c = \beta_{02} + \beta_{12}P^c + \beta_{22}W^c + \beta_{32}Y_p + \beta_{42}D2 + \beta_{52}(P^{cs})DP + \beta_{62}(W^{cs})DP + \mu_{2t}$$

where:

$D2 = dummy\ for\ year$ 1983–86; $D2 = \begin{cases} 1\ for\ 1983 \leq year \geq 1986 \\ 0\ for\ all\ other\ years \end{cases}$

$P^{cs} = P^c_t - P^c_{t_0}$; $t_0 = 1983$, *onset of SAP in Ghana*;

$W^{cs} = W^c_t - W^c_{t_0}$; $t_0 = 1983$, *onset of SAP in Ghana*;

$DP = dummy\ for\ the\ structural\ adjustment\ period\ in\ Ghana$; $DP = \begin{cases} 1\ if\ year > 1983 \\ 0\ if\ year \leq 1983 \end{cases}$

	Estimated Results			Pre-adjustment			Post-adjustment		
Variables		Coefficients	t-Values		Marginal Values	Est. Elast.[1]		Marginal Values	Est, Elast.[a]
Constant	β_{02}	76.78	0.272	β_{02}	76.78		β_{02}	76.78	
P^c	β_{12}	−5.76	−1.17	β_{12}	−5.76	−0.11	$\beta_{12}+\beta_{52}$	−2.54	−0.1
W^c	β_{22}	9.12***	3.261	β_{22}	9.12	0.11	$\beta_{22}+\beta_{62}$	−1.48	0
Y_p	β_{32}	7.80***	3.475	β_{32}	7.8	0.93	β_{32}	7.8	1.05
$D2$	β_{42}	−148.34**	−2.545	β_{42}	−148.3		β_{42}	−148	
$(P^{cs})DP$	β_{52}	3.22	0.622						
$(W^{cs})DP$	β_{62}	−10.59**	−2.76						
R-square = 0.891	Adjusted R-square = 0.857			DW statistic = 1.58			No. of observations = 31		

[a]Elasticities were calculated by using the means in the respective periods.
***Coefficients statistically significant at 1% level. **Coefficients statistically significant at 5% level.
*Coefficients statistically significant at 10% level.

above, there is a strong belief that maize and other food crops are important determinants of forest loss in tropical countries.

To summarize, the regression results do not support the hypothesis that expansion in maize land is a significant proximate cause of forest loss, either in the pre or post-adjustment period in Ghana. Cocoa land expansion was a significant proximate cause in the pre but not in the post-adjustment period. However, industrial roundwood production is a significant proximate factor in both periods, though less so in the post-adjustment period. A tentative inference from the above results is that if the 'right' incentives that influence these commodities such as output and input prices can be found, their role in forest loss in tropical countries could be reduced. The next step in the analysis is to look at how output and input prices in the agricultural and forestry sectors during the pre and post-adjustment periods may have influenced these proximate causes of forest loss in Ghana.

Harvested Cocoa Land

A Chow test performed on equation (30) confirmed a significant difference in cocoa land expansion between the pre and post-adjustment period. The estimated piecewise linear regression results for cocoa land, which was preferred to the switching regression in estimating the structuring shifts associated with the SAP, and the computed marginal values and elasticities are presented in table 3. The input price of cocoa (W^c), GDP per capita (Y_p) and the dummy for the bush fires effect in 1983–1986 ($D2$) appear to be the most important variables determining the rate of cocoa land expansion between 1965–95.[15]

[15] Other price variables' P^m, P^h, W^m, W^h, and the population density (*popd*), were not significant and therefore were dropped in the piecewise regression. The inference is that, from the point of view of the cocoa farmer in Ghana, maize is not an alternative crop in land use decision making, and thus maize output and input prices (P^m and W^m) are not relevant to the cocoa farmer. The insignificance of population density

In the pre-adjustment period in Ghana, the relationship between the price of cocoa and cocoa land expansion is negative but not significant (table 3). The explanation for this result is the low fixed producer prices of cash crops in that period, which had very little influence on cocoa land expansion. Cocoa land expansion in Ghana in that period was more influenced by factors other than the producer price of cocoa. The influence of the producer price of cocoa on forest loss in the pre-adjustment period was therefore very minimal.

In the post-adjustment period, the relationship between the price of cocoa and cocoa land is still negative but also not significant. However, the producer price of cocoa in Ghana in the adjustment period was generally higher. This may be attributable to the rate devaluation which enabled the country to consistently increase the producer price of cocoa in the post-adjustment period (Benhin and Barbier 1999). The negative relationship between price of cocoa and cocoa land may therefore indicate that with the consistent increases in the producer price of cocoa during the post-adjustment period, farmers with expectations of further, higher prices may have had the incentive to rehabilitate and invest in existing farms rather than open up new lands. The conclusion is that although higher prices in the post-adjustment period may have helped reduce the impact of the producer price of cocoa on cocoa land expansion the prices are still not high enough to significantly influence a reduced cocoa land expansion. As noted by Benhin and Barbier (1999) the real prices of cocoa are still below the 1970s prices. Factors, other than the producer prices of cocoa may have contributed more to the reduction in the rate of cocoa land expansion.

The regression results show a significant positive relationship between the price of insecticides (W^c) and the demand for cocoa land in the pre-adjustment period in Ghana (table 3). This means that in that period, insecticides were a substitute to cocoa land in cocoa production. A 1% increase in the price of insecticides led to about 0.11% increase in cocoa land. Although in the pre-adjustment era there were high subsidies on insecticides, given the low producer price of cocoa, many cocoa farmers could not afford to buy the input. Moreover, insecticides were very scarce because of the lack of foregin exchange to import them. Therefore, the alternative to using more insecticides to increase production was to rely on new opened lands for production. The unavailability of insecticides, in spite of the subsidies, increased the pressures on the forest due to cocoa land expansion in Ghana in the pre-adjustment period.

The impact of the price of insecticides on cocoa land changed significantly in the post-adjustment period in Ghana (table 3). Insecticides and cocoa land now appear to be complements in cocoa production. A 1% increase in the price of insecticides leads to a 0.024% fall in cocoa land. Given the increasing producer price of cocoa, farmers may now have the incentive to rehabilitate existing farms. The use of insecticides becomes a significant factor in that effort and so is its price. Although all subsidies on inputs were removed in the post-adjustment period, because of expected increases in the producer price of cocoa, farmers found it relatively cheaper to rehabilitate existing farms by using insecticides rather than opening up new lands. Moreover, the increased availability of the input may have helped its more widespread use of cocoa farms.

The *D2* variable represents a dummy for the period 1983–86, a period when there was a drastic fall in cocoa land as a result of major bush fires in 1982/83. This variable is negative and significant (table 3), confirming that bush fires had a significant effect on reduced cocoa land in the years immediately following the fires. Real per capita income (Y_p) has a positive influence on cocoa land. A 1% increase in real per capita income leads to 0.9% and 1.05% increase in harvested cocoa land in the pre and post-adjustment periods respectively (table 3).

The above results provide no strong evidence that in Ghana increases in cocoa prices in the post-adjustment period may have led to increased forest loss through cocoa land expansion. However, higher prices of insecticides have rather helped to reduce the expansion in cocoa land. The tentative inference from these results is that the post-adjustment period policies, through both higher producer price of cocoa and the price (and the availability) of insecticides, may have made it possible for farmers to invest in existing lands rather than opening up new lands. The pressures on the forest land through cocoa land expansion in the adjustment period in Ghana should, therefore, be lower. The general conclusion from the cocoa land estimates for Ghana is that significantly higher prices for cocoa and the availability of agricultural inputs, even where subsidies are removed, may help reduce the dependence of cocoa production on

variable (*popd*) suggests that population changes have very little or no impact on cocoa land expansion in Ghana.

Table 4. Ordinary Least Squares Estimation of the Maize Land Equation Dependent Variable = L^m (Harvested Maize Land in '000 ha.)

Estimated switching regression

$$L^m = \beta_{03} + \beta_{13}P^m_{t-1} + \beta_{23}popd + \beta_{43}D2 + \beta_{63}(P^m_{t-1})DS + \beta_{73}(W^m)DS + \mu_{3t}$$

where:

P^m_{t-1} = *real price of maize lagged one year*

DS = *dummy for the structural adjustment period in Ghana*; $DS = \begin{cases} 1 \text{ if year} \geq 1983 \\ 0 \text{ if year} < 1983 \end{cases}$

Variables	Estimated Results		t-Values	Pre-adjustment			Post-adjustment		
		Coefficients			Marginal Values	Est. Elast.		Marginal Values	Est. Elast.
Constant	β_{03}	−338.5	−1.34	β_{03}	−339		$\beta_{03}+\beta_5$	−530.72	
P^m_{t-1}	β_{13}	−0.004	−0.01	β_{13}	0	0	$\beta_{13}+\beta_6$	1.899	0.337
W^m	β_{23}	9.48*	2.05	β_{23}	9.48	0.306	$\beta_{23}+\beta_7$	−0.095	0
popd	β_{33}	14.62**	2.77	β_{33}	14.62	1.75	β_{33}	14.62	1.564
D2	β_{43}	51.09	0.64	β_{43}	51.09		β_{43}	51.09	
DS	β_{53}	−192.26	−1.34						
$(P^m_{t-1})DS$	β_{63}	1.90**	2.75						
$(W^m)DS$	β_{73}	−9.57*	−1.72						
R-square = 0.752		Adjusted R-square = 0.653			DW statistic = 1.768			No. of observations = 30	

***Coefficient statistically significant at 1% level. **Coefficient statistically significant at 5% level.
*Coefficient statistically significant at 10% level.

the forest land and reduce the rate of forest loss. These results, to a large extent, support the significantly reduced role of cocoa land expansion in forest loss estimated equation in table 2.

The Chow test on equation (31) confirmed a significant difference in harvested maize land between the pre and post-adjustment period. However, the switching regression was preferred to the piecewise linear regression in estimating the structural shifts. The estimated results are presented in table 4.[16] The variables that appear to influence the demand for maize land in Ghana are the population density (*popd*), the lagged price of maize (P^m) and the price of fertilizer (W^m). The price of maize is more relevant in the post-adjustment period while the price of fertilizer is important in both periods.

The lagged price of maize was not a significant factor in the demand for maize land in the pre-adjustment era in Ghana. This is not surprising, as during this period, maize prices were administratively determined, resulting in low and unstable price trends in Ghana (Benhin and Barbier 1999). As a consequence, maize farmers had little incentive to expand production. Moreover, the poor storage facilities and the government's inability to purchase all maize produce at the administratively determined prices meant that any excess supply of maize was a cost to the farmer, who had to dispose of them at relatively lower prices in the open market. Maize prices therefore became an irrelevant consideration in determining the area of maize cropping.

In the post-adjustment period, the relationship between the lagged real price of maize variable and maize land in Ghana was positive and significant, indicating that a 1% increase in the lagged price of maize led to a 0.34% increase in the demand for maize land in the current year (table 4). With the removal of the guaranteed or controlled prices under the adjustment program, the price of maize

[16] Other price variables' P^c, P^h, W^c, W^h, and the real per capita GDP variable (Y_p) were not significant and therefore were dropped. As expected, cocoa prices are not relevant because it is not easy to convert maize land to cocoa land. This requires a high capital investment to restore soil fertility depleted after maize farming. These investments, in most cases, could not be afforded by farmers in Ghana. Moreover, the majority of trees which initially may have been needed to support cocoa cropping would have been cleared under maize farming. The insignificance of timber output and input prices was also expected, as the maize farmer has no influence on the allocation decisions of the forest for timber production in Ghana. The per capita GDP variable (Y_p) also appear not to influence the demand for maize land. The *D2* variable was included in the maize equation to test the hypothesis that, given the drastic fall in cocoa land in the 1983–86 period, farmers may have diverted to food crop production such as maize. However, as this variable was not significant, this hypothesis of a substitutional shift from cocoa production into maize farming was rejected.

Table 5. Ordinary Least Squares Estimation of the Timber Production Equation Dependent Variable = *H* (Total Industrial Roundwood in '000 cum)

Estimated linear regression:

$$H = \beta_{01} + \beta_{11}\frac{P^h}{W^h} + \beta_{21} popd + \beta_{31} Y_p + \mu_{1t}$$

		Estimated Results = Pre-adjustment = Post-adjustment		
Variables		Coefficients	t-Values	Estimated Elasticities
Constant	β_{01}	1893.43	1.52	
P^h/W^c	β_{11}	254.73**	3.142	0.318
popd	β_{12}	−8.943	−0.719	−0.295
Y_p	β_{13}	−3.34	−0.536	−0.338
R-square = 0.326		Adjusted R-square = 0.218		
DW statistic = 1.81		No. of observations = 31		

***Coefficient statistically significant at 1% level
**Coefficient statistically significant at 5% level
*Coefficient statistically significant at 10% level

became more market-determined, and thus a significant consideration in maize land expansion. If the price of maize increases in the previous year, farmers expect it to stay the same or even rise in the current year, and they therefore modify their demand for all inputs, including maize land, in order to increase production.

The estimated results also show that, the price of ammonium sulphate (W^m) had a positive and significant influence on maize land in the pre-adjustment period in Ghana. A 1% increase in the price of ammonium sulphate led to about 0.31% increase in the demand for maize land (table 4). This suggests that ammonium sulphate and maize land were substitute inputs in maize production. The inference is that given the relative low and unstable prices of maize, maize farmers could not afford to purchase other farm inputs like fertilizer and therefore tended to substitute land for fertilizer in production.

In the post-adjustment period in Ghana, the impact of the price of ammonium sulphate on maize land was significantly negative, suggesting complementarity between these two inputs in maize production in Ghana (table 4). A 1% increase in the price of ammonium sulphate leads to a 0.004% fall in the demand for maize land. The high dependence of maize farmers on land for production is therefore expected to fall. This result also suggests that in the post-adjustment period in Ghana, higher prices of fertilizer may also have led to a fall in the demand for maize land.

The population density variable (*popd*) had a positive impact on maize land expansion in the pre and post adjustment periods in Ghana (table 4). The results show that in the period 1965–95, a 1% increase in population density led to a 1.6%–1.8% increase in the demand for maize land in Ghana. These results reflect the importance of maize as a food crop in Ghana.

To summarize, in the pre-adjustment period in Ghana lower and unstable prices of maize and the unavailability of agricutlural inputs, in spite of high subsidies, may have led to increased maize land expansion. In the post-adjustment period, relatively stable and rising maize prices may have increased maize land expansion. However, the availability of inputs, in spite of the removal of subsidies, may have counteracted the pressures for the maize land expansion. The results also show that population pressure may be a significant factor in the demand for maize land in Ghana.

The Chow test did not show any significant difference between the pre and post-adjustment period regressors for equation (29). This was confirmed by the insignificance of the relevant dummy variables in both the piecewise linear and the switching regressions. Therefore, the linear regression without the adjustment coefficient dummy best describes industrial roundwood production in Ghana between 1965–95. Table 5 shows that in Ghana, the relative output and input price of timber, P^h/W^h, is the only significant variable influencing timber production over this period.[17]

A 1% increase in the relative price of timber

[17] Other price variables (for cocoa and maize) were not significant in explaining timber production in Ghana. The coefficients of the real per capita GDP (Y_p) and the population density (*popd*) were both negative but insignificant.

leads to a 0.32% increase in timber production (table 5). This result indicates that if timber extraction is inefficient, price increases which may lead to increased timber extraction may lead to increased forest loss in Ghana. To mitigate such effect, the cost of logging, in one or the other must be increased. The inference from the timber results is that increases in timber price, due both to higher world market prices and the recent devaluation in the post-adjustment period, may lead to increasing deforestation in Ghana through stimulating timber production.

To summarize the analyses of this section, increased crop prices in the post-adjustment period in Ghana may have led to greater demand for crop land. However, the removal of subsidies on agricultural inputs, the complementarity between agricultural inputs and land in crop production and the subsequent availability of inputs may have reduced crop land expansion. The combination of these changes together with other factors may help reduce the demand for converted forest land and therefore limit agricultural related forest loss, especially from cash crops like cocoa. For timber production, higher prices in the post-adjustment period may have increased timber production and timber-related deforestation. However, higher prices may not necessarily increase forest loss if they result in greater efficiency in timber extraction. Possible evidence of this effect is supported by the reduced role of timber extraction in forest loss equation in the post-adjustment era (see table 2).

Price Impacts on Forest Loss

Using the results from tables 2–5, elasticities are computed to examine the relative impacts of output and input prices of cocoa and timber, on forest loss in the pre and post-adjustment periods. The estimated price elasticities for forest loss are presented in table 6.

In the pre-adjustment period, a 10% rise in the rate of change in the producer price of cocoa led to about 0.01% fall in forest loss, whilst the same level of increase in the post-adjustment period leads to about 0.08% fall in forest loss.[18] Thus, in Ghana, increasing cocoa prices in the post-adjustment period may lead to increasing falling rates of deforestation.

[18] But as noted from the cocoa results in table 3, since in the pre-adjustment period real producer prices of cocoa were falling, this negative relationship implies high forest loss due to lower cocoa prices.

Overall, relative timber output-input prices appear to have the greatest impact on forest loss in Ghana in both the pre and post-adjustment period, but adjustment policies have dampened this impact. A 10% increase in the relative output-input price of industrial roundwood will lead to about a 2.8% and a 0.98% increase in the rate of forest loss in the pre and post-adjustment period respectively. The results imply that policies that increase the relative returns to timber production in Ghana could still be contributing to additional forest loss, but at a lower rate in the post than in the pre-adjustment period. This may be due to increased efficiency in timber production, or alternatively greater 'rent capture' by the government through increased stumpage royalties may be reducing timber-related deforestation (Richards 1995).

There is a significant difference between the impact of a change in the price of insecticide used in cocoa production and forest loss in Ghana (table 6) in the pre and post-adjustment period. A 10% increase in the change in the price of insecticides led to a 0.3% increase in the rate of forest loss in the pre-adjustment period, whilst the same level of increases in the change in the price of insecticides leads to about a 0.005% fall in the rate of forest loss. This result confirms the result in table 3 that in the pre-adjustment period forest land was more of a substitute in cocoa production. And as noted before, in spite of the high subsidies on inputs, farmers could still not afford the input, and therefore were more dependent on the forest land for increased production. In the post-adjustment period, the negative relationship shows that even though subsidies on inputs have been removed, which have led to higher input prices, it has not led to increased forest loss. The reason may be that higher cocoa prices, as noted before may have induced increased demand for insecticides rather than forest land.

Conclusions and Policy Implications

This paper set out to investigate the impacts of the Structural Adjustment Program (SAP) introduced in Ghana in 1983 on forest loss, directly through the proximate causes of agricultural land expansion and timber production and indirectly through output and input prices for cocoa, maize and timber. Piecewise linear and switching estimation procedures, which separated the pre from the post-adjustment period influences, were used to estimate a recursive model consisting of forest loss as well as cocoa land, maize land and timber produc-

Table 6. Output and Input Price Elasticity of Forest Loss

Variable	Estimated Elasticities[a]			
	Pre-adjustment		Post-adjustment	
Cocoa price (P^c)	*I*	−0.0133	*II*	−0.081
Price of insecticides (W^c)	*III*	0.31	*IV*	−0.0049
Ratio of timber price and cost of logging (P^h/W^h)	*V*	2.82	*VI*	0.9795

Note:[a] Assumes a 10% change in output and input prices. Each period's price averages were used in the elasticity estimations, except for the ratio timber price and cost of logging where the whole period averages were used.

$$I = \beta_{14} \cdot \beta_{12} \cdot \frac{\overline{\hat{P}^c}}{\overline{\hat{F}}}; \quad II = \beta_{14} + \beta_{44} \cdot (\beta_{12} + \beta_{52}) \cdot \frac{\overline{\hat{P}_c}}{\overline{\hat{F}}}; \quad III = \beta_{14} \cdot \beta_{22} \cdot \frac{\overline{\hat{W}^c}}{\overline{\hat{F}}};$$

$$IV = (\beta_{14} + \beta_{44}) \cdot (\beta_{22} + \beta_{62}) \cdot \frac{\overline{\hat{W}_c}}{\overline{\hat{F}}}; \quad V = \beta_{24} \cdot \beta_{11} \cdot \frac{\overline{P}_h/\overline{W}_h}{\overline{\hat{F}}}; \quad VI = (\beta_{24} + \beta_{54}) \cdot \beta_{11} \cdot \frac{\overline{P}_h/\overline{W}_h}{\overline{\hat{F}}}.$$

tion equations as functions of input and output prices developed from an optimal control problem.

The empirical results do not support the hypothesis that maize land expansion is a proximate cause of forest loss, either in the pre or the post-adjustment period. Cocoa land expansion and timber extraction are significant factors, but their impacts on forest loss are reduced in the post-adjustment period. The inference is that the SAP has significantly reduced the impacts of cocoa land expansion and to a lesser extent timber extraction on forest loss. Expansion in cocoa land in the post-adjustment period led to a reduced rate of forest loss as compared to the pre-adjustment period. This is attributable to some increased investment in existing cocoa land, probably as a result of an increased producer price fore cocoa, the availability of needed inputs, and other efforts aimed at rehabilitating existing cocoa farms.

The price impact analysis of forest loss indicates that the ratio of timber output-input price has a relatively higher impact on forest loss than cocoa output and input prices. In fact, higher producer prices of cocoa may encourage cocoa farmers to invest in existing cocoa farms including purchasing inputs such as insecticides rather than converting new forest lands. Although our analysis did not show that maize land expansion directly influences forest loss, higher prices of, and the removal of, input subsidies may help reduce the dependence of maize production on land.

In conclusion, we have demonstrated that the cocoa and maize policies undertaken under the SAP since 1983 have influenced the demand for crop land and thus forest loss. Although we found little difference in the pre and post-adjustment timber harvesting trends, we found that the relative returns to timber production have an important impact on the rate of deforestation in Ghana, as well as possible evidence that in the post-adjustment period increases in the relative returns have less of an impact on forest loss. More importantly, SAP policies such as the removal of subsidies on agricultural inputs, together with higher crop prices, appear to reduce the reliance of crop production such as cocoa on the forest and therefore reduce crop-related deforestation. Other related structural adjustment policies, like devaluation, the availability of agricultural and other inputs, access to market and storage facilities, may further help reduce forest loss in Ghana (Benhin and Barbier 1999).

References

Amelung, T. and M. Diehl. 1992. "Deforestation of Tropical Rainforests: Economic Causes and Impact on Development." *Kieler Studien 241.* Tubingen: J.C.B. Mohr.

Barbier, E.B. 1994. "The Environmental Effect of the Forestry Sector." *The Environmental Effects of Trade.* Paris: Organization of Economic Cooperation and Development (OECD).

Barbier, E.B. and J.C. Burgess. 1997. "The Economics of Tropical Forest Land Use Options." *Land Economics* 73(2):174–95.

Barbier, E.B., J.C. Burgess, B.A. Alyward, and Bishop, J.T. 1994. *The Economics of the Tropical Timber Trade.* London: Earthscan.

Bateman, M.J., et al. 1989. *An Analytical Review of Ghana's Cocoa Pricing Policy with Recommendations for Future Policy Formulation.* Washington, D.C.: World Bank.

Benhin, J.K.A. and E.B. Barbier. 1999. *A Comparative Analysis of the Effects of Structural Adjustment on Agriculture and on Forest Cover in Cameroon and in Ghana.* Final report for the Center for International Forestry Research (CIFOR). York: University of York.

Brown, K. and D. Pearce (eds.) 1994. *The Causes of Tropical Deforestation.* London: University College London Press.

Capistrano, A.D. 1994. "Tropical Forest Depletion and the Changing Macroeconomy." *The Causes of Tropical Deforestation.* Brown, K. and D.W. Pearce, Eds. London: University College London Press.

Chachu, R. 1989. "Allowable Cut from the Forest." Ghana Forest Inventory Project Seminary Proceedings. J. Wong, Ed. Accra: Ghana Forestry Department and ODA. 29–30 March.

Cropper, M. and C. Griffiths. 1994. "The Interaction of Population Growth and Environmental Quality." *American Economic Review* 84(2):250–254.

Deacon, R.T. 1995. "Assessing the Relationship between Government Policy and Deforestation." *Journal of Environmental Economics and Management* 28:1–8.

Ehui, E.K. and T.W. Hertel. 1989. "Deforestation and Agricultural Productivity in the Côte d'Ivoire." *American Journal of Agricultural Economics* 71(3):701–11.

FAO. 1993. "Forest Resources Assessment 1990: Tropical Countries." FAO Forestry Paper 112. Rome: FAO.

FAO. 1997. *State of the World's Forests 1997.* Rome: FAO.

Gujarati, D.N. 1995. *Basic Econometrics.* (3d ed). New York: McGraw-Hill, Inc.

Hawthorne, W.D. 1989. "The Flora and Vegetation of Ghana's Forests." Ghana Forest Inventory Project Seminar Proceedings. J. Wong, Ed. Accra: Ghana Forestry Department and ODA. 29–30 March 1989.

ISSER. 1992. *The State of the Ghanaian Economy in 1991.* Legon: ISSER, University of Ghana.

ISSER. 1997. *The State of the Ghanaian Economy in 1996.* Legon: ISSER, University of Ghana.

ITTO. 1993. *Study of Incentives for the Sustainable Management of the Tropical High Forest of Ghana.* A report prepared by IIED and the Forestry Department of Ghana for the ITTO. (Unpublished).

Kaimowitz, D. and A. Angelsen. 1998. *A Users Guide to Economic Models of Deforestation.* Draft. Bogor: Center for International Forestry Research (CIFOR).

Khan, M.S. 1987. "Macroeconomic Adjustment in Developing Countries: A Policy Perspective." *The World Bank Observer* 2(1):23–42.

López, R. 1995. *Environmental Externalities in Traditional Agriculture and the Impact of Trade Liberalization: The Case of Ghana.* Maryland: College Park, University of Maryland. (Unpublished).

Martin, C. 1991. *The Rainforests of West Africa.* Accra: Elseiver Publishers.

Ministry of Agriculture. 1991. *Agriculture in Ghana: Facts and Figures.* Accra: Policy Planning, Monitoring and Evaluation Department (PPMED), Ministry of Agriculture.

Munasinghe, M. 1999. "Special Topic 1: Structural Adjustment Policies and the Environment: Introduction." *Environment and Development Economics* 4(1):9–18.

Nash, S. (Ed.) 1990. *Project: Green, Final Report.* Cambridge University.

Pindyck, R.S. and D.L. Rubinfeld. 1991. *Econometric Models and Economic Forecasts.* New York: McGraw-Hill, Inc.

Repetto, R. 1988. *The Forests for the Trees? Government Policies and the Misuse of Forest Resources.* Washington, D.C.: World Resources Institute.

Reis, E.J. and S. Margulis. 1991. "Options for Slowing Amazon Jungle Clearing." *Global Warming: Economic Policy Responses.* R. Dornbusch, and J.M. Porterba, Eds. Cambridge: MIT Press.

Richards, M. 1995. *Role of Demand Side Incentives in Fine Grained Protection: A Case Study of Ghana's Tropical High Forests.* London: ODA.

Rudel, T. and J. Roper. 1997. "The Paths to Rain Forest Destruction: Crossnational Patterns of Tropical Deforestation, 1975–90." *World Development* 25(1):53–65.

Southgate, D., R. Sierra and L. Brown. 1991. "The Causes of Tropical Deforestation in Ecuador: A Statistical Analysis." *World Development* 19(9):1145–1151.

Stryker, J.D., et al. 1990. "Trade, Exchange Rate, and Agricultural Pricing Policies in Ghana." *World Bank Comparative Studies.* Washington, D.C.: World Bank.

Sun, C. 1995. *Tropical Deforestation and the Economics of Timber Concession Design.* Doctoral Dissertation Proposal. Urbana: Department of Agricultural Economics, University of Illinois at Urbana-Champaign.