Economic Incentives for Entry and Exit in Gum Arabic Agroforestry System in Sudan

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Abstract

The gum tree (*Acacia senegal*) in the Sahel-Sudan zone has many environmental benign functions. An important function is to control desertification. In this paper we analyze farmers' economic incentives to preserve the existing gum trees and their incentives to create new plantations using a real options approach. Results indicate that agricultural crops provide higher economic benefits as compared to gum agroforestry system. However, on the one hand, as gum arabic is produced during the dry period and land is abundant, there are low incentives for deforestation. Instead, farmers' tend to leave the land idle and let the tree growing. On the other hand, our results suggest that an increase in the prices of gum arabic of about 330 per cent is needed to induce entry and a shift in land use system from continuous agricultural production to gum agroforestry system.

Key words: gum arabic, deforestation, entry and exit, real options, Sudan.

JEL Classification: D4, N5, O13, Q12, Q23

1. Introduction

The gum belt in Sudan provides a natural buffer zone between the desert in the North and the more fertile agricultural lands in the South. Therefore, deforestation within the belt increases desert encroachment and threatens agricultural production. Additionally, the gum tree (*Acacia senegal*) provides valuable economic and environmental functions beside gum production which generates income to the farmers and dollar earnings to the country. *Acacia senegal* is leguminous tree, which stabilizes soil, and provides fodder and firewood (Barbier 2000).

The key concerns about the gum belt in Sudan from a socio-economic perspective are how to preserve the existing gum forest and how to induce new gum plantations as protection against an expansion of desertification. One key requirement in this context is that preservation and/or expansion of the gum forest provides economic benefits to the owner of the forest. As gum forests allow farmers to benefit from the trees over a number of production periods the uncertainty over gum returns, the quasi-irreversible nature of the land allocation, and flexibility in preserving, abandoning and adopting interact to generate a real option value for planting additional gum arabic trees and for abandoning gum arabic forests (Dixit and Pindyck 1994).

In this paper we analyze farmers' incentives as regard to two options: the option to *abandon* (exit) and the option to *expand* (enter) the gum forest. The option to abandon implies either temporary suspension (abandonment here does not entail any extra costs and includes the opportunity to start cultivating gum trees again) or switching the land use system for the production of a portfolio of annual crops. More formally, we can say a gum farmer will continue cultivating gum trees down to a critical *value of abandoning* below which stopping (exit) gum tree cultivation becomes economically viable. Furthermore, the option of *expanding* (entering) will be exercised if planting of gum trees either as a forest or agroforest (including intercropping during the first years) generates a higher economic value than using land and labor for alternative purposes e.g. agriculture production during the rainy season and off-farm work during the dry season.

The paper will answer the following research questions: first, how much do the opportunity costs of labor have to rise that farmers will abandon the gum forest? And second, how much do gum prices have to rise in order to induce an expansion of the area under gum forest? The remainder of the paper is structured as follows. The next section describes the model we use for the analysis followed by section 3 that presents the data base and the calibration of the model. Section 4 presents and discusses the results. The major conclusions are drawn in the last section.

2. The model

For the purpose of exposition we model the bush-fallow cycle of gum cultivation which is an agroforestry system based on integrating annual crops with gum tree on a temporal sequence. Other land use systems for gum cultivation include: agroforestry system based on spatial mixture- where annual crops and gum are produced from the same land unit simultaneously – and pure stand gum forest for the production of gum only. Figure 1 illustrates the bush-fallow cycle of gum cultivation.

The normal bush-fallow rotation allows the farmer to obtain returns from cultivating annual crops during the first four years of the rotation and returns from harvesting gum when the tree is six years and older. At the end of the life span (T) the trees are coppiced and start to rejuvenate. The total gross-margin in present value obtained from one rotation, TGM_{AGF1}[1], of length T is:

$$TGM_{AGF1} = \left(\int_{t=0}^{t=4} R_A \cdot e^{-\mu t} dt + \int_{t=4}^{T} R_G(t) \cdot e^{-\mu t} dt + S \cdot e^{-\mu T} \right) - \left(\int_{t=0}^{t=4} VC_A \cdot e^{-\mu t} dt + \int_{t=4}^{T} VC_G(t) \cdot e^{-\mu t} dt \right), \tag{1}$$

where $R_A = P_A Y_A$ is the gross revenue and VC_A the variable costs from annual agricultural crops with P_A, YA and VC_A being the price, yield and variable cost vectors, respectively and $R_G = P_G Y_G$ the gross revenue and VC_G the variable costs of the gum crop with P_G as the price per unit of gum, Y_G the yield of gum and VC_G the variable cost vector. S is the net benefit of harvesting the timber, the stumpage value, at the end of the rotation cycle (T). μ is the private discount rate, equivalent to the "private rate of time preference", and measures how future benefits and costs are weighted relative to immediate ones. The optimal rotation rate,

[1] AGF stands for Gum Agroforestry system and the subscript (1) on the present value terms indicates the number of rotation.

T^*, is obtained where the marginal benefit of the gum forest left growing for an additional period equals the marginal opportunity cost of this choice (Perman et al. 2003).[2]

Starting at time $t = 0$ the total gross margin of the gum agroforestry over an infinite time horizon is given by

$$TGM_{AGF} = \frac{TGM_{AGF1}}{1 - e^{\mu T^*}} \tag{2}$$

Alternatively, the present value obtained from annual crops, TGM_{A1}, over a rotation of length T^* is given by:

$$TGM_{A1} = \left(R_A - VC_A\right) \int_{t=0}^{t=T^*} e^{-\mu t} dt \tag{3}$$

which gives over an infinite time horizon and constant gross margin:

$$TGM_A = \frac{TGM_{A1}}{1 - e^{\mu T^*}} = \frac{R_A - VC_A}{\mu} \tag{4}$$

The incremental total gross margin of abandoning the gum agroforestry system over an infinite time horizon, TGM_{ABG}, [3] is measured as the incremental benefit of annual crops. This is the difference between the present value of annual crops TGM_A and the present value of gum agroforestry TGM_{AGF}:

$$TGM_{ABG} = TGM_A - TGM_{AGF} \tag{5}$$

If farmers want to abandon gum agroforestry and convert the land to agriculture, they need to either uproot the gum tree or coppice it every year. This deforestation decision can be seen as an irreversible decision, as farmers cannot reverse the decision without having to bear additional cost of replanting the trees. The costs of deforestation are denoted by *DF*.

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[2] To avoid notation clutter we do not differentiate further between an agroforest and forest system.

[3] ABG refers to Abandoning Gum Agroforestry.

Similarly, if farmers want to expand their gum arabic forest they need to prepare the land and have to plant new trees, which can also be seen as an irreversible decision and the costs for afforestation decision are denoted by *AF*.

As Dixit and Pindyck (1994) show, entry and exit under irreversibility, uncertainty and flexibility creates option values that add additional costs for entering or expanding an activity as well as additional costs for exiting an activity. In this specific case, there are no irreversible costs for exiting gum arabic production as the land can just be left idle, that is *DF* can be considered to be zero and no extra value from waiting to exit the gum arabic production exists. The exit condition for a gum arabic farmer will be met, if the expected total gross margin from gum agroforestry turns out to be less than the opportunity costs (*OC*), $TGM_{AGF} < OC$. The opportunity cost here is mainly the opportunity cost of labor e.g. working off-farm, since land is not scarce, therefore, land is assumed to have zero opportunity cost.

The situation looks different if a farmer considers to enter or to expand gum arabic production. In this case farmers will face irreversible afforestation costs, *AF*, and hence there are gains from postponing planting of new trees. To model the uncertainty of gum agroforestry revenue, we assume that the annual incremental benefits from agroforestry, denoted by[4]

$$R_{AGF} = \frac{\left[\frac{\left(\int_{t=0}^{t=4} R_A e^{-\mu t} dt + \int_{t=4}^{T^*} R_G(t).e^{-\mu t} dt \right)}{1 - e^{-\mu T^*}} \right] - TGM_A}{\mu} \qquad (6)$$

[4] For simplification we compare the revenue from gum agroforestry with the total gross margin from agriculture.

follow a geometric Brownian motion[5] of the form $dR_{AGF} = \alpha R_{AGF} dt + \sigma R_{AGF} dz$, with α being the drift rate, σ the variance rate, and dz a Wiener process. Following Dixit and Pindyck (1994, pp. 186-195) in solving for the critical incremental annual value R^*_{AGF}, where expanding the gum agroforestry system would be economical, provides the following two non-linear equations for an optimal solution:

$$A_1 {R^*_{AGF}}^{\beta_1} = B_2 {R^*_{AGF}}^{\beta_2} + R^*_{AGF} / \delta - \left(C_{AGF} - S_a\right)/\mu - AF \quad (7)$$

$$\beta_1 A_1 {R^*_{AGF}}^{\beta_1 - 1} = \beta_2 B_2 {R^*_{AGF}}^{\beta_2 - 1} + 1/\delta \quad (8)$$

where $\beta_{1,2}$[6] is

$$\beta_{1,2} = \frac{1}{2} - (\mu - \delta)/\sigma^2 \pm \left[\left((\mu - \sigma)/\sigma^2 - \frac{1}{2} \right) + 2\mu/\sigma^2 \right]^{1/2}, \quad (9)$$

δ is the convenience yield and $\delta = \mu - \alpha$[7]. C_{AGF} is the sum of the weighted average cost of production for annual crops and gum. S_a is the average annual timber benefits based on $S_T e^{-\mu T}$ for an infinite horizon. $A_1 {R^*_{AGF}}^{\beta_1}$ is the value of the option to plant new gum trees. This value needs to be matched by the value of planting gum arabic trees, the right-hand-side of equation 7. $R^*_{AGF} / \delta - \left(C_{AGF} - S_a\right)/\mu$ indicates the total gross margin from gum arabic and AF the irreversible planting costs. $B_2 {R^*_{AGF}}^{\beta_2}$ captures the value of future abandoning gum arabic production if prices drop but production can restart without any additional irreversible costs. B_2 is defined as $B_2 = \frac{\left(C_{AGF} - S_a\right)^{1-\beta_2}}{\beta_1 - \beta_2} \left(\frac{\beta_1}{\mu} - \frac{\beta_1 - 1}{\delta} \right)$ (Dixit and Pindyck 1994, pp. 189).

[5] Geometric Brownian motion (GBM) is assumed because of analytical tractability. GBM is a Markov process and contains a drift term so that the expected value of the gum agroforestry is either increasing (positive drift) or decreasing (negative drift) over time.

[6] β_1 and β_2 are the two roots of a second order homogenous equation as a result of the solution for the real option value.

Equation 8 is another optimality condition, the so-called smooth pasting condition that needs to be met at the optimum. Solving equation (7) and equation (8) for A_1 gives the following equation:

$$(\beta_1 - \beta_2)B_2(R^*_{AGF})^{\beta_2} + (\beta_1 - 1)\, R^*_{AGF}/\delta - \beta_1(C_{AGF} - S_a)/\mu + AF) = 0 \qquad (10)$$

As B_2 is known Equation 10 can be solved numerically to give the critical value R^*_{AGF} for the investment which can be compared with current values of the annual incremental benefits of gum agroforestry R_{AGF}. This allows us to examine farmers' incentive to expand (enter) the gum business either by converting an idle land to gum agroforestry or switching the land use system from annual crops to gum agroforestry. Computation of the current values of R_{AGF} requires the calculation of the average annuity of revenues and costs for annual crops portfolio, gum agroforestry system and for a pure stand gum forest. In the following section we will describe the data and the calculation procedure in more details.

3. Data and Calculation

In order to calculate the expected value of the gum forest and since the production of gum trees is related to its age, we estimate the age-yield function of gum trees using the Hoerl function $y = vg^{\xi}e^{kg}u$ following others such as Haworth and Vincent (1977). Figure 2 shows the age-yield function estimated using data from Pearce (1988). The estimated age-yield function for a forest of 400 trees gives a maximum yield of 520 kg of gum arabic per hectare at age 11.

The gum arabic timber at the end of the rotation is mainly used for charcoal. As the gain from charcoal is relatively small, we assume for simplification that the benefits equal the costs and set $S_a = 0$. Gum prices, labor inputs and costs for gum forest management and harvest and

[7] We assume that $\delta > 0$ implying $\mu > \alpha$ this assumption is made to ensure the existence of an optimum

agriculture production are obtained from a farm-level survey in the 2002/03 season. The farm level survey included hypothetical questions designed to measure the rate of time preference, μ, of the farmers in the study area following Holden et al. (1998). We use the maximum, minimum and mean computed farmers' real rate of time-preference as the discount rate in the different models.

We use Monte-Carlo simulation to calculate the average annuity of revenues and costs from gum agroforestry, agriculture and from a pure stand of gum forest trees following the model described in Wesseler (1997). As mentioned before we assume that the incremental revenues R_{AGF} follow a geometric Brownian motion. We estimate drift and variance rates of gum agroforestry revenues from the price and total revenue time series of crop portfolio and gum arabic data and use those results in a form of sensitivity analysis to calculate the critical R^*_{AGF} using Microsoft Excel following Campbell et al. (1997).

4. Results and Discussion

The results of the Monte-Carlo simulation are presented in table 1. The three columns show the expected annuities for using one hectare of land either for agriculture, for a gum arabic agroforestry system intercropped during the first four years with a portfolio of crops or for a pure stand of gum arabic trees. Table 2 shows the estimated drift and variance rates for gum arabic, the three agricultural crops and the weighted average for the portfolio of agricultural crops using different data sources. Those results are used to calculate the critical values for establishing gum arabic agroforest or forest system.

Table 3 reports the critical incremental value needed for switching land use either to gum arabic agroforest or forest system calculated using different drift and variance rates and for different discount rates μ (minimum, mean and maximum), and assuming an irreversible

otherwise waiting is always optimal.

afforestation costs, *AF*, of 1000 SD for one hectare with 400 trees. These values can be compared with the actual values of gum arabic production as reported in table 1.

4.1 Abandoning gum arabic

The results in table 1 clearly show that agriculture currently provides the highest expected economic benefits. Nevertheless, the observed cultivation of gum arabic can be explained by the aforementioned different requirements for labor over time. Gum arabic does not directly compete with agriculture but with off-farm labor opportunities during the off-season. Gum arabic forests, therefore, might be abandoned if farmers find better off-farm opportunities. This is not a threat to desertification as long as the trees are just left behind continuing to grow. Leaving the forest behind, in this case, will take place when the critical value for the opportunity costs of labor is equal to the average revenues from gum arabic per unit of labor. For this to happen the average opportunity costs of labor have to increase by about nine to ten times (5304/548).

4.2 Expanding gum arabic production

Here we consider two options: the option of converting idle land with zero opportunity costs and the other to convert agricultural land to gum arabic production. Both types of land can either be converted to an agroforestry system, including agriculture production during the initial years or a pure stand of gum trees without agricultural production.

Converting idle land to a gum arabic forest

The current incremental average annual benefits for gum arabic agroforest and forest system, as shown in table 1, are 76599 and 5304 SD per hectare respectively. Both values are above the calculated critical values for gum agroforestry R_{AGF}^{*} and gum forestry R_{GF}^{*} reported in table 3. Given this, we would expect farmers to expand gum arabic production. Why is this not happening? There are two main factors that may explain the current situation. One factor is labor availability. Labor has been priced in our model at average costs over all farmers and not at marginal costs of individual farmer, as marginal costs of labor by farmer are very difficult to observe. It is reasonable that for some farmers they are higher than the reported average costs, so expansion of gum arabic may be limited by labor availability. A second factor is property rights. We have assumed that farmers will face no problem in securing their access to the harvest of gum over an infinite life-time of the forest. The current political instability in the country may force families to abandon their farms and move to a different place. This discourages long-term investments. One would expect that this may result in extremely high discount rates. The time preference elicitation method we applied does not include such kind of circumstances and hence may also explain why we do not observe the conversion of idle land to gum arabic forest.

Converting agriculture land to a gum arabic forest

The current incremental average annual benefits for converting agriculture land to a gum arabic forest or a gum arabic agroforest are about 5304 – 45151 = - 39857 or 76599 – 45151 = 31448 respectively. Both values are below the calculated critical values reported in table 3. Currently, we can not expect farmers to convert agriculture land to gum arabic forest or agroforest. If we compare the incremental average annual benefits for a gum arabic agroforest system with the critical values reported in table 3 we observe that the average annual benefits from the gum arabic agroforest have to increase by at least 56 per cent. This is equivalent to an increase in prices for gum arabic of at least about 330 per cent (48937-31448)/5304. Even much higher price increase are needed for inducing a shift to gum arabic forest, i.e. the price for gum arabic has to increase by at least 775 per cent.

5. Conclusion

This paper focuses on the analysis of the economic incentives for entry and exit in gum arabic agroforestry (forestry) systems in Sudan. We show that agriculture currently provides higher expected economic benefits than gum agroforestry (forestry) system. However, because of abundance of land resources in Sudan and since gum arabic is produced during the dry season where it does not compete with other agricultural crops for labor demand, farmers' can abandon gum production and leave the trees on the land. Abandonment does not result in deforestation. Based on our results, abandoning (exiting) gum production will be a concern if the opportunity cost of labor increases substantially. An increase of about nine to ten times on the average opportunity costs of labor is necessary in order for farmers to further abandon gum arabic production and neglect the gum forest.

As for the entry decision or the expansion of gum forest our results show that the incremental average annual benefits of gum agroforestry or forestry systems are above the critical values for converting *idle* land to a gum arabic forest. This suggests that farmer's would expand gum forest. However, this is not observed, and we suggest two interpretations to explain the observed non-expansion of gum forest into idle lands: scarcity of labor and insecure property rights caused by political instability in the country which discourage long-term investments.

Furthermore, the current incremental average annual benefits for converting *agricultural* land to gum arabic agroforestry (forestry) system are below the calculated threshold values needed for the investment. Results suggest that an increase in the prices of gum arabic respectively of about 330 per cent and 775 percent are needed to induce a shift in land use system from continuous agricultural production to gum agroforestry or forestry land use systems respectively. This specific result suggests that even if the constraints on the labor market are reduced and the political uncertainty is resolved conversion of agricultural land into gum arabic forest is unlikely to happen in the near future without any additional support.

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Table 1. Expected annuities for agriculture, gum arabic agroforestry, and gum arabic forestry for one hectare of land in SD#.

	Agriculture	Gum arabic Agroforest	Gum arabic Forest
Annuity reversible benefits	107751	76599	5304
Annuity reversible cost	62600	43640	548
Annuity reversible net-benefits	45151	32959	4756
Annuity irreversible afforestation costs	0	363	363

SD refers to Sudanese Dinar – 1 USD is equivalent to 250 SD during the survey period.

Table 2. Drift (α) and variance (σ) rates calculated from different data sources.

	Gum	Sesame	Ground nut	Roselle	Portfolio[1]
			based on real total revenue[2]		
Drift rate	-0.049	-0.102	0.145	0.170	0.029
Variance rate	1.904	1.086	1.273	1.613	1.282
			based on real prices[3]		
Drift rate	-0.021	-0.015	0.235	-0.020	0.033
Variance rate	0.468	0.808	0.660	0.638	0.728
			based on real floor price[4]		
Drift rate	-0.042				
Variance rate	0.448				

[1]Portfolio is based on a weighted average of crops with weights of 0.5, 0.2 and 0.3 for sesame, ground nut and roselle, respectively.

[2]Total revenue is calculated from the amount traded during one calendar year weighted with the average real price of the calendar year.

[3]Average real price of the calendar year.

[4]Real floor price for gum arabic as published in the annual report of the Gum Arabic Company (GAC) of Sudan.

Sources: Computations of total revenue and real prices are based on data obtained from Alobeid Auction Market Bureau various annual reports. Computations of real floor price are based on data obtained from Gum Arabic Company 27th annual meeting report (2000).

Table 3. Critical values for entering gum arabic production for a selection of various drift (α) and variance (σ) rates and using different discount rates (μ).

	Minimum discount rate $(\mu = 0.19)$	Mean discount rate $(\mu = 0.28)$	Maximum discount rate $(\mu = 0.53)$
	Drift and variance rate based on real total gum revenue		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	59140	59459	60250
Gum forest $(R_{GF}{}^{*})$	3731	3875	4254
	Drift and variance rate based on real gum price		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	48937	49265	49954
Gum forest $(R_{GF}{}^{*})$	1296	1399	1668
	Drift and variance rate based on real floor price for gum		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	48969	49276	49933
Gum forest $(R_{GF}{}^{*})$	1302	1401	1665
	Drift and variance rate based on real total revenue of the portfolio		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	54189	54561	55421
Gum forest $(R_{GF}{}^{*})$	2395	2531	2883
	Drift and variance rate based on real price of the portfolio		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	50300	50689	51515
Gum forest $(R_{GF}{}^{*})$	1547	1668	1974

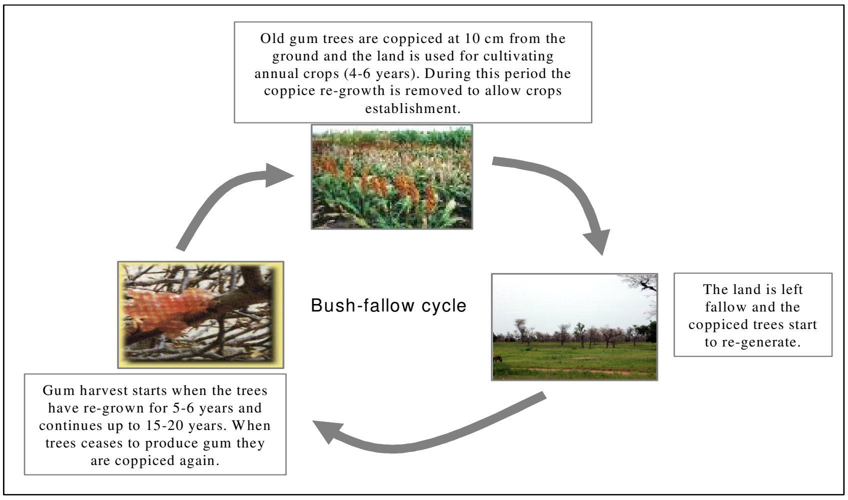

Fig. 1 The bush-fallow cycle of gum cultivation.

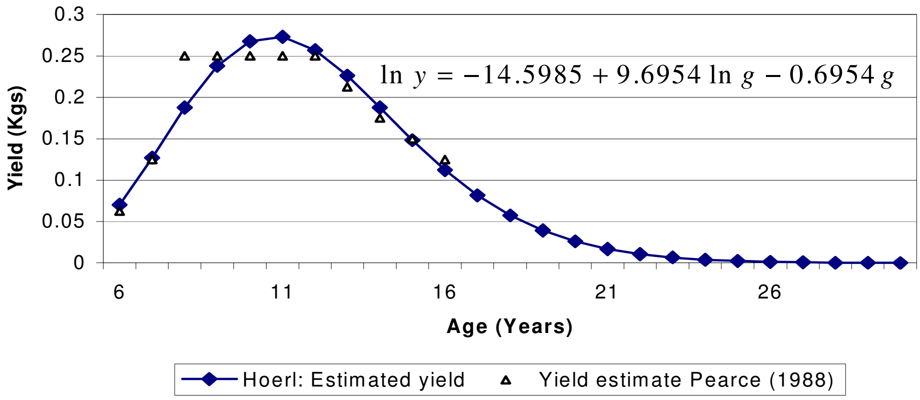

Fig. 2 Age yield function of gum arabic tree.