DEFORESTATION IN THE DRYLANDS OF AFRICA: QUANTITATIVE MODELLING APPROACH

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Abstract. This paper has developed a two-sector model of forestry that gives some insights into the interactions of poverty, land tenure insecurity, economic growth, trade and deforestation in the context of the drylands of Africa. Externally, the model results show that the world demand for non-timber forestry products can lead to a win–win situation whereby both trade and environmental sustainability can be promoted. Monopolistic measures to control the supply of these products, for short-term price gains, are harmful economically and environmentally. By contrast, productivity-raising measures have a favourable impact on both the economy and the environment. Internally, the model results show that the growth of the rest of the economy has driven the economic growth of the forestry sector, but at the same time, its environmental degradation. Poverty and land tenure insecurity also contribute to this degradation. Fortunately, policies promoting basic needs satisfaction and property rights security are shown to be effective in mitigating environmental degradation in the forestry sector. The paper results contribute towards a more sustainable exploitation of forestry.

Key words: environmental management, forestry, government policy, land, models.

1. Introduction

In the drylands of Africa, forestry is the source of many products on which the local population subsist. Two important forestry products are wood and gum arabic, along with a few other minor products. Unlike tropical rain forests, dryland forests are not known for their export-oriented timber production (Dufournaud et al., 1995). They are a source of wood that is used locally as fuel, and for construction and furniture. They also produce a few non-timber products that are traded on the world market. One main export product of African dryland forests is gum arabic, which is produced in a belt that runs from east to west Africa. Sudan is a major producer of gum arabic, producing more than 80% of the supply on the world market (Larson and Bromley, 1991; Beshai, 1984). Wood that is used for fuel contributes more than 80% of the energy supply in most Sub-Saharan countries (Pearce and Turner, 1990, 344). In addition to its economic importance, forestry provides important environmental functions. For example, gum trees, which are known for their soil stabilising properties, act as a buffer against soil erosion and desertification (Pearce et al., 1990).

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Forests in the drylands region of Africa face the problem of deforestation, which jeopardises their sustainable exploitation into the future. It is estimated that deforestation proceeds at a varying annual rate of 1–5% (Salih, 1994; ADB, 1994), giving an average rate for the past decade of 3%. There are different factors that cause deforestation in the African drylands. Two of the main driving forces behind wood-land deforestation are poverty and the lack of well-defined property rights (Angelsen and Kaimowitz, 1999; Mendelsohn, 1994). Wood trees are utilised as a common property resource, and poor people cut and sell them as a source of income. In the case of gum land, on the other hand, the problem is directly related to the fluctuations on the world demand for gum. Since gum arabic is exclusively an export commodity, the decision to plant or cut gum trees depends primarily on world demand for the product. Unlike the case of wood trees, property rights over gum trees are well defined and secure (Simpson, 1991).

Another factor that drives deforestation is agricultural expansion. This has been modelled in another paper that brought together all the land-using sectors in a general equilibrium framework; see Abdelgalil and Cohen (2001). Therefore, this paper does not model deforestation that is driven by agricultural expansion.

In this paper, a quantitative forestry model has been developed that captures the main dynamics of deforestation in the drylands of Africa, using the case of Sudan as an illustrative example. Sudan provides a good example since it is characterised by almost all the stylised facts of dryland forests in the Sahelian region. The model is intended to make a contribution towards a sustainable exploitation of forestry in that region of the world. The conclusions and policy recommendations of this paper are based on the results of the model that is described below.

The paper is divided into six sections. Section 2 describes the model and spells out its underlying assumptions. Section 3 is the estimation of the model. Section 4 discusses the model baseline projection. Section 5 contains policy simulations and an appraisal of alternative policies. Section 6 presents a few concluding remarks.

2. Model description

Forestry is divided into two sectors: the wood sector and the gum arabic sector. The two sectors are linked together through the allocation of forestry land between the two economic activities. There are some differences between the two sectors, such as property rights regimes and market orientation. These differences have important implications for land use and, therefore, for policy making. The model is based on the differences between the two sectors and is used to simulate and appraise the impact of four sector-specific policies on the use of forestry land. These policies are tenure security and basic needs satisfaction in the wood sector; and productivity-raising and supply control measures in the gum sector.

We start by assuming that, from an agroforestry point of view, there is a desirable stock of tree biomass per unit of forestry land.[1] Any shortfall from this desirable stock is an indication of deforestation and this is formalised in Equation (1). The idea of this equation is to measure the shortfall of the actual stock of tree biomass per unit of forestry land relative to the desirable stock. The shortfall is used as a measure of deforestation in the wood and gum sectors. This is approximated by the ratio of the actual stock of trees per unit of land F_i to the desirable stock $F_{i,\text{des}}$. This ratio Q_i is called the forest land stocking index. The desirable level of Q_i is unity, and whenever Q_i is below unity this indicates deforestation.

The wood sector is indicated by 1 and the gum sector by 2. The time lag subscript $t-1$ indicates the stock of trees at the end of the previous year. The current year time subscript t is suppressed for convenience and it should be understood that variables with no time subscript are current year variables.

$$Q_i = \left(\frac{F_{i,t-1}}{F_{i,\text{des}}}\right) \quad Q_i \leq 1 \;\; i = 1, 2 \tag{1}$$

The actual stock of tree biomass per unit of land in the current year F_i is the stock last year $F_{i,t-1}$ plus its natural growth rate g_i, both adjusted for forest land conditions as indicated by Q_i with some elasticity η_i, plus new tree planting $F_{i,\text{new}}$ minus tree cutting $F_{i,\text{cut}}$. This is formalised in Equation (2), where it is assumed that forest land degradation, captured by Q_i, adversely affects the existing stock of trees.

$$F_i = F_{i,t-1}(1 + g_i)Q_i^{\eta_i} + (F_{i,\text{new}} - F_{i,\text{cut}}) \quad i = 1, 2 \tag{2}$$

There are two main motives that drive the planting of new trees in the wood sector, namely, wood-land tenure security and price incentives. These are formalised in Equation (3). The equation states that new planting of wood trees per unit of land $F_{1,\text{new}}$ is the function of wood-land tenure security S_1 and the relative price of wood $P_{1,\text{index}}$, with some elasticities α_1 and β_1.

$$F_{1,\text{new}} = \frac{\phi_1}{N_1}(S_1)^{\alpha_1}(P_{1,\text{index}})^{\beta_1} \tag{3}$$

The cutting of wood trees per unit of land $F_{1,\text{cut}}$ is the output value of the wood sector X_1 divided by the size of wood land N_1 and the price per unit of wood P_1.[2] This is formalised in Equation (4).

$$F_{1,\text{cut}} = \frac{X_1}{N_1 P_1} \tag{4}$$

The output of the wood sector X_1 is used for two purposes. The first type of wood is used for household domestic consumption, i.e. traditional use, where wood is cut and sold by the poor forestry-dependent population. The amount of this type of wood depends on the gap between the basic needs income of this section of the population Y_{bas} and their actual income. The actual income of the poor forestry-dependent population comprises (i) their wage income from the two sectors $\sum_{i=1}^{2}(1 - b_i)Y_i$, (ii) income from the sale of gum trees that are cut due to falls in the world demand for gum and sold as wood at the price of wood $|F_{2,\text{new}}P_1|$,[3] and (iii) transfers from the government to this group T_{gov}; where b_i is the share of land as a factor of production in the value added of sector i. The second type of wood is the one used by the rest of the economy for industrial and construction purposes, i.e. modern use. This type of wood is cut and sold commercially as an intermediate input A_1. The amount of this type of wood is determined exogenously, and is assumed to grow in correspondence with the gross domestic product of the economy. This is formalised in Equation (5), where traditional wood cutting is driven by poverty and modern wood cutting by economic growth.

$$X_1 = \left\{ Y_{bas} - \sum_{i=1}^{2}(1 - b_i)Y_i - |F_{2,new}|P_1 - T_{gov} \right\} + A_1 \quad \text{iff } F_{2,new} < 0 \tag{5}$$

The value added of sector i is the value of sectoral output X_i minus the intermediate deliveries received by the sector, where a_i is the input–output coefficient. This is formalised in Equation (6).

$$Y_i = (1 - a_i)X_i \tag{6}$$

The per unit value of forest land Z_i is the share of factor of production land b_i in the output value per unit of land O_i. This is formalised in Equation (7).

$$Z_i = b_i O_i \quad i = 1, 2 \tag{7}$$

The output value per unit of land O_i is the total value of output X_i divided by land N_i. This is formalised in Equation (8).

$$O_i = \frac{X_i}{N_i} \quad i = 1, 2 \tag{8}$$

Gum is exclusively an export commodity. Therefore, whether gum producers plant new trees or cut the already existing ones depends primarily on the world demand for gum exports E_2. The net new planting of gum trees per unit of land $F_{2,new}$ is given as a function of the growth of gum exports per unit of land, with some elasticity θ_2 that reflects producers' reaction to changes in the world demand for gum.[4] Gum producers do not plant or cut gum trees immediately and proportionately in reaction to changes in the world demand for gum, but their reaction is a delayed one and takes some years to fully materialise. This is because it takes five years for newly planted trees to start producing gum. This is formalised in Equation (9).

$$F_{2,new} = \frac{F_{new,0}}{N_2}\left(\frac{\Delta E_2}{E_{2,0}}\right)^{\theta_2} \tag{9}$$

The sum of wood land N_1 and gum land N_2 constitutes forestry land N_{for}. In this study, 'forestry land' does not comprise all forestry land in Sudan, but only forestry land in the region where the wood and gum trees intersect. This region constitutes a belt that extends from the eastern to the western part of the country in the Savannah climatic zone (UNDP and World Bank, 1988). This belt of forestry land is a subset of the wider drylands region of Africa south of the Sahara. It is assumed that forestry land is fixed exogenously. This is formalised in Equation (10).

$$N_1 + N_2 = N_{\text{for}} \tag{10}$$

The demand for gum land depends on the value of gum land relative to that of wood land measured from the base year, with a one-year lag. The elasticity of demand for gum land with respect to its value relative to that of wood ζ_2 reflects factors such as the regional distribution of wood and gum trees, among others. Wood land is determined as a residual after the demand for gum land is first met. This is formalised in Equation (11).

$$N_2 = N_{2,t-1}\left(\frac{Z_{2,t-1}/Z_{2,0}}{Z_{1,t-1}/Z_{1,0}}\right)^{\zeta_2} \tag{11}$$

The total volume of gum exports E_2 is equal to total output of gum, since all gum output is exported. This is formalised in Equation (12), where H_2 is the annual average yield of gum trees, F_2 is gum tree biomass per unit of gum land and J_2 is an exogenous variable that reflects the monopoly power of gum producers in Sudan. The fact that Sudan provides more than 80% of the world supply of gum exports allows it to influence the price by controlling the supply. In the baseline projections of the model, J_2 is set to unity to indicate that all gum output is exported. In the policy projections, J_2 is set to less than unity to simulate the impact of gum supply control on the world price of gum. In fact, Equation (12) is a demand-supply balance equation.

$$E_2 = J_2 H_2 F_2 N_2 \tag{12}$$

The total value of gum output X_2 is the total volume of gum exports E_2 multiplied by the price per unit of gum P_2.[5] This is formalised in Equation (13).

$$X_2 = P_2 E_2 \tag{13}$$

The world demand for gum depends on world income and the relative price of gum, this is formalised in Equation (14). The current world demand for gum exports E_2 is made dependent on the initial world demand $E_{2,0}$, the growth of real world income $Y_{w,\text{index}}$ and the price of gum $P_{2,\text{index}}$ relative to the price of synthetic substitutes of gum $P_{w,\text{index}}$, with some elasticities γ_2 and δ_2. $Y_{w,\text{index}}$ and $P_{w,\text{index}}$ are proxied by the growth rate of real GDP index and the general price index of the major industrial countries, since they are the major consumers of gum. γ_2 and δ_2 are the world income and price elasticities of demand for gum, respectively.

$$E_2 = E_{2,0}(Y_{w,\text{index}})^{\gamma_2}\left(\frac{P_{2,\text{index}}}{P_{w,\text{index}}}\right)^{\delta_2} \qquad \gamma_2 > 0,\quad \delta_2 < 0 \tag{14}$$

The forestry land degradation cost is defined in relation to the desirable value of $Q_i = 1$. The average degradation cost for a piece of land has been estimated at

10% of its foregone output (cf. Gigengack et al., 1990). The foregone output of land is the lost output share of the factor of production land b_i, valued at the price P_i. The output loss is dependent on the difference between the desirable and the actual stock per unit of land ($F_{i,\mathrm{des}} - F_i$). Then, the degradation cost per unit of land is multiplied by N_i to give total degradation cost D_i and this is formalised in Equation (15). In the case of gum land, H represents the average yield of gum trees. In the case of wood land, H is set to unity since wood trees do not produce gum. When the actual stock per unit of land F_i approaches the desirable one $F_{i,\mathrm{des}}$, then the degradation cost becomes zero.

$$D_i = P_i b_i H_i c_i (F_{i,\mathrm{des}} - F_i) N_i \quad i = 1, 2 \tag{15}$$

The forestry model contains 21 equations in total: 10 for the wood sector and 11 for the gum sector, with 21 unknowns. Therefore, we have a determinate system of equations, which will be estimated and solved in the next section.

3. Model estimation

The model is estimated for the base year 1990 and is assumed to be valid until the year 2010; 1990 has been chosen as the model base year because it marks the beginning of a major economic reform programme in the country. Several sources are used to estimate the model. The values assigned to the parameters are either calibrated from the Social Accounting Matrix (SAM) of Sudan (Abdelgalil, 2000) or taken from the literature. The behavioural parameters are denoted by small Greek letters and the technical parameters by small Latin letters. The values of these parameters are presented in Table I.

The exogenous variables of the model are taken from different sources such as the publications of the Sudanese Ministry of Agriculture, Ministry of Finance and Department of Statistics; and the publications of regional and international organisations such as the African Development Bank, the UNDP, the IMF and the

TABLE I. Parameter estimates.

Symbol	Description	Value
α_1	Elasticity of newly planted wood trees with regard to land tenure security	0.500
β_1	Elasticity of newly planted wood trees with regard to relative price of wood	0.500
γ_2	Income elasticity of world demand for gum	0.100
δ_2	Price elasticity of world demand for gum	−1.775
ζ_2	Elasticity of demand for gum land with regard to its relative value	0.015
η_i	Elasticity of tree growth with regard to land degradation in sector *i*	0.130
θ_2	Elasticity of newly planted gum trees with regard to growth of gum exports	0.200
ϕ_1	Constant term of the function determining newly planted wood trees	1.192
a_i	Input–output coefficient of sector *i*	0.065
b_i	Share of factor of production land in the value added of sector *i*	0.535
c_i	Reclamation cost expressed as a proportion of foregone output in sector *i*	0.100
g_i	Annual natural growth rate of trees in sector *i*	0.060

TABLE II. Exogenous variables.

Symbol	Description	Measurement	Value	Growth p.a. (%)
A_1	Forestry intermediate deliveries to rest of the economy	Million Ls	8838.9	5.0
H_2	Gum yield per cubic metre of gum trees biomass	Metric ton	0.0008	Constant
J_2	Variable showing gum producers' monopoly power	Index	1.0	Constant
N_{for}	Total forestry land	Million feddans	88.0	Constant
$F_{1,\text{des}}$	Desirable wood tree biomass per feddan	Cubic metre	65.0	Constant
$F_{2,\text{des}}$	Desirable gum tree biomass per feddan	Cubic metre	64.7	Constant
P_1	Price of wood per cubic metre in the base year	Ls	888.6	Constant
$P_{1,\text{index}}$	Relative price index of wood to that of agricultural product	Index	1.0	−0.5
$P_{w,\text{index}}$	Price index of major industrial countries	Index	1.0	2.2
S_1	Land tenure security index in wood sector	Index	1.0	Constant
T_{gov}	Government transfers to poor forestry population	Million Ls	0.0	Constant
$Y_{w,\text{index}}$	Real GDP growth rate of major industrial countries	Index	1.0	2.1
Y_{bas}	Required basic needs income of poor population	Million Ls	11477.4	5.0
Y_{GDP}	Gross domestic product of the economy	Million Ls	192660.3	5.0

World Bank. Generally speaking, these data sources are the best that one can hope for, despite their occasional shortcomings. Therefore, the uncertainties in data from these sources can have an impact on the model results and, thus, on the conclusions and policy recommendations. The values of the exogenous variables are presented in Table II.

Given the parameter estimates and the exogenous variables, the model is solved to reproduce the observed values of the endogenous variables in the base year. The model is then solved for a period of 20 years until the year 2010. For the growth rates of the exogenous variables, see Table II.

4. Baseline projection

The model baseline projection for the period 1990–2010 is presented in Table III. Although, the wood and gum sectors are not doing well in terms of degradation cost D and stocking index Q, the gum sector is in a relatively better position than the wood sector. In the wood sector, the degradation cost rises by 4.0% and the stocking index falls by 8.8% per annum (p.a.). In the gum sector, these figures are 2.2% and 6.0%, respectively. Land N does not change in the wood sector, but in the gum sector it declines by 1.3% p.a. due to the fall in its value, Z, by 6.8%. The falling value of gum land is prompted by the falling output per unit of gum land O. The world demand for gum exports E declines by 8.0% p.a. as a result of the rising gum price, which increases by 7.2%. Also, the stock of gum trees per unit of land F and the net new planting of gum trees F_{new} fall by 6.8% and 6.9% p.a., respectively.

In the wood sector, the value of land rises by 5.2% p.a. due to the rising output per unit of wood land. New planting of wood trees increases marginally, by 0.1%.

TABLE III. Model baseline projection.

Symbol	Description	1990 value	2010 value	Growth p.a. (%)
Wood				
D_1	Total degradation cost in million Sudanese pounds	116 849.974	254 673.947	4.0
N_1	Wood land measured in million feddans	87.985	88.148	0.0
$F_{1,\text{new}}$	Newly planted trees per feddan measured in cubic metres	0.0136	0.0138	0.1
$F_{1,\text{cut}}$	Cutting of trees per feddan measured in cubic metres	0.179	0.479	5.0
F_1	Stock per feddan measured in cubic metres	37.064	4.227	−10.3
O_1	Output per feddan measured in Sudanese pounds	159.289	425.403	5.0
Q_1	Stocking index per unit of wood land	0.580	0.093	−8.8
X_1	Total value of output in million Sudanese pounds	14 014.999	37 498.518	5.0
Y_1	Total value added in million Sudanese pounds	13 104.024	35 061.114	5.0
Z_1	Value per unit of wood land in Sudanese pounds	85.219	236.497	5.2
D_1/Y_1	Degradation cost per unit of value added in pounds	8.917	7.264	−1.0
Gum				
D_2	Total degradation cost in million Sudanese pounds	17.195	26.677	2.2
E_2	Total volume of gum exports in thousand metric tons	21.164	4.000	−8.0
N_2	Gum land measured in million feddans	0.715	0.552	−1.3
$F_{2,\text{new}}$	Net planted gum trees per feddan in cubic metres	−0.033	−0.138	−6.9
F_2	Stock per feddan measured in cubic metres	37.000	9.062	−6.8
O_2	Output per feddan measured in Sudanese pounds	601.399	147.296	−6.8
$P_{2,\text{index}}$	Cumulative price index of gum	1.000	4.044	7.2
Q_2	Stocking index per unit of gum land	0.580	0.169	−6.0
X_2	Total value of output in million Sudanese pounds	430.000	81.279	−8.0
Y_2	Total valued added in million Sudanese pounds	402.050	75.996	−8.0
Z_2	Value per unit of gum land in Sudanese pounds	321.748	78.803	−6.8
D_2/Y_2	Degradation cost per unit of value added in pounds	0.043	0.351	11.1

The value added of the wood sector Y grows by 5.0% p.a., which is equivalent to the assumed growth rate of the economy GDP. Therefore, in terms of economic growth, the performance of the wood sector is better than that of the gum sector, but the latter is far better in terms of environmental sustainability.

In terms of degradation cost per unit of sectoral value added D/Y, although the wood sector has a higher D/Y relative to the gum sector, the D/Y is declining by 1.0% p.a. in the wood sector and rising by 11.1% in the gum sector. This is explained by the outcome that the wood sector valued added Y is rising while that of the gum sector is declining, given their degradation cost D.

Figure 1 shows that the stocking index of gum land is relatively better than that of wood land in any given year, although they are both falling over time. The figure depicts a situation whereby the conditions prevailing in the base year 1990 continue until the year 2010 without any change. But again, things may change for either the better or the worse, and in this situation the two lines may move upward or downward. The relatively better position of the gum sector may be explained by the fact that it is not characterised by market failure like the wood sector. The two causes of market failure in the wood sector are poverty and the lack of well-defined property rights, neither of which are present in the case of gum.

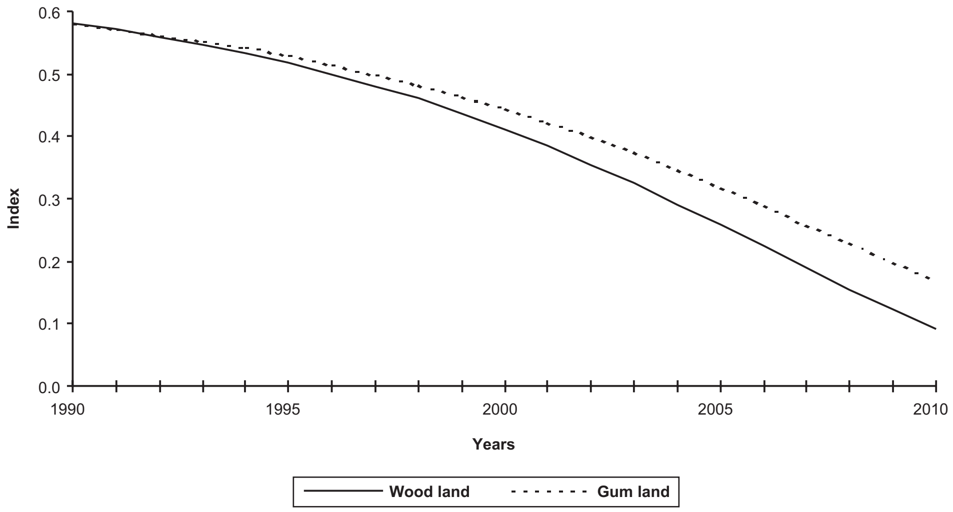

Figure 1. Forest land stocking index.

It is interesting to note that there is a trade-off between economic growth and environmental degradation, i.e. deforestation, in the wood sector. As we have seen above, the wood sector is economically doing well, but not environmentally. On the other hand, the gum sector is not doing well either economically or environmentally. In other words, economic and environmental considerations go hand in hand in the gum sector.

As we have mentioned before, the gum sector is totally export-oriented while the wood sector is inward-oriented. For the wood sector, the growth of the rest of the domestic economy has driven its economic growth as well as its environmental degradation. This is in addition to the adverse impact of poverty and land tenure insecurity on environmental degradation in the wood sector. For the gum sector, the economic and environmental decline of the sector is prompted by adverse world market conditions. These are a relatively high gum price coupled with a high price elasticity of world demand for gum, and a relatively low growth rate of the world economy coupled with a low-income elasticity of world demand for gum.

The different orientations and dynamics of the wood and gum sectors require different policies that take into account sector-specific policy needs. The following section addresses these policy considerations.

5. Policy simulations

The forestry model is used to simulate two policy changes in the wood sector and two in the gum sector. The former are (i) land tenure security and (ii) basic needs satisfaction, while the latter are (iii) raising gum productivity and (iv) controlling gum supply.

TABLE IV. Policy results.

	Δ value (%)			
	Tenure security	Basic needs	Productivity raising	Supply control
Wood				
D_1	−0.1	−0.4	−0.0	0.0
N_1	0.0	0.0	−0.0	0.0
$F_{1,\text{new}}$	22.5	0.0	0.0	0.0
$F_{1,\text{cut}}$	0.0	−2.1	−0.0	0.0
F_1	1.6	5.5	0.1	−0.0
O_1	0.0	−2.1	−0.0	0.0
Q_1	1.3	4.2	0.1	−0.0
X_1	0.0	−2.1	−0.0	0.0
Y_1	0.0	−2.1	−0.0	0.0
Z_1	0.0	−2.1	−0.0	0.0
Gum				
D_2	0.0	−0.6	7.9	0.3
E_2	0.0	−0.7	37.1	−13.9
N_2	0.0	−0.6	1.8	−0.4
$F_{2,\text{new}}$	0.0	0.0	1.8	−0.6
F_2	0.0	−0.1	22.4	−4.0
O_2	0.0	−0.1	34.7	−13.6
$P_{2,\text{index}}$	0.0	0.4	−11.5	2.4
Q_2	0.0	−0.1	19.3	−3.4
X_2	0.0	−0.7	37.1	−13.9
Y_2	0.0	−0.7	37.1	−13.9
Z_2	0.0	−0.1	34.7	−13.6

The above-mentioned four policy changes are simulated and appraised. The size of the policy changes are put at a comparable effort level, so as to make an unbiased comparative appraisal of the changes. Each policy change is made as one shock to the system.

The model projections of the endogenous variables for the year 2010 under the policy changes, henceforth called policy projections, are compared with the model projections for the year 2010 in the absence of these policy changes, henceforth called baseline projections. The policy results are presented in Table IV as percentage changes relative to the baseline projections.

5.1. Simulation I: Tenure security

This policy simulation is relevant for the wood sector, where wood-land tenure is insecure. In the baseline projections, the property rights security index S_1 is set at 1.0 to represent the current property rights situation in this sector. In this policy simulation we set it at 1.5 to represent a relatively more secure tenure than in the baseline situation.

The relatively greater land tenure security in the wood sector leads to the outcome that the newly planted wood trees $F_{1,\text{new}}$ increases by 22.5%. As a result, the stock of wood trees per unit of land F_1 and stocking index Q_1 increase by 1.6% and 1.3%, respectively. Ultimately, the degradation cost D_1 falls marginally by 0.1%. This policy change has no impact on the gum sector. This is because the only transmission mechanism between the two sectors is the movement of land, which does not change in this simulation.

The policy lesson to be learnt from this simulation is that land tenure security in the wood sector reduces deforestation, whether measured by the decline of the stock of wood trees per unit of land or that of the forest land stocking index, and consequently mitigates the land degradation cost.

5.2. Simulation II: Basic needs

In the baseline projections of the forestry model, government transfers to the poor population T_{gov} is set to zero. In this policy simulation it is set to 10% of their basic needs income to represent a reduction in their poverty.

This policy change leads to a 2.1% reduction in wood trees cutting $F_{1,\text{cut}}$ and therefore a similar reduction in the output of wood sector X_1. This causes the stock of wood trees per unit of land and the stocking index to increase by 5.5% and 4.2%, respectively. Eventually, the wood-land degradation cost declines by 0.4%. This policy has a marginal impact on the gum sector, and is relatively more effective than the previous policy of land tenure security in reducing deforestation and, consequently, wood-land degradation.

The conclusion to be drawn from this simulation is that policies which help the poor forestry population satisfy their basic needs contribute positively to environmental sustainability by reducing deforestation and wood-land degradation.

5.3. Simulation III: Productivity-raising

In this policy change, the productivity of the gum sector is raised by 10% relative to the baseline situation. Its impact on the gum sector is that the price of gum $P_{2,\text{index}}$ falls by 11.5%. As a result, the world demand for gum exports E_2 increases by 37.1%, leading to a similar increase in gum output X_2 and value added Y_2. An increase in the value of gum land Z_2 of 34.7% results in the reallocation of forest land to the production of gum. Gum land increases by 1.8%, and so does the net new planting of gum trees $F_{2,\text{new}}$. Both the stock of gum trees per unit of land and the stocking index increase by 22.4% and 19.3%, respectively. The gum land degradation cost increases by 7.9%, due mainly to the reallocation of more land to the production of gum. For the wood sector, this policy has a very marginal impact.

It is obvious that this policy change has a favourable impact on the gum sector, except for degradation cost. Therefore, policy measures that are conducive to raising the productivity of the gum sector are rewarding both economically and environmentally.

5.4. Simulation IV: Supply control

This policy change is intended to create a monopoly advantage by controlling the supply of gum exports in the world market with a view to raising its price. In the baseline projections of the model, the exogenous variable J_2, which reflects gum producers' monopoly power, is set to unity, indicating that all gum output is exported. This policy change is simulated by reducing J_2 by 10%, i.e. it becomes 0.90.

This policy change indeed leads to a rise in the price of gum $P_{2,\mathrm{index}}$ by 2.4%. However, this causes the world demand for gum exports E_2, and consequently gum output X_2, to decline by 13.9%. The stock of gum trees per unit of land and the stocking index fall by 4.0% and 3.4%, respectively. Also, land is reallocated away from gum production as a result of its falling value. The wood sector is not affected by this policy.

The conclusion from this simulation is that this policy change is devastating for the gum sector and that the resulting economic and environmental losses significantly exceed the marginal price gains. Comparing this policy change with the previous one of raising gum productivity, it can be argued that policy measures that raise productivity are preferred to monopolistic measures that control supply.

6. Concluding remarks

There are different dynamics that drive deforestation in the drylands region of Africa; depending on which forestry product we are talking about. The problem is perpetuated by an interwoven group of economic, social and institutional factors. At the domestic level, poverty, land tenure insecurity and economic growth in the rest of the economy have an adverse impact on the environmental sustainability of the wood sector. At the international level, world market conditions such as the price of gum, the growth of the world economy and consumer preferences have far-reaching effects on environmental sustainability in the gum sector.

The trade-off between economic growth and environmental degradation is not inevitable. The case of the gum sector has shown that there can be a win–win situation where both economic growth and environmental sustainability can be promoted. In the situations where a trade-off exists, as in the case of the wood sector, fortunately there are policies that can reconcile the conflicting objectives of economic growth and environmental sustainability. Policies such as the promotion of land tenure security and the satisfaction of basic needs are shown to be effective in mitigating environmental degradation in the wood sector. For the gum sector, policy measures that raise gum productivity are shown to be beneficial while monopolistic tendencies have turned out to be harmful for both economic growth and the environment. Finally, we must bear in mind that these conclusions and policy recommendations are based on the results of the model described in this paper, and are therefore dependent on the degree to which the model can be validated.

Notes

[1] The unit of land used in this paper is the feddan, which is equivalent to 0.42 ha.

[2] The price per unit of wood can be written as $P_{1,0}P_{1,\text{index}}$, where $P_{1,0}$ is the absolute price level per unit of wood in the base year and $P_{1,\text{index}}$ is the relative price index of wood.

[3] A restriction is imposed in that the net new gum tree planting has to be negative, $F_{2,\text{new}} < 0$. This is to ensure that the poor forestry-dependent population gets income from the sale of cut gum trees as wood if, and only if, there are trees that are cut due to a fall in the world demand for gum.

[4] The elasticity of net newly planted gum trees with regard to growth of gum exports θ_2 reflects the delayed reaction of gum producers to changes in the world demand for gum over a period of five years.

[5] The price per unit of gum can be written as $P_{2,0}P_{2,\text{index}}$ where $P_{2,0}$ is the absolute price level per unit of gum in the base year and $P_{2,\text{index}}$ is the relative price index of gum.

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