DEFORESTATION AND THE EXTERNAL COSTS IMPOSED ON AGRICULTURE IN SUDAN

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Abstract

An important cause of deforestation in arid and semi-arid countries is the overcutting of forests for domestic fuel and agricultural use. This paper constructs a dynamic model of deforestation in Sudan and compares optimally managed forests with common property forests. The optimal management plan was calculated with an optimal control model solved with non-linear programming. The common property plan was calculated with a simulation model. Results show that the optimal management plan maintains the stock of trees whereas the common property plan exhausts the stock of trees. Agricultural yields first increase and then decrease with increasing deforestation. The value of the optimally managed forest was 25% higher than that of the common property forest.

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Overgrazing, the extensive removal of tree cover for dry-land farming and cutting of wood resources for fuel purposes are the main causes of deforestation in arid and semi-arid environments. This has led to serious desertification problems in some regions and has contributed towards recent famines in Africa.

Over 50% of the wood stock removed annually is burned for energy in central and east African countries (the World Bank). This study addresses the problem of overcutting gof fuelwood in one of these countries, Sudan. Sudan obtains 82 % of it's total energy requirement and 95% of it's domestic energy reqiurements from biomass sources (UNDP/the World Bank).

Sudan's forests provide a typical example of an underpriced common property resource being depleted at an excessive rate. So critical is the deforestation problem that the Sudanese National Energy Administration (NEA,1984a) estimated that Sudan's forest stock could be depleted within 25 years. The potential effects on the economy and environment through the loss of a major energy source and on the dry-land agricultural industry contributing 40 % to GDP (Europa) are enormous.

Firewood is freely collected in Sudan and charcoal producers pay a negligble royalty of 4% of the retail price (UNDP/the World Bank). Although firewood and charcoal prices have rapidly increased in recent years, this is due to the ever increasing distance of wood stocks from the population centres of demand and in no way reflects the scarcity of the wood (NEA,1984b).

Removal of native vegetation for fuel wood and agriculture has caused loss of previously arable land as well as a general decline in agricultural yields through environmental changes. This represents a significant externality to deforestation.

Technical solutions to this problem are discussed in many articles (Hassan, the World Bank, NEA) and include expenditure on research into improved efficiency in energy conversion, afforestation techniques and alternative energy sources.

The potential economic solutions to this problem include a) the granting of wider individual property rights, b) supply side regulation or c) price control through government intervention. The aim of these would be to either maintain the forest stocks at some level or to deforest at a more socially optimal rate.

Whilst granting of property rights may overcome intertemporal scarcity inefficiencies, external costs may still be incurred by the agricultural industry. Supply side regulation may control the depletion of forest stocks but the user cost is captured by individual producers. Price controls may halt the overexploitation of forest stocks as well as capture the user cost for future generations. The administrative mechanism for this is already in place through the Unregistered Land Act (1970) which effectively gives government control over large areas of the country (Bennett).

Hence the central theme of this paper is to determine the extent to which wood resources are under-priced and over-exploited, both from an intertemporal scarcity and an externality viewpoint, and to determine user costs chargable to obtain an optimal allocation of resources.

This was achieved through the empirical development of a model of deforestation in Sudan and the external effects imposed on agriculture. The model was derived from the theoretically developed model of Hassan and Hertzler. A similar model was developed by Ehui and Hertel for deforestation in the Ivory Coast, but this produced only static equilibrium results. The results are compared to those generated with a simulation model to examine the change in the time path of tree stocks and the net social welfare generated.

Analytical Framework

The common property nature of forests and the external diseconomies to agriculture of deforestation are evidence of market failure. The objective of optimal control in this context is maximisation of social welfare. Social welfare is maximised at a dynamic equilibrium that considers the user costs to future generations of tree cutting in the present and is thus derived from the management of the stock of trees in conjunction with the agricultural industry.

The objective function is:

$$(1) \quad J(S_o) = \underset{Q_w, Q_{af}}{MAX} \sum_{t=0}^{\infty} \{ \int_0^{Q_w} [P_w(q) - C_w(q,S_t)]dq + \int_0^{Q_a} [P_a(q,S_t) - C_a(q)]]dq - C_{af} Q_f \}$$

J is the optimal value as a function of the initial stock of trees, S. The control variables are the quantity of energy consumed from the stock of trees, Q_w, and the rate of afforestation, Q_{af}. The social rate of discount is r. The price P_w is an inverse demand system for energy from wood fuel and the cost of wood fuel, C_w, is an increasing function of quantity and deforestation. The price P_a is an inverse demand system for agricultural produce. The quantity of agricultural produce Q_a is a function of the area of arable land and the stock of trees. As deforestation proceeds, climatic change in an area destroys agricultural production so yields decrease with the stock of trees. The cost of agricultural production is an increasing function of production.

The stock of trees decreases with wood cutting and increases with natural growth and afforestation.

(2) $\dot{S}_t = - w(Q_w) + g(S_t) + Q_{af}$

where w is the rate of conversion of wood into energy, g is the rate of natural growth and Q_{af} is the amount of afforestation.

This model was solved as a non-linear programming problem using MINOS software (Murtagh and Saunders, 1987). The potential benefit of managing the country's wood resources can be estimated by comparing the results of the optimal control model with the current state and predicted depletion of forest stocks in the absence of management. The latter was estimated with a non-optimising simulation model employing the same equation as above. Sensitivity was conducted with respect to: cost of afforestation, elasticity of demand functions and the agricultural yield function.

Specification of Functions and Assumptions

The model represents the aggregated wood fuel market in Sudan and production from the rain fed agricultural sector. The stock of trees is divided into two geographical regions (the World Bank) with the following characteristics.

the North:

- largely deforested already
- closer to population centres so incurs lower wood fuel transport costs
- has a greater opportunity cost of agricultural production.

the South:

- largely uncleared
- high transport costs of wood fuel to consumers
- less opportunity for productive agricultural development due to higher transport costs.

60% of the rain fed agricultural sector is based in the northern region. The potential future yield in this area is suggested to be dependant on environmental changes induced by deforestation. Limited data availability and the range of price that needed to be included in the model prevented accurate estimation of the demand functions. For both the wood fuel and agricultural production markets curves of pre-defined constant elasticity were fitted through an estimate of the current market equilibrium price and quantity. Initial stocks were based on 1984 figures, the most recent accurate figures and initial market equilibriums were averages adjusted to 1984 prices, herafter referred to as 'current'. The initial tree stocks are 31 million hectares (m ha) in the southern region and 20 m ha in the northern region. Initial agricultural production comes from 6 m ha in the southern region and 9 m ha in the northern region.

Wood Fuel Market

Current Production

The current market equilibrium consumes 4.5 million Tonnes of Oil Equivalent (TOE) at a price of 200 LS/TOE (Sudanese pounds) (NEA 1984a,b,1987).

Wood Fuel Demand

Wood fuel demand was estimated as a constant elasticity function. The only known points on this function were clustered around the current (low) price, whilst the only other (inferred) point on the function is that at which the principle alternative energy source becomes cheaper and demand for fuel wood approaches zero. The current alternative energy source is kerosine and LPG the supply and price of which is highly uncertain, especially with fluctuating exchange rates and import quotas (NEA,1984b).

The demand for wood fuel might be considered to be highly inelastic in the short run but implicit in the shape of the long run demand curve is that higher wood prices would induce consumer level adoption of more efficient cooking technology, incentive for private plantations and development of other biomass fuel sources. Against this is the relatively small amount currently spent on fuelwood and charcoal of 4% of income (UNDP/the World Bank), suggesting an ability to absorb higher fuel wood costs.

Bohi's (1981) literature review on long run price elasticities of demand for fuels shows a range from -0.17 to -2.82. This model uses -1.1. The demand function was estimated to be:

$$P_W = 800\ Q_W^{-0.9}$$

where price P_W is in LS / TOE and Q_W is the amount of energy derived from wood harvested in the northern plus southern regions.

Wood Fuel Supply

The function was assumed to be linear with coefficients corresponding to the current supply and adjusted for increased transport cost from the southern region anticipated if northern stocks are exhausted.

$$P_W = 45\ Q_{wn} + 130\ Q_{ws}$$

where Q_{wn} and Q_{ws} are the amounts of energy derived from wood harvested in the northern and southern regions, in TOE. The average yield is 3.64 TOE/ha which is converted for final use to charcoal and fuel wood with an average efficiency of 47%, providing 1.71 TOE/ha (NEA,1984a).

Afforestation

The cost of afforestation ranges from 38 LS/ha for agroforestry to 1526 LS/ha for irrigated plantations (the World Bank). Although limited labour and capital would lead to increasing costs for large areas of afforestation, the cost was taken to be 160 LS/ha for mechanical reseeding of abandoned farm land.

$$C_{af} = 160\ Q_{af}$$

where Q_{af} accounts for afforestation in both the north and the south, in million ha.

Natural Growth

Natural growth was taken to be 3% , year (the World Bank). Although biomass and area of forest are independant and growth is strictly a function of biomass, specification of the model required that stocks of trees be measured by area and thus grow by area.

Agricultural Produce Market

Current Production

As irrigated agricultural yields are essentially independant of climate and thus deforestation, mechanised and traditional rainfed agricultural production constitute the agricultural component of the model. Current agricultural production was the total tonnage produced from dryland agriculture. Current area of dryland agriculture was 15 m ha. This gave a current average yield of 0.566 t/ha, producing 8.5 mt at an average price of 555 LS/t (Europa,FAO).

Agricultural Yield

Area of forest influences both the area available for agricultural production and the average yield. Insufficient information was available to accurately estimate agricultural yields as a function of deforestation. The known points on the function are current and past agricultural yield. The other (inferred) point is that at which deforestation produces sufficient adverse environmental effects to reduce yields to zero. This was assumed to occur when all tree stocks are removed. A negative exponential function was postulated as follows:

$$\text{yield(kg/ha)} = \text{yield(max)}\ (1 - \exp(-0.15\ S_t)$$

where yield(max) was taken to be current agricultural yields. This assumes no change in yield from technological or other factors.

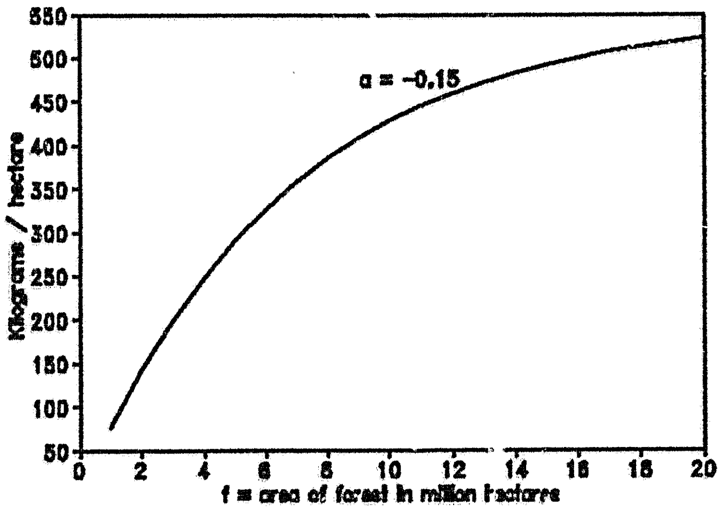

Figure 1: Agricultural yield, Y = 0.55(1 − exp(−af)).

Agricultural Produce Demand

International commodity markets would set a relatively constant export price suggesting a highly elastic demand curve. Whilst this may be the case for high production levels, Sudan's agriculturally dominant exports would lead to increased agricultural commodity prices if supply fell below domestic demand, as has occured in years of poor rainfall (the World Bank). The demand function used was assumed to have an elasticity as for wood fuel:

$$P_a = 3800\, Q_a^{-0.9}$$

Agricultural Produce Supply

The supply function used was assumed to be linear:

$$P_a = 65\, Q_a$$

where Q_a is in tonnes.

Other Assumptions

Other assumptions include:

- a discount rate of 5%.
- constant population and thus stationary demand curves through time
- constant agricultural prices at the market equilibrium through time
- all markets operate in the northern regions. This region contains all the major population centres (75% of the population) and all the port facilities for agricultural trade
- in a managed equilibrium forest consumption cannot exceed 10% of forest stocks
- transport costs are equivalent on a weight basis for wood and agricultural produce.

Simulation Model

The aim of the simulation model was to apporximate the depletion of the forest stocks under the current common property arrangements. This assumes that deforestation continues regardless of decreasing agricultural yields. Agricultural production moves to the southern region in order to maximise social welfare and deforestation also moves to the southern region when northern stocks of wood are exhausted.

Results

The simulation model produces a net social welfare of 8.1 * 10^5 million Sudanese Pounds (mLS) over the life time of the forest stocks. The optimally managed forest produces a net social welfare of 10 * 10^5 mLS, an increase of 25%.

The simulation model indicates that with current consumption patterns the entire forest stock will be exhausted within 40 years. This depletion path is slower than the 25 years estimated by NEA (1984a) but considers the critical factors mentioned in their discussion such as "..response to higher costs reflecting scarcity and increased distance from the demand centre".

The optimal control model was solved for the same number of time periods for comparative purposes. Figure 2. shows the optimal depletion and equilibrium paths for forest stocks for the simulation model and the optimal control model.

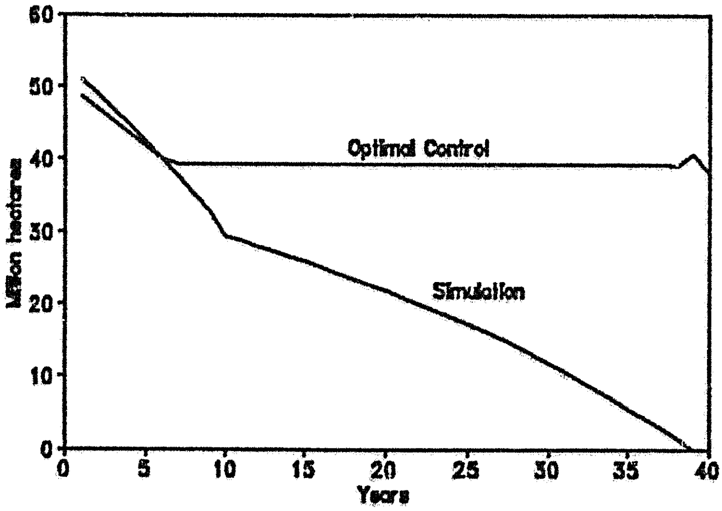

Figure 2: Time path of total wood stocks under optimal control and simulation.

The simulation model depletes the forest stock in the lower cost northern region initially at a rate of 4.55 TOE/year, once consumption switches to the southern region the higher cost produces a lower level of consumption (2.60 TOE/year) and a smaller surplus, the depletion rate thus decreases. Agricultural production, which moves to the southern region as yields decrease in the northern region incurs higher transport costs.

In the optimal control model the northern stock of trees is depleted to an equilibrium level of 8.25 million ha at which it is maintained, this area is dependent upon the shape of the agricultural yield function and reflects the greater relative surplus of the agricultural market compared to the wood fuel market.(45000 m LS cf 8000 m LS in undiscounted values). The southern stock of trees is not harvested as the user cost (equal to the afforestation cost) is less than the transport cost of wood from the southern regions, Figure 3. Agricultural producti⁄.n does however shift to the northern region to save transport costs. The rate of consumption with a user cost of 160 LS/ha is 3.6 TOE/year.

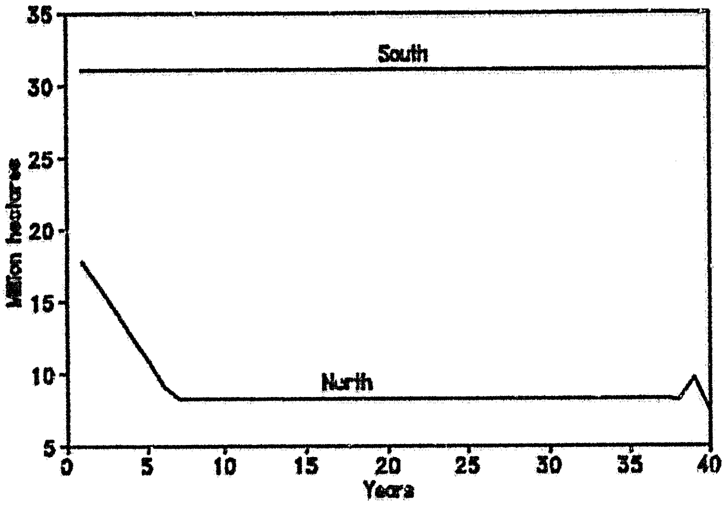

Figure 3: Time paths of wood stocks in the North and South under optimal control.

Figure 4a illustrates this further as the undiscounted user cost in the north rises [illegible] the cost of afforestation at the equilibrium. Whilst forest stocks in the north are decreasing, the user cost is less than 160 LS/ha and annual consumption is greater than at the equilibrium. The user cost of southern forests is less than zero throughout, thus this stock of trees is not depleted. Figure 4b shows the discounted user cost of northern forests.

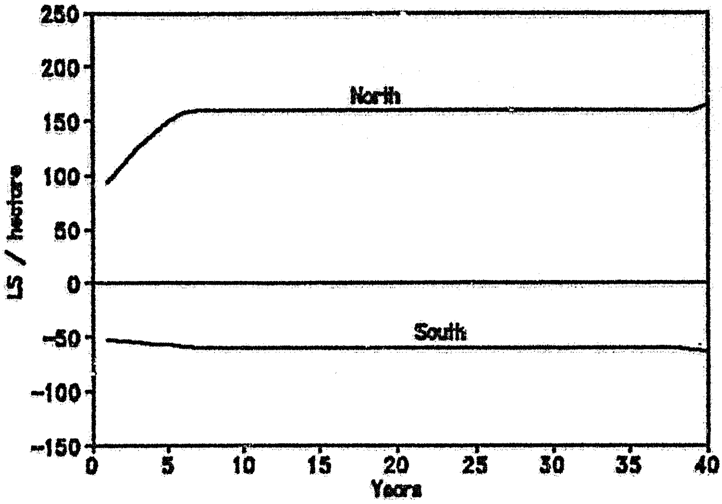

Figure 4a: Undiscounted marginal user-costs in the North and South.

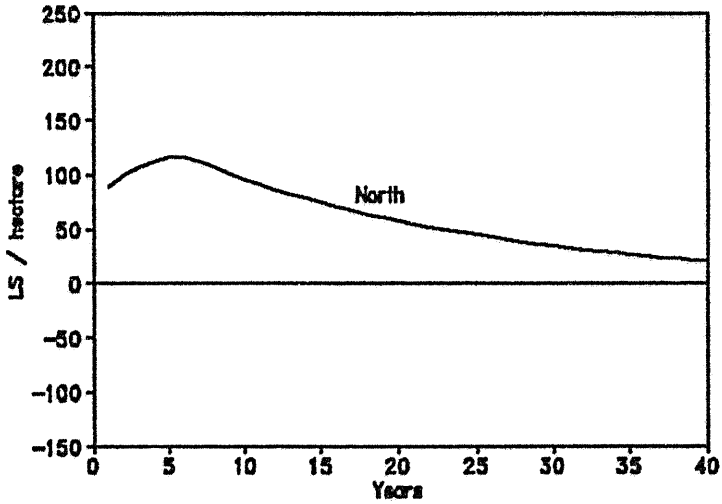

Figure 4b: Discounted marginal user-costs in the North.

Afforestation costs

Figures 5-7 illustrates the sensitivity of the model to the cost of afforestation and are comparable to figures 1-3. If the cost is greater than that of transporting wood from the southern region to the northern region (225 LS/ha or 130 LS/TOE) then the scenario changes to that of controlled deforestation. Figure 5 compares the time path of tree stocks with the standard model. The increased afforestation cost switches the user cost to equal the transport cost and deforestation proceeds at a rate corresponding to a user cost of 220 LS/ha, which is 3.25 TOE/year. There is only a small difference in net social benefit between the optimally sustained forest stock at LS 160/ha afforestation cost and the optimally depleted forest stock at LS 220/ha afforestation cost.

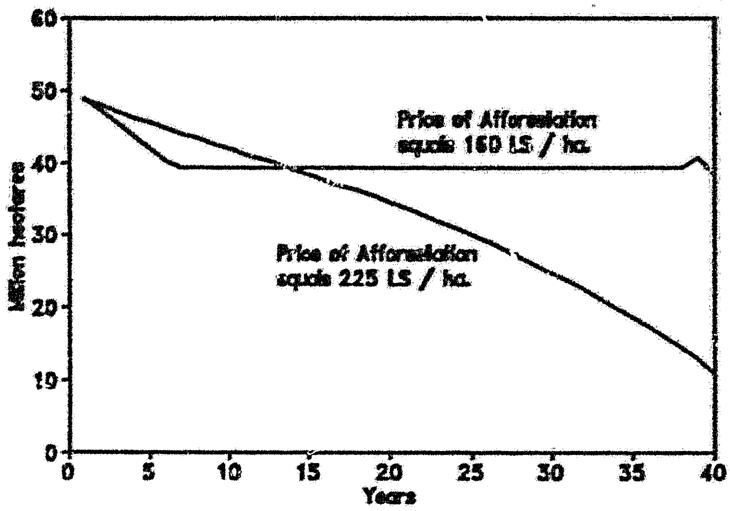

Figure 5: Time paths of total wood stocks under different prices of afforestation.

Figure 6 shows the time path of the tree stocks. The northern stocks attain an equilibrium as in figure 3 but the southern tree stocks are depleted at a rate that will take it to zero within a time frame of 50 years (not shown).

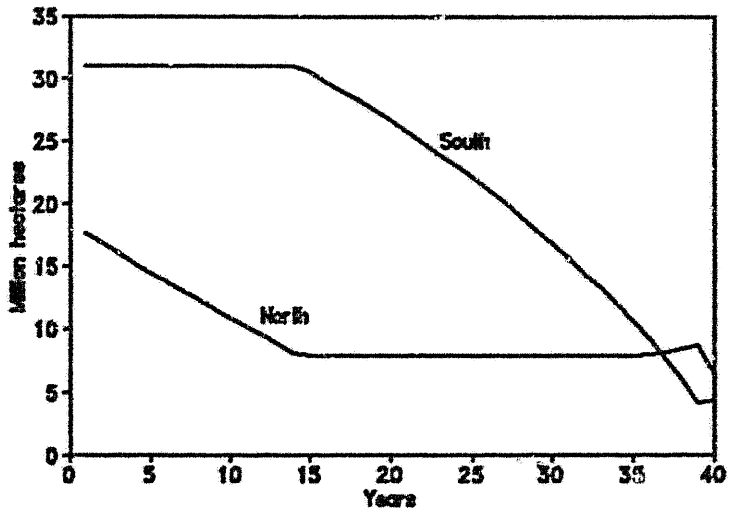

Figure 6: Time paths of wood stocks for a price of afforestation of 225 LS / ha.

Figure 7 indicates that the user cost of southern tree stocks is now equal to the additional cost of transporting wood from the south to the north. No afforestation occurs in the north as the user cost of southern tree stocks is now above zero.

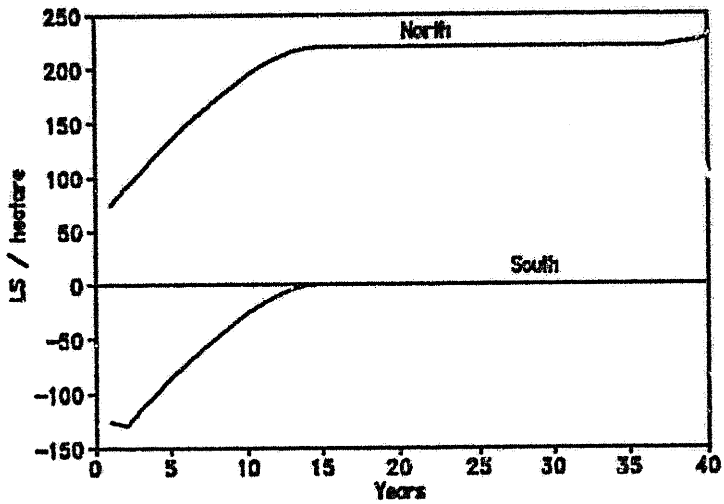

Figure 7: Undiscounted marginal user-costs for price of afforestation of 225 LS / ha.

Elasticity of demand

The objective function was sensitive to the elasticities of the wood and agricultural produce demand curves as shown in table 1. The level of consumption of agricultural produce remained the same. The equilibrium level of consumption of fuel wood decreased from 3.57 m TOE to 3.32 m TOE with the increase in elasticity, whilst the level of forest stocks remained the same and afforestation decreased.

Table 1. Present value of producer plus consumer surplus for different elasticities in billion Sudanese pounds.

		elasticity of demand for wood fuel -1.1	-1.7
SIMULATION			
elasticity of demand for agricultural produce	-1.1	810	700
	-1.7	250	130
OPTIMAL CONTROL			
elasticity of demand for agricultural produce	-1.1	1010	880
	-1.7	340	210

Agricultural yield function

The equilibrium area of forest in the northern region is dependant on the coefficient in the agricultural yield function as shown in table 2. (yield = yield(max) * (1-EXP(rS(t)))). The equilibrium area of forest land in the northern region is shown for varying agricultural yield relationships.

Table 2. Northern forest stocks for different yield functions in million hectares.

	yield function coefficient		
	-0.1	-0.15	-0.25
equilibrium area of northern forest stock	9.2	8.25	3.80

Conclusions

The optimal control model produced a consumer surplus 25% greater than that generated with a simulation model. The results suggest that wood reserves are currently underpriced by the value of the user cost which is equal to the price of afforestation, 160 Sudanese Pounds / ha. As a consequence current consumption is greater than optimal whilst the cheaper northern tree stocks are depleted and future consumption is less than optimal as the higher cost southern tree stocks are depleted.

The optimal management plan involves deforestation of northern tree stocks from 20 million ha to 8 million ha, transferring agricultural production to the northern region and maintaining the southern region's forest stocks. This is due to the transport costs of moving wood from the south to the north being greater than the afforestation costs in the north.

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