Economic Analysis of Deforestation

The Case of the Gum Arabic Belt in Sudan

Promotors: **Prof. dr. E. C. van Ierland**
Hoogleraar Milieu-economie en Natuurlijke Hulpbronnen,
Wageningen Universiteit

Prof. dr. R. Ruben
Hoogleraar Ontwikkelingsstudies en Directeur van het
Center for International Development Issues, Nijmegen
Radboud Universiteit Nijmegen

Co-promotor: **Dr. J. H. H. Wesseler**
Universitair hoofddocent bij de leerstoelgroep Milieu-
economie en Natuurlijke hulpbronnen,
Wageningen Universiteit

Promotiecommissie: **Prof. dr. J. C. J. M. van den Bergh**
Vrije Universiteit Amsterdam

Prof. dr. ir. A. J. Oskam
Wageningen Universiteit

Prof. dr. W. J . M. Heijman
Wageningen Universiteit

Dr. N. Elamin
Food and Agriculture Organisation (FAO)
Rome, Italy

Dit onderzoek is uitgevoerd binnen de Mansholt Graduate School van de Social Sciences Group

Economic Analysis of Deforestation

The Case of the Gum Arabic Belt in Sudan

Afaf Hassan Abdel Rahim

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit
prof. dr. M.J. Kropff,
in het openbaar te verdedigen
op maandag 20 november 2006
des namiddags te half twee in de Aula.

Rahim, A.H.

Economic Analysis of Deforestation: the Case of the Gum Arabic Belt in Sudan
PhD-thesis Wageningen University (2006)-with ref.-with summaries in English and Dutch.
ISBN 90-8504-469-3

TABLE OF CONTENTS

PREFACE iii

CHAPTER 1 GENERAL INTRODUCTION

1.1 Problem statement 1

1.2 Objectives 5

1.3 Methods applied in the thesis and organization 8

CHAPTER 2 NATURAL RESOURCES DEGRADATION IN SUDAN

2.1 Introduction 13

2.2 Natural resource degradation in Sudan 14

2.3 The gum belt location and role 18

2.4 Factors affecting the deforestation of the gum belt 21

2.5 Motivation of the study choices 28

2.6 Conclusion 30

CHAPTER 3 EXAMINING DISADOPTION OF GUM ARABIC PRODUCTION

3.1 Introduction 34

3.2 Background information 35

3.3 Survey design 39

3.4 Disadoption layers 41

3.5 The model 44

3.6 Hypothesis and summary statistics 45

3.7 Determinants of disadoption 50

3.8 Conclusion 53

CHAPTER 4 ECONOMIC INCENTIVES FOR ENTRY AND EXIT: THE GUM AGROFORESTRY

4.1 Introduction 56

4.2 Theoretical framework 58

4.3 Model setting 61

4.4 Data and calculation 66

4.5 Results and discussion 71

4.6 Sensitivity analysis and the choice of the discount rate 79

4.7 Conclusion 81

4.8 Summary and caveats 83

CHAPTER 5 COMPETITION IN THE GUM MARKET: POLICY IMPLICATIONS TO SUDAN

5.1 Introduction 88

5.2 Theoretical background 93

5.3 The model 95

5.4 Data and parameters 99

5.5 Scenario analysis 104

5.6 Scenario results and discussion 105

5.7 Sensitivity analysis 108

5.8 Conclusion 108

CHAPTER 6 DISCUSSION AND CONCLUSION

6.1 Introduction 113

6.2 Empirical results 114

6.3 Policy implications 117

6.4 Study limitations and research recommendations 120

REFERENCES 125

SUMMARY 133

SAMENVATTING (SUMMARY IN DUTCH) 137

CURRICULUM VITAE 141

PREFACE

I see my PhD study program as a process of personal and professional development. From the onset I had the desire to pursue this process – though I must admit I thought it would be rather shorter and less cumbersome. Nevertheless this desire did not leave me inspite of all the difficulties I came through. Throughout the process I learnt to control my expectations as well as my occasional frustrations and gained patience, confidence and determination along the way. I am not the person that I used to be before I started my PhD study.

Having completed this thesis, it is a pleasure to express my gratitude to a number of individuals for their help and support along the way. My foremost thanks go to my promoters Ekko van Ierland and Ruerd Ruben who played an important role in completing this thesis. I am very grateful to Ekko for his critical review, skillful advice, endless support, and above all, his patience. Thanks Ekko for your encouragement when I felt like giving up and for your understanding when I was preoccupied. I am also greatly indebted to Ruerd for his precise comments and advice on the manuscript. His critical and stimulating attitude towards my research activities helped to bring this thesis to a successful end.

I specially want to thank my supervisor Justus Wesseler for his great contribution in guiding and facilitating the PhD process. He has been actively interested in my work and has always been available to advice me. The discussions in his office gave me the necessary motivation and shaped my research to a considerable extent. Thank you Justus for also encouraging me to submit papers to conferences I still remember you saying: ‘submit the paper first and then later worry about the funding’. I would like to express my sincere gratitude to Hans Peter Weikard for his enthusiastic cooperation while building the model in Chapter 5 and for his valuable suggestion regarding this chapter. I would like to thank Eligius Hendrix, Kees Burger, Pierre van Mouche and Eisa Abdelgalil. Some chapters of this thesis benefited greatly from the discussion with them at an earlier stage. Arie Oskam from the reading committee deserves special thanks for evaluating my work and for providing me with valuable feedbacks.

Many individuals and institutions have helped me during the data collection phase in Sudan. Many thanks go to all the staff members of the Gum Arabic Company (especially to Hisham Mohamed Hassan, Musa Karama and Taha

Soueg). My deep appreciation goes as well to the staff members of the Agricultural Research Station and the Statistical Bureau at El Obeid for providing the available information and helping in the data collection. Above all, I want to thank the farmers for their time and hospitality.

My profound gratitude goes to all members of the Environmental Economics and Natural Resources Group of Wageningen University. Most importantly, Wil den Hartog who always been my friend in need! Thank you Wil and Leo for the warmth and friendship you extended to me and being there during the difficult times of the study. My PhD colleagues and friends at the department: Enoch, Miyuki, Morteza, Erik, Kelly, Juan Carlos, Lonneke, Kidist, Ada, El Hadji and Michael. I have enjoyed your company and the frequent discussion we had about research and about life in general. I want to thank specially my office mates: Kelly, Lonneke and Erik for the nice time we had in the office and for working together as a team on the *Dutch Summary,* you must have produced an excellent translation. My special thanks go to Miyuki for taking care of me when I was in Japan and to Morteza and Enoch for volunteering to help me with the graduation arrangement.

Thanks are also extended to my fellow doctoral colleagues and friends from the development economics group: Girmay, Feng, Mercy and Mose, I had fun and informative discussions with you- sharing the ups and downs of the PhD work. I salute also my former PhD colleagues at Wageningen University: Pius Odunga, Muyeye Chambwera and Beatrice Salasya. Your presence, the discussion I had with you and the moral support you extended to me at an early stage of the program kept me going.

I am deeply indebted to my nice friends Svitlana Levchuk, Najala Yosef, Daniel Haile and Ashraf Abdelhay. We have shared memorable moments together and you helped ease my loneliness and your presence made a remarkable difference to me. I owe gratitude to my special friends: Precious Zikhali, Chris Noell and Innocent Kabenga: They made me realize that life goes on despite its difficulties, that humor is vital and taking things personally is not on the agenda. My sincere gratitude goes to Precious whose practical attitude to life and quick intellect are admirable.

At this point, I also would like to gratefully acknowledge the various financial supports I have received over the course of the research. First of all, I thank the Netherlands Foundation for Tropical Research (WOTRO) for financing my research work for four years and Mansholt Graduate School and the

Environmental Economics and Natural Resources Group of Wageningen University for supporting me thereafter. I am also very grateful to SIDA for their scholarship which made it possible for me to pursue advanced courses in economics in Göteborg University in Sweden. Besides benefiting from the courses I enjoyed the social environment at the economics unit and made good friends and built up a network over there. Storm van der Chijs Fund, FAO and WOTRO are gratefully acknowledged for their financial support for participating in conferences in Minnesota, Kyoto and Brisbane.

Research can only be possible in inducive and morally supporting social environment. My family has contributed to this, and I would like to express my appreciation for that. My particular thanks go to my parents (Buthina and Hassan), who are ultimately responsible for teaching me to strive for education. To my mother I say *rayatik wa dawatik* did not go in vain. Many thanks go to my brothers (Abdo, Khalid, Hafiz, Ahmed, Tarig, Moez and Basil) for encouragement and my sisters (Sara, Huwida and Hanan) for moral support and their concerns about my well-being. I extend my gratitude to all my extended family. My aunt Khalda deserves special thanks, not only for her self-sacrifice and her unfailing helpfulness, but also for her great sense of humor and beautiful mind that made me always enjoy talking to her.

Once again, thank you all!

Afaf Rahim

October, 2006

CHAPTER 1

GENERAL INTRODUCTION

1.1 Problem statement

Scientists and others have drawn attention to the serious and mounting ecological problems caused by deforestation and the loss of tree in the dry lands of Africa. These concerns date back many years even before Stebbing's paper in 1935 on the *'encroaching Sahara'*. Both policy makers and the general public have become aware of the fact that tropical deforestation carries high opportunity costs in terms of the different economic and environmental benefits that tropical forests render. For example, tropical forests contribute to the local and national economy by producing not only timber but also non-timber products, they are the natural habitat for a wide variety of flora and fauna, and they play a considerable role in regulating the climate both at local and global level.

However, despite the fact that awareness of the problem has increased, the rate of deforestation is high: in tropical Africa forest area decreased by approximately 10%, or 0.7% per annum, between 1980 and 1995 (FAO 1997). In many respects the loss of forests is not surprising, given population growth and the increasing demand for arable land, fuel wood and timber. There are appreciable short-run benefits from the value of the harvested wood and from economic output on lands cleared for agriculture. The concern, however, is that such benefits are accompanied by huge ecological costs in terms of long-run threat to the carrying capacity or fertility of the soil over large areas.

A critical determinant of forest land decline in Africa is agricultural expansion (Reenberg et al., 1997; Wardell et al., 2004). Increase in cultivated areas is repeatedly suggested by the literature on rural land use change in Africa (Mortimore and Turner 2005). The high rate, at which forests are currently converted to agriculture in Africa, indicates that the economic return from agriculture is higher than from forests, at least in the short term, and that the land is more valuable deforested than forested (Gaston et al. 1998). Pressurized by their poverty poor people adopt a short run survival strategy and therefore forest protection is of low priority to them. By doing so, they contribute further to deforestation and land degradation and hence to long term poverty. Consequently poverty is considered both a cause and a consequence of environmental degradation and poor people are trapped in the *poverty-environment trap* (Dasgupta et al. 2003). Deforestation is also driven by the one-time economic return from the harvest of wood for timber and fuel wood regardless to land-use thereafter. In Africa, almost all countries rely on forest to meet basic energy needs. The share of wood fuels in African primary energy consumption represents on average 86% of total African energy consumption (Amous 1999).

Unlike tropical rainforest dry land forests in Africa are not known for their export-oriented timber production (Dufournaud et al. 1995) but they are a source of wood that is used locally as fuel and for construction and building. Also they produce non-timber products that are traded on the world market. One main non-timber export of African dry lands forests is gum arabic, which is produced in a belt that runs from East to West Africa, with Sudan as a major exporter of this forestry product. In addition to its economic importance in terms of foreign exchange earnings to the producing countries and income source from gum and wood products for the poor farmers in the Sudano-Sahelian countries, gum forests provide important environmental functions. For example, the gum tree *Acacia senegal* has a deep tap root with almost 40% of the tree biomass being underground and this makes it highly valuable for its soil stabilizing functions, containing sand dunes, acting as a buffer against wind erosion and decreasing water run off (Pearce et al. 1990; Barbier 2000). The tree is also known for its nitrogen fixing ability and improving the soil fertility and its tolerance for temperature and rainfall variations. Because of these functions *Acacia senegal* is widely sought as a mean of controlling desertification which is a major environmental problem in the Sudano-Sahelian zone.

Sudan is historically known to be a major gum exporter, producing more than 80 percent of the supply on the world market (Beshai 1984; Larson and Bromley 1991; Macrae and Merlin 2002). However, according to national statistics the total production from Sudan is decreasing and becoming increasingly varied, the average production in Sudan has declined from 46,000 metric tons in the sixties to 28,000 metric tons in the nineties (Elmqvist 2003). In addition the gum arabic belt in Sudan is suffering from increased deforestation due to drought, fluctuating gum prices, wrong economic incentives and the associated changes in the international market for gum arabic (Keddeman 1994; Macrae and Merlin 2002). Figure 1.1 shows the total exports on the world market since 1925 and the exports of Sudan. Years of the Sahel drought (1970s-1980s) marked a turning point in the export of gum arabic with the level of export declining to around 25,000 metric tons; this led many importers to seek alternative sources of supply and to turn to manufactured substitutes. During the 1990's world exports have started to pick momentum again, however, exports from Sudan almost remained the same, due to stagnating production in Sudan as well as the growing competition of other exporters, mainly Chad and Nigeria.

In the past, policy makers had attributed the decline in gum production mainly to drought and desertification and the resulting tree destruction. Restocking of the gum belt was therefore perceived as a way of reversing the trend of environmental degradation and sustaining the economic and environmental benefits of gum land use system. An understanding of the root causes of gum belt deforestation, however, involves the identification and analysis of several levels, (see Figure 1.2). The first level of establishing the linkages is by understanding the factors at play at the micro level of the agents of deforestation i.e. factors that are related to the characteristics of the farmers (e.g. objectives and preferences and resource endowments) and their choices with regard to allocation of factors of production e.g. land allocation, labor allocation and migration. Factors at the micro-level, according to Angelsen and Kaimowitz (1999), are the choice variables of the agents and the direct sources of deforestation. The choice variables can then be linked to meso-level causes. These are variables that influence farmers' decisions with respect to the choice variables, but are external to individual farmers e.g. marketing and prices, central and regional policies, infrastructure and services, social transformation and research and extension. The marketing of gum arabic and the mechanism through which gum prices evolves takes place at three sub-systems. These are the rural traditional market, the auction and the export market, the latter is dominated by the Gum Arabic Company (GAC). [1]

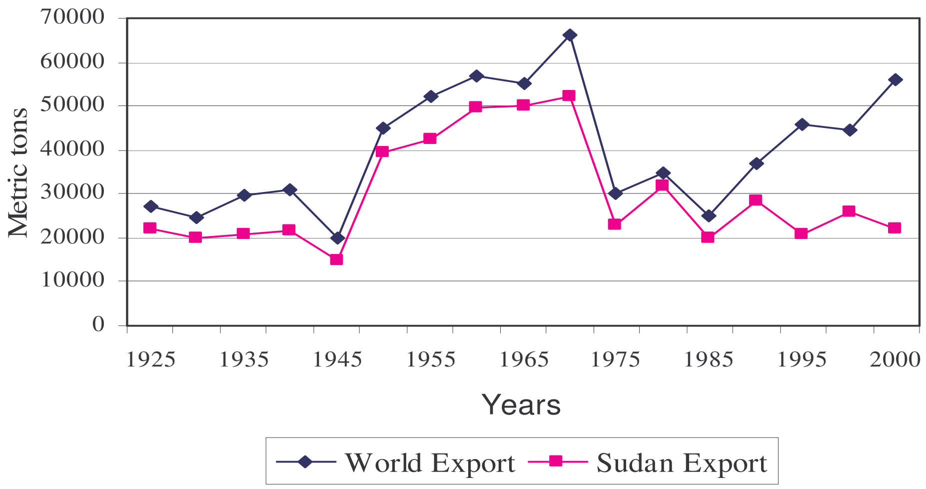

Figure 1.1 World exports and Sudan exports of gum arabic (1925-2000)
Source: Macrae and Merlin (2002).

The third level for establishing the causation is the macro-level and example of variables at this level are world market prices for gum, macroeconomic trends affecting the level of consumption, and the technological innovations and development for gum substitutes. The causal relations between the factors operating at the three levels go in two directions: for instance, the world market price at the macro level affects the prices the farmers get at the micro level and their decision to produce gum and the quantity produced which in turn have a feedback effect on the world market price. In addition, the international pricing

[1] As a practical matter, the complexity of the gum marketing chain and the interaction between the different customary, legal, political and economic institutions and socio-economic factors governing gum production and affecting the deforestation of the gum belt makes it difficult to separate variables operating at the farmer, regional and national level. For the sake of simplicity we did not make a distinction between variables at the regional and national level and grouped them as meso-level variables, since they are both external to the farmer.

policy of Sudan which is set by the GAC affects the world market demand and this will have a feedback effect on gum prices and future gum pricing policy followed by Sudan.

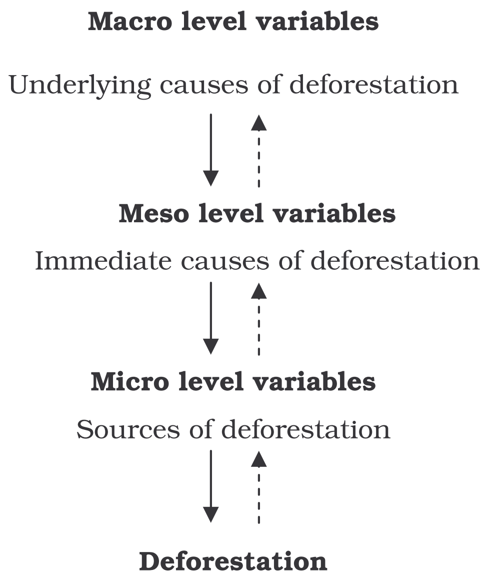

Figure 1.2 Main causes of gum belt deforestation at various levels
Source: Adapted from Angelsen and Kaimowitz (1999).

1.2 Objectives

The broad objective of this study is to analyze the problem of deforestation in Sudan gum arabic belt and the factors influencing gum arabic production in recent decades in order to understand the future sustainability of gum production. The study first aims to explain the farmers' attitude towards deforestation and investigate the factors that affect the conservation of the gum belt.

Secondly, the aim is to analyze the effect of price uncertainty and time preference of gum farmers in their decision to conserve or plant acacias. It has been claimed that poverty may lead to a short planning horizon, which may prevent poor households from investing in conservation to protect their natural resource base (Mink 1993). Yet, there are few empirical studies that link the rate of time preference among the rural poor and the adoption of sustainable practices (Place et al. 2002).

The third aim is to analyze the declining gum production in Sudan with respect to the recent changes in the market structure for gum arabic following the Sahel drought. The erratic supplies of gum from Sudan during and after the Sahel drought, the development of starch-based substitutes and the emergence of other exporting countries have changed the structure of the international market and in turn affected Sudan market share and revenue from gum export. The discussion on the recent changes of the gum arabic market in the literature, however, remains qualitative and no recent study attempted to quantify and analyze the current competition in the gum arabic market.

To achieve the above objectives the study is guided by the following research questions:

1. What are the socio-economic and institutional factors that influence the farming strategy of the traditional gum producer and the conservation of the gum belt?
2. Considering the *uncertainty* on prices, what are the costs and benefits of various agricultural systems including the gum agroforestry system and what are the economic incentives required for the preservation of the existing gum forest and for establishing new plantations at farm level?
3. What is the role of the international market structure and what are the effects of market interventions- such as international subsidies, on the gum market equilibrium and Sudan's profits from gum export?

As a starting point for our analysis we investigate the socio-economic and institutional factors that influence the conservation of the gum belt at the farm level. While previous studies show that gum arabic based farming system offer a potentially high financial rate of return to farmers (Sharawi 1986 and Pearce 1988, Ahmed 2000), however, it does not necessarily follow that economic profitability of the gum forest system is the only factor affecting the conservation of the gum forest. Therefore, question 1 is important as other factors and concerns, such as diversification of income sources or the uncertainty over economic returns, may affect farm household's decisions to include or exclude gum cultivation as part of their farming system.

The incentive to retain the tree or invest in planting the tree necessarily depends on the economic gain they obtain from the gum forest system as compared to other cropping system. Expected returns from the trees depend on the value of services the tree produce. These in turn are determined by economic and biophysical factors such as costs, output prices and growth and yield functions. From a theoretical point of view well-operating market-based incentives will encourage farmers to engage in financially and environmentally beneficial gum tree planting and conservation activities, and there will be less need for the government to engage in significant public restocking investment. But generally investing in planting or preserving perennial trees implies less flexibility in changing the land use system and responding to the price incentives. Moreover, previous studies on gum arabic generally applied conventional cost benefit analysis; however, it has been observed that gum prices do fluctuate considerably (Pearce 1988, Larson and Bromley 1991, Barbier 2000 and Elmqvist 2005).

Therefore, we pose question 2 in order to investigate the effect of the *uncertainty* over gum returns and the quasi-irreversible nature of the land allocation problem on farm households' investment decisions to deforest or plant gum trees. Question 2 is also important in identifying the adequate pricing policy that promotes preservation and expansion of the gum forest. The approach followed to answer question 2 is to link the time preference of farmers and the uncertainty over prices with the adoption dynamic using real option theory. The study, therefore, contributes to the existing adoption literature specifically in the empirical application of real options theory to agroforestry system. It also contributes to policy discussions on poverty-environment interactions and the resulting implications.

Question 3 is intended to analyze the recent changes in the gum market structure particularly with regard to the increased competition from Chad and Nigeria and the desire on the part of importers to diversify the gum supply sources so as to spread the risks involved in purchasing gum from a part of the world which is liable to climatic, social, economic and political upheavals. We do this by analyzing the competition in the gum market between Sudan, Chad and Nigeria (the two most important producing countries after Sudan) based on oligopoly theory. We then investigate the effect of international subsidy granted to the major gum exporters on market equilibrium and Sudan's profit and discuss the policy implications of our findings to Sudan.

1.3 Methods applied in the thesis and organization

Table 1.1 gives a schematic overview of the thesis structure showing the research questions and methods applied per chapter. The study is organized into six chapters including the introductory chapter. In *Chapter 2* we provide a historical overview of natural resource degradation in Sudan, mainly deforestation and desertification. We start with reviewing the literature on the debate surrounding the causes and extent of deforestation and desertification in the Sahel -with particular emphasis on Sudan- and their subsequent human and environmental consequences. We then continue with an overview on the environmental role of the gum belt in natural resource management and the sustainability of the agricultural system in the Sahel dry-lands. Then we provide a generic overview of the factors affecting gum production and the deforestation of the gum belt as mentioned in the literature. Chapter 2 also motivates the analytical choices of the study and the methodological approach we followed.

Table 1.1 Schematic overview of thesis structure

Chapter	Research Questions	Approach
Chapter 1: General introduction.		
Chapter 2: Natural resource degradation in Sudan.	Conceptual background.	Literature survey.
Chapter 3: Examining disadoption of gum arabic production.	1	Household field survey and logit analysis.
Chapter 4: Economic incentives for entry and exit: the gum agroforestry.	2	Real option theory.
Chapter 5: Competition in the gum market.	3	Oligopoly theory.
Chapter 6: Conclusion and discussion.		Reflections on the thesis.

The next three chapters (3, 4 and 5) consistently follow the sequence of the research questions. *Chapter 3* answers research question 1 and examines the factors leading to the disadoption of gum production and gum agroforestry in Sudan. With few exceptions (Neil and Lee 2001), most of the literature that has studied technology adoption does not consider subsequent disadoption, yet this dimension is important to designing the right policy incentives for continued adoption and use of the technology. The chapter contributes to the discussion and literature on the evolution of agroforestry systems, since it focuses on the discontinued adoption of sustainable technology by farmers who adopted the technology in the past.

Chapter 3 deals with factors at the micro level of the agents of deforestation i.e. factors related to the characteristics of the farmers and their choices with regard to allocation of factors of production. Since the problem of deforestation is location specific we start the analysis by investigating the factors that shape the decision of the farmer at the micro level (see Figure 1.2). Based on the general objective of the study and the specific research questions, a household survey was designed in order to capture the socio-economic characteristics of farmers and their rate of time preference and to estimate the costs and benefits of agricultural and gum agroforestry systems. The focus of the study is to analyze the deforestation of the gum belt in Sudan, however, as it is difficult to undertake a survey that covers all the producing regions in Sudan, we have selected Kordofan region - a major gum producing region which contributes over 50% of total gum production in Sudan - as the region for administering the survey. Using the collected farm-level data we then perform a logit analysis and examine the significant factors that lead farmers to disadopt gum production and the gum agrofrestry system.

Chapter 4 addresses research question 2 and the subsequent sub questions. In Chapter 4 we link the time preference of farmers and the *uncertainty* over prices with the adoption dynamic using real option theory. The real option theory is an investment valuation tool for decision making and is basically suited for investments with the following characteristics (Dixit and Pindyck 1994):

Uncertainty: There should be some uncertainty about aspects of the investment in the future (e.g. revenue, operating cost, environmental cost), which is the case of almost all real life decisions.

Irreversibility: An investment is irreversible if part or the complete investment cost is a sunk cost and can not be recovered. Irreversibility of an investment can also refer to situations when there is a cost involved in undoing the investment (e.g. re-planting the trees after deforestation).

Flexibility in investment timing: refers to the ability to delay an irreversible investment option until further information is gathered. Making irreversible investment expenditure implies losing the option to invest later, which may be preferred in the light of new information obtained after waiting. This lost option to invest is called the opportunity cost of investing, and should form part of total investment costs (Dixit and Pindyck 1994). However, it might be the case that investors do not always have the opportunity to delay investments, due to, for example, strategic considerations for firms or in our case desperate poverty situation for farmers.

In contrast to the analysis in Chapter 3, which examines disadoption of gum agroforestry at fixed farm gate prices, Chapter 4 analyzes adoption and abandonment of gum agroforestry in a dynamic setting whereby farmers are assumed to maximize the sum of discounted (uncertain) annual stream of gross margin over time. In Chapter 4 a model is developed based on real option theory in which the annual incremental benefit from gum agroforestry is assumed to follow a geometric Brownian motion. Data on prices and costs of gum and annual crops are obtained from the survey data as well as other secondary data sources, e.g. Gum Arabic Company and El Obeid auction market. The model is applied to examine the trade off between agriculture and gum agroforestry by using the farm level data on farmers' rate of time preference as the discount rate.

Chapter 4 mainly deals with the decision making of the farmer on investing in tree planting and removal i.e. the chapter focuses on micro level variables (see Figure 1.2). While we did not undertake a quantitative analysis for the variables at the meso-level (national and regional institutions and policies affecting the deforestation of the gum belt), the analysis carried out in *Chapter 4* partly deals with factors at the meso level e.g. output prices, labor costs, government policies, security and migration. It also discusses the marketing and pricing policy of gum arabic at both the regional and central level.

Chapter 5 investigates the historical change of gum market industry from one monopolized by Sudan to an oligopoly structure in which Sudan, Chad and Nigeria control the gum market trade. Chapter 5 addresses factors at the macro level e.g. world market prices for gum, international demand for gum and the technological innovations and development of gum substitutes. The analysis in Chapter 5 is based on using Stackelberg model (non-cooperative oligopoly model) to represent the competition in the gum market with Sudan as the leader and Chad and Nigeria as followers. Chapter 5 focuses on research question 4 and looks at the effects of market interventions such as international subsidies, on gum market equilibrium and Sudan's profits from gum export. The strategy space of each country (firm) is the possible quantity of each gum quality (high quality gum and low quality gum) that it can produce and export in order to maximize profit. The model is applied using available data on gum prices; gum export and the export value for the three exporters, and accordingly we predict the best profit maximizing strategy for Sudan to pursue. I also study which quality of gum arabic Sudan should promote further in the face of increasing competition from Chad and Nigeria.

Chapter 6 reflects on the results and insights from Chapters 2-5 and discusses the most important findings and the major policy conclusions drawn from the analysis, the limitations of the study, and it provides suggestions for future research.

CHAPTER 2

NATURAL RESOURCES DEGRADATION IN SUDAN

2.1 Introduction

Sudan is located in north-east Africa and extends for about 2100 kilometers from north to south and about 1800 kilometers from east to west with a total area of about 2.5 million square kilometers. This vast area of land covers a number of different ecological and climatic zones, from the desert in the north to the tropics in the south with the Nile crossing the country from south to north. Agriculture generally provides the livelihood for the great majority of the population. Nevertheless, the ecological conditions for agriculture and energy are fragile in many parts of Sudan, with the exception of the southern part of the country. The potential of the south to export resources to the north is severely limited by poor infrastructure and civil war (Pearce et al. 1990). Sudan suffered from a north-south civil war for around forty years (1955-72 and 1983-2004). Issues of natural resource management might seem not to be a priority during the war time; however, Sudan recently signed a peace protocol in May 2004 and the political context in Sudan started to improve. In the near future the development needs and the environmental problems of the country are likely to be the focus.

The gum arabic land use system in Sudan has often been cited as a good example whereby environmental quality and economic development can be achieved simultaneously (Pearce 1988). Nevertheless, at the beginning of the 1990s some authors suggested that the system is moving towards a collapse (Larson and Bromley 1991 and Freudenberger 1993). Gum production, and accordingly the conservation of the gum belt, is affected by a complex combination of climatic (physical) factors and socio-economic, technological and institutional factors. This chapter discusses the main factors affecting gum production and driving the deforestation of the gum belt and thereby provides a context in which our analysis will be made. Its purpose is therefore: 1) to provide an overview of natural resources and environmental problems in Sudan with special emphasis on the role and deforestation of the gum belt. 2) To discuss the factors behind the recent decline of gum production in Sudan and the various aspects of deforestation of the gum belt. 3) To motivate the methodological approach of the study.

The remainder of this chapter is structured as follows. In Section 2.2 we discuss some important issues in natural resource degradation in Sudan. Section 2.3 provides an overview of the ecological and economic functions of the gum belt in Sudan. Section 2.4 discusses the factors affecting the deforestation of the gum belt and reviews the studies done so far on gum arabic. Motivation of the methodological choices of the study is given in Section 2.5. Section 2.6 contains the conclusion.

2.2 Natural resource degradation in Sudan

Deforestation and desertification are the major environmental problems in Sudan and affects more than 60% of the country (ADB 1994). The combined effects of drought and desertification in Sudan (as well as other Sahelian countries) have led to severe shortages of food and famine in the years 1970s and 1980s (De Waal 1989). The drought has also lead to large scale population movements and change in the social structure and economic activities. Two main views attempted to explain the underlying mechanisms for the Sahel drought. The first consider the destruction of the vegetation through over grazing and deforestation for fuel woods/timber and agricultural expansion to be the main reason. The second view suggests that changes in ocean temperature caused by global warming might be the main culprit (Rowell et al. 1995; Chang et al. 1997). The two attributions, if warranted, have different political implications for the Sahelian drought (Hulme and Kelly 1993). The former would imply that the drought is driven by socio-economics processes and in principle can be reversible by the pursuit of different land use policies. The latter put the blame on the increasingly carbonized global energy economy which is driving global warming, but for which Sahelian nations can hardly take responsibility (Hulme 2001).

Neither of these two attributions, however, is substantiated at present but nevertheless both the regionally and globally induced changes are a result of human interventions and the ongoing human-ecology transformation. In this chapter we focus on the first attribution and discuss in further details the extent and causes of the two major environmental problems in Sudan (deforestation and desertification) highlighting the interaction between the socio-economic process and natural resource degradation in Sudan.

2.2.1 Deforestation

In the mid-fifties forests in Sudan constituted about 36% of the total area in Sudan (Harrison and Jackson 1958). The Global Forests Resources Assessment (FRA) undertaken by FAO in 2000 estimated the country forest cover to be 17% and the area of other wooded land to be 10%. Accordingly the total area under forest or wooded vegetation in Sudan was 27% of the total area of the country. The scarcity of forest resources in Sudan is further aggravated by a high deforestation rate. FAO estimates ranked Sudan as the third country following Brazil and Indonesia in terms of net forest loss per year between 2000 and 2005 (FAO 2005). Deforestation in Sudan is mainly attributed to three important factors: agricultural expansion, burning to create grazing pastures and the inefficient methods in the production and use of fuel wood (ADB 1994).

Traditional producers in Sudan respond to internal population pressure and low land productivity by increasing the areas under food and cash crops and this horizontal expansion of agriculture comes at the expense of land devoted to trees and other vegetation (Elnagheeb and Bromely 1994). During the period 1961-1991 crop land has increased at an annual average rate of 4% and forest land has declined by an annual average rate of 2% (Abdelgalil 2000). On the other hand demand for fuel wood increased in recent years due to rapid population growth, urbanization and shortage of alternative energy sources contributed also to the degradation of the forest resources in Sudan (FOSA 2000). In addition to that pastures' overstocking and the concentration of animals on certain grazing areas because of the unavailability of water in other grazeable areas has also led to forest degradation in Sudan (Salih 1994).

Furthermore, forest resources in Sudan are inversely proportional to population density, 68 per cent of Sudan's forests are in the south where 15 per cent of the population lives and only 15 per cent of the northern states in Sudan -where 85 per cent of the population lives- is forested (MOED 2003). The deforestation problem in Sudan, is therefore, manifested at different levels of intensities in the different ecological zones. In the Northern part of the country (desert, semi-desert and acacia grass ecological zones) vegetation is sparse and re-growth and re-establishment of forest cover is slow and difficult. Therefore, removal of trees in these ecological zones causes severe environmental damage and leads to growing signs of desertification such as dust storms and soil erosion (ADB 1994). The gum belt lies within the acacia grass ecological zone and therefore acts as a natural barrier to protect more than 40% of the total area of Sudan from desert encroachment (Mohamed 2005).

2.2.2 Desertification and land degradation

In addition to the alarming deforestation rate, Sudan was in fact the location for an early study which appears to have contributed to the idea of the Southwards 'creep' of the Sahara desert (Olsson 1984; Pearce et al. 1990). Despite being perceived as an environmental issue of major importance, desertification has been subject to debate due to lack of clarity regarding its characteristics and occurrence. While the belief of an encroaching desert was more or less constantly present it received a major focus with the droughts in the 1970s and 1980s (Dregne 2002). At the Rio Earth Summit in 1992 desertification is figured out as one of the three main themes, along with biodiversity and climate change.

There are, however, conflicting propositions regarding the dynamics of the Sahelian desert. Lamprey (1976) used a vegetation index based on earlier work by Harrison and Jackson (1958) in order to identify the desert boundary compared to the earlier study and he suggested the desert is creeping with rates of movement of about 5-6 km per year. Olsson (1985) and Hellden (1992), however, refuted the idea of a creeping desert and argue that desertification has been exaggerated and not based on scientific approach. Recent research suggest a trend of increasing vegetation greenness in the Sahelian region and a recovery from the Sahelian drought between the late 1960s and early 1990s (Eklundh and Olsson 2003; Olsson et al. 2005). There are, however, large uncertainties as to which processes have influenced the changing vegetation pattern in the Sahel. Proposed explanations include increased rainfall and land use changes as a result of migration a consequence of which is often abandoned fields and reduced grazing pressure (Olsson et al. 2005). A study conducted by Hinderson (2004) to explain the observed changes in vegetation cover in semi-arid Kordofan, however, did not confirm a positive trend in vegetation pattern; instead suggested a decrease in vegetation cover.[2]

The lack of consensus on the exact meaning of the term 'desertification' contributed to the lack of clarity on the definition, scale and nature of desertification. In its widest sense, desertification means an irreversible environmental crisis producing desert like conditions implying an evolution from viable to non-viable land. In its practical meaning desertification implies a set of actions which leads to an irreversible degradation of the vegetation cover, the soils and the socio-economic conditions (Mainguet and Da Silva 1998). Generally speaking there are three different views that attempt to explain the causes of desertification process. The first attributes land degradation to sectorial development which took place during colonization that resulted on the marginalization of smallholders and pastoralists and this marginalization continued through the neo-colonial time (Mainguet and Da Silva 1998). The second view attributes desertification to climate change and the frequent drought incidents in the dry lands. The third is the *neo-Malthusian* approach and it portraits overpopulation, poverty and the associated mining of soils in the dry lands as the main causes of desertification (Movik et al. 2003). According to this argument the desertification of parts of sub-Saharan Africa is not only due to drought but also to the actions of local

[2] Hinderson (2004) compared areas that showed a positive Normalized Difference Vegetation Index (NDVI) with areas that showed a neutral NDVI during the period 1982-1999. He also used field work of vegetation estimation and interviews and complemented the data with high resolution Landsat data and precipitation data. The main conclusion of the study is that it is difficult to explain the observed trend in NDVI during the period 1982-99 on a local scale based on the available data.

inhabitants, whose desperate poverty left them with no choice but to continue their exploitation of natural resources. This link, however, is not so well established compared to the more obvious link from resource degradation to poverty. This has been demonstrated tragically by famine incidents in Sudan. One of the major contributing factors to the 1984/5 famine in Sudan were drought and desertification (De Waal 1989). The link between resource degradation and poverty suggest that efforts, policies and measures to conserve natural resources can be justified by a concern for poverty, in addition to the objective of ensuring the sustainability of the resource base.

In general one can say that desertification is attributed to both physical (e.g. drought) and human factors e.g. excessive use of natural resources and expansion of farming into marginal lands beyond the agronomic boundary and these factors are likely to have feed back effect on each other. The decline in the area of dry tropical woodland, including savanna and shrub woodland, relative to other types of land cover, including its transformation into farmland and permanent pasture contribute to desertification problem (Geist and Lambin 2001). Deforestation, therefore, assumes a prominent place in conceptions of desertification.

2.3 The gum belt location and role

Gum arabic is a non-timber forest product and sought after in the industrialized countries for use in food and other applications. The first known uses of gum arabic were in the ancient Egypt as early as 2000 BC, in food, adhesives and paint (Seif el Din and Zaroug 1996). Locally gum arabic is used as a laundry starch, famine food and in plastering (Freudenberger 1993). But local trade and uses have been, and still are, insignificant in relation to the amount exported (Seif el Din and Zarroug 1996). One of its major uses today is an emulsifier for citrus oils in fruit based drinks and cola type drinks (Chikamai 1996). Other uses are in confectionery, pharmaceutics and photography (Barbier 2000). Gum arabic is a product of the genus Acacia; namely *Acacia senegal* and *Acacia seyal* locally known in Sudan as *Hashab* and *Talha* respectively. The two acacias are found in Sub-Saharan Africa in a belt widely known as the gum belt. The term *arabic* was added because the gum reached Europe from the Arabian ports.

The gum belt refers to an area situated at latitude of between 12° and 16° north stretching across Sub–Saharan Africa (Macrae and Merlin 2002). Figure 2.1 shows the location of Sudan, Chad and Nigeria in Africa and provides an estimate of the distribution of *Acacia senegal* based on limiting isohyets, which are approximately 150 mm in the north and 600 mm in the south. Within this zone, however, the density of *Acacia senegal* varies. In Sudan the main zone of production of gum arabic is the western part of the country. *Acacia senegal* (the focus of our study) has a remarkable adaptability to drought and frost (NAS 1983). *Acacia seyal* on the other hand grows on the gum belt where the rainfall is slightly higher than in the regions populated with the *Acacia senegal.* Therefore, *Acacia seyal* is affected at a later stage as compared to *Acacia senegal* with the desertification process (Macrae and Merlin 2002). Countries through which the gum belt passes either appear in trade statistics as sources of gum arabic with different proportions or have the potential to produce gum because of the presence of *Acacia senegal* or *Acacia seyal* on their soil. Sudan is the world's largest producer of gum arabic, followed by Chad and Nigeria (Verbeken et al. 2003).

In Sudan the gum belt covers an area of 520,000 km^2 across central Sudan and accounting for one fifth of the country total area (IIED and IES 1990).[3] *Acacia senegal* is a multipurpose tree, not only producing gum, but also preventing desert encroachment, restoring soil fertility, and providing fuel and fodder. Although it is difficult to quantify the environmental benefits of *Acacia senegal* land use system a distinction can be made between benefits such as soil stabilization, water retention and nitrogen fixation which are to some extent 'internalized' through maintaining or enhancing the yield of field crops within the system and more 'external' benefits such as dune fixation and large scale desertification control (Barbier 1992).

[3] For comparison: The surface of the Netherlands is 30,000 km^2.

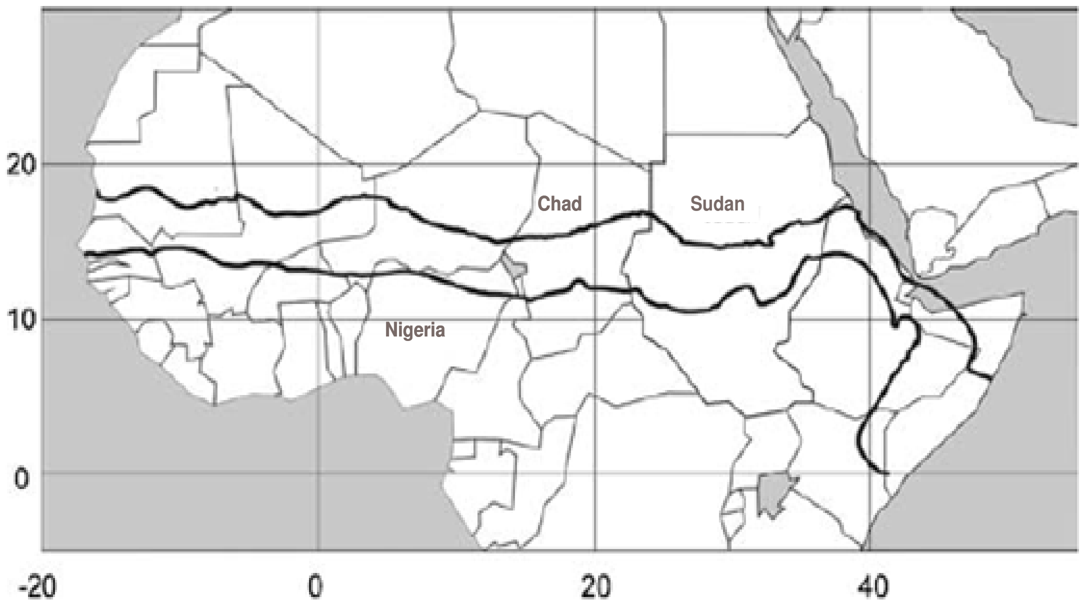

Figure 2.1 The distribution of *Acacia senegal* based on limiting isohyets

Source: Elmqvist et al. 2005.

The traditional land use system for gum production in the western part of Sudan is a bush-fallow system where *Acacia senegal* is rotated with field crops. Until recently the traditional *Acacia senegal* based agroforestry was recognized as one of the successful forms of natural forest management in the tropical dry lands (Fries 1990). *Acacia senegal* is a nitrogen-fixing species, and therefore, is important in reclaiming degraded lands in the tropics through the improvement of soil properties (Alstad 1991, Njiti and Caliana 1996). Jewitt and Manton (1954) compared an exhausted site, that had been under continuous cultivation for 30 years, with an area taken out of cultivation and allowed to regenerate as a gum forest (*Acacia senegal)*. Organic nitrogen, exchangeable calcium and pH level were much higher in the gum forest. After clearing the gum forest, the two sites were cultivated with sesame (*Seasamum orientale*) and groundnuts (*Arachis hypogae*). The sesame yield was five times higher and groundnut yield one and a half times higher for the cleared forest compared to the exhaustible site.

In recent years, however, the increased demand for food due to population increase combined with decreasing yields, however, have forced some farmers to extent their cultivated area primarily by reducing fallow periods. As a result the bush-fallow land use system have changed from a rotation system with long fallow periods of around 15 to 20 years interspersed with short period of cultivation of around 4 to 5 years to more or less continuous cultivation over the past three to four decades (IEED and IES 1990; Olsson and Ardö 2002). During the same period, crop yields have decreased mainly due to a marked decline of rainfall but also to some extent due to the abandonment of the fallow periods (Olsson 1993). Shortening the fallow period threatened the sustainability of the agricultural system and gum production.

Furthermore, a survey carried by IEED and IES (1990) suggests that the belt moved southwards and no *Acacia senegal* tree exist north of latitude 13˚ 45' North. Recent vegetation maps based on satellite images also depict the southward shift of the belt, and there is evidence that the northern area of the gum belt has been denuded and current gum production mainly comes from the southern part (MOED 2003). Moreover, over the last three decades gum production in Sudan has declined and also varied increasingly from year to year. Table 2.1 shows the mean annual gum production during the period 1960 -2004. It can be seen that the drought years (1973/4 and 1984/5) have adversely affected gum production. In addition to drought gum production is affected by several factors, including among others, the socio-economic setting of the gum farmers and the policy environment under which gum production takes place and the supply and demand factors at the international market.

2.4 Factors affecting the deforestation of the gum belt

Most of the existing literature on deforestation typically distinguishes the causes of deforestation into direct (first level) factors often referred to as sources of deforestation and indirect (second level) factors and often referred to as underlying causes of deforestation (Grainger 1993; Barbier et al. 1994 and Caviglia 1999). However, the interaction between factors driving deforestation at the two levels makes it difficult to separate their impact and determine their relative importance.

Table 2.1 Decline of gum production in Sudan

Period	Mean annual production (metric tons)	Percentage decrease from base period
1960-1969	46,000	Base period
1970-1979	34,000	26%
(1973/74)*	23,460	49%
1980-1989	28,000	39%
(1984/85)*	11,310	75%
1990-1999	28,986	37%
2000-2004	21,850	52%

*Drought years

Source of data: Department of Research -GAC annual reports.

Factors that affect gum belt deforestation operate at three main levels the macro/ international level, the meso/national level and the micro/farmer level. Factors operating at the international level are the underlying causes of gum belt deforestation and include macro-level factors such as world market demand and price for gum, macroeconomic trends and technological innovations for developing manufactured gum substitutes. Factors at the national level are the immediate causes of deforestation and are external to the farmer e.g. marketing and pricing of gum arabic, central and regional policies, infrastructure and services and research and extension. Whereas the direct causes of deforestation are the factors that operate at the micro/farmer level such as the farmer's resource endowment and the opportunity cost of labor and land which affects the decision on land and labor allocation and the gum prices. Figure 2.2 illustrates the main factors driving the deforestation of the gum belt and provides a simple logical approach for our analysis.

2.4.1 Macro level factors

The demand for gum at the international market depends on the per capita income in the consuming countries and the environment and health concern of consumers in industrialized countries[4]. For instance the Second World War and the first oil crisis at the beginning of the 1970s and its consequences on the level of consumption had an initial impact on exports of gum arabic. The major decline in exports, however, occurred during the prolonged drought that affected Africa (Macrae and Merlin 2002). The demand for gum also depends on the price of gum substitute. Gum arabic has the advantage that it is a natural product containing few calories, which consumers are increasingly requesting (ITC 2000). Nevertheless, the insecurity of gum supply, which started with the Sahel drought, and the associated high gum prices have resulted in an intense competition from manufactured substitutes such as modified starches, matlodextrins and celluloses particularly in the pharmaceutical and food industry. If end-users change to substitutes, they are unlikely to switch back to gum because of the high investment costs. This has already happened in the confectionery industry, where the high prices of gum in the 1980s forced many manufacturers to replace gum arabic with modified starches (Anderson 1993).

Substitution is feasible in most uses, but demand for gum is also likely to be inelastic in uses that rely on the low-calorie characteristics of gum arabic such as slimming food products or in the soft-drink industry (Coppen 1999). In other industries, however, such as in ink production, the natural aspect of gum arabic may confer fewer advantages. Gum arabic also faces competition from other natural gums. G*um karaya* and *gum tragacanth* are the most widely used natural gums other than gum arabic in food and non-food applications. Gum karaya is obtained from the genus *Sterculia* which is found on the dry and rocky hills of central and northern India and also grows in Pakistan, Senegal, Sudan and Mali (Verbeken et al. 2003). Whereas gum *tragacanth* is obtained from the genus *Sterculia* that grows in the highlands and deserts of Turkey, Iran, Iraq, Syria, Lebanon, Afghanistan, Pakistan and Russia (Geçgil et al. 1975 and Verbeken et al. 2003).

[4] Viz. consumer concerns with food quality and the increased demand for natural and organic food, which normally increase with the increase in well being and per capita income.

The price of gum arabic is important in determining the competitive position of gum arabic *vis a vis* its major natural and manufactured substitutes. In the long run the price level of gum arabic and the security of gum supply are important in curtailing or triggering further technological development of manufactured substitutes and switching from gum arabic use. Apparently gum pricing is a delicate balance between what the end-users are prepared to pay and what the gum farmers find remunerative for their effort. End-users of gum would hope for reasonable and stable prices, while producing countries want to maximize their revenue by raising the price especially when the supply is short. Moreover, remunerating and giving adequate incentives to gum farmers who start the gum supply chain is an issue of vital importance. Poor financial returns to the farmers (which can arise from low export prices[5]) increase the danger that they will turn away from gum collection as a mean of income generation. This also threatens the sustainability of the gum supply and the acacia resource, because farmers when faced with low gum prices can decide to cut the tree and sell it for fuel wood or charcoal, and use the land for the production of annual crops.

2.4.2 Meso level factors

The meso level factors are mainly the domestic policies in Sudan with respect to the marketing of gum and the pricing policies. The marketing of gum arabic in Sudan is conducted under a regulated government control since 1969 when the Gum Arabic Company (GAC) was established to control the export marketing of gum. The GAC was authorized to announce an export price at the beginning of the gum season and also to supervise a minimum floor price at the local auction markets. The level at which the

export price (FOB Port Sudan) is set is decided as a result of market intelligence gained through network of overseas agents, which enables estimates to be made of likely demand for Gum arabic, and the anticipated availability of gum from other supply sources. Through its ability to determine both producer floor price in domestic markets and

[5] Producers in Sudan receive about one fifth of the final export price (Macrae and Merlin 2002).

the export price, the GAC was able to manipulate directly producer incentives to supply gum arabic and aggregate demand on the international market. Larson and Bromley (1991) argue that the flawed pricing policies adopted by the GAC, along with the effect of the Sahel drought on gum production have induced technological innovations that permanently altered the structure of the international market.

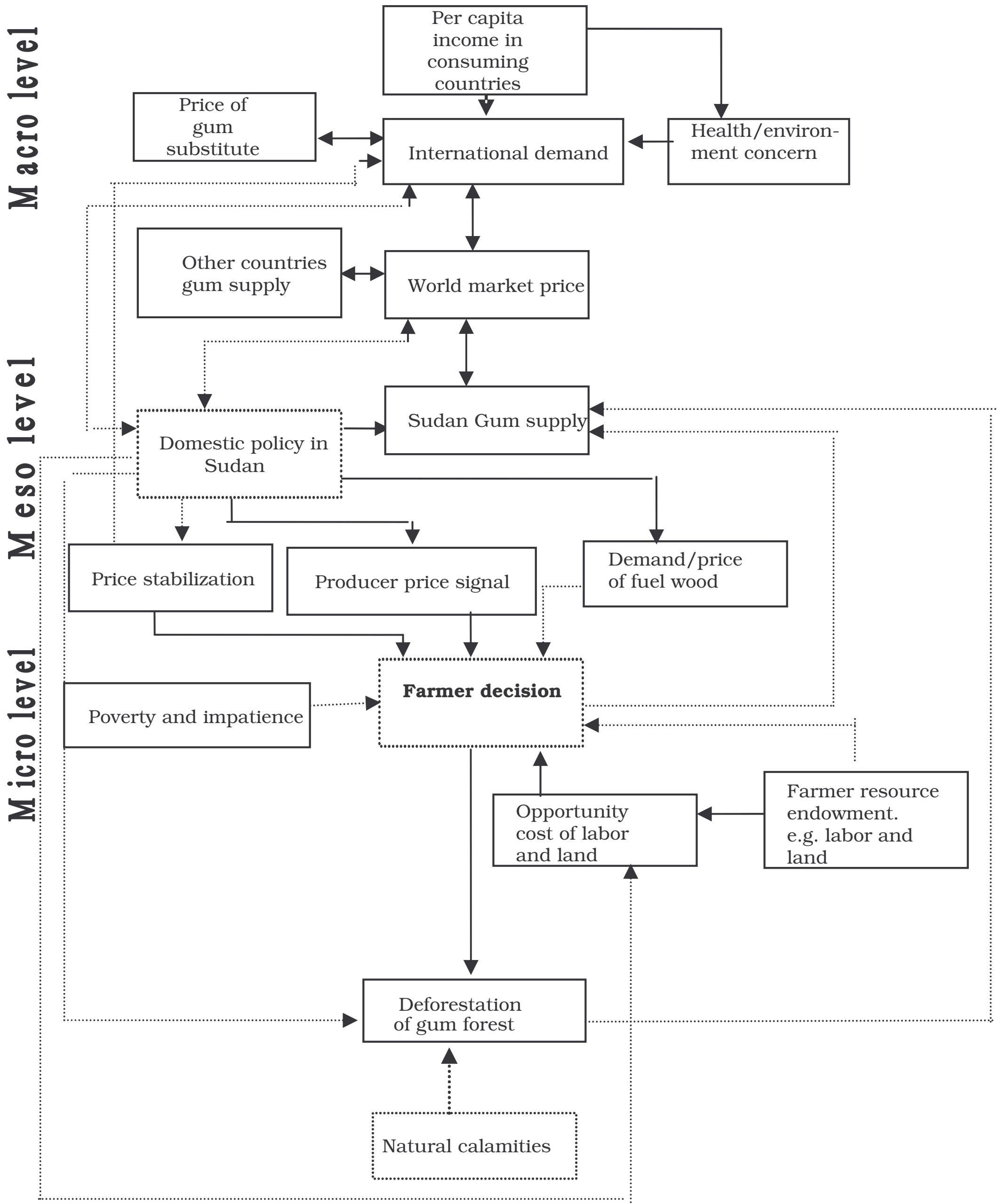

Figure 2.2 Generic structure of the factors affecting gum belt deforestation in Sudan

At the country level gum producers can sell their gum in the auction markets organized by the government, whereby the product is sold to specialized merchants who are responsible for cleaning, grading and packaging. Most farmers, however, are often prevented from selling their produce at the auctions by lack of cash, transport or labor (Chikamai 1996). Instead farmers sell their gum to middlemen/merchants at the village or nearby city market. In addition farmers sell their gum unsorted, although the grading is simple, based on physical parameters of color, shape, size and purity. The existence of middlemen/merchants between the gum arabic company and the gum farmers creates an imperfection of the gum marketing system as it divorces producer's response from official pricing policy (EL-Dukheri 1997). Merchants adopt the 'sheil' system of loan to farmers. This is basically a form of sharecropping in which farmers' mortgage part of their crop to the merchant in exchange for other goods. Figure 2.3 shows a flow chart of the activities and the groups involved in the process of gum production and marketing in Sudan.

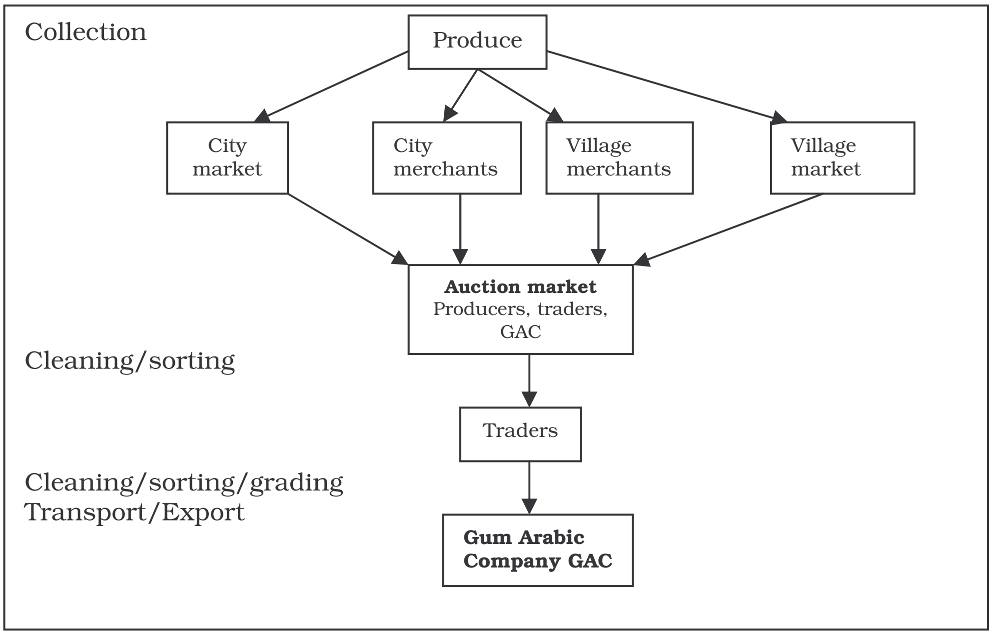

Figure 2.3 Production and marketing channels of gum arabic in Sudan

A great deal of attention has focused on the pricing policy of gum arabic from both producer and consumer points of view. While a rise in producer price is a sure way of increasing gum arabic production and in turn slowing down deforestation and maintaining the productive capacity of the agricultural sector, the high prices offered to the producers in 1973/4 might have led to deforestation as some trees were over-tapped and killed in the process (UNSO 1983). Given the poverty situation of the farming population the need to maintain consumption in the short run may have overwhelmed the future environmental costs from over-tapping and killing the trees (Larson and Bromley 1991).

2.4.3 Micro level factors

A complex set of factors interact and affect farmers' decision on gum production and land use system. The decision of the traditional gum producer on which and how much of each crop to produce depends not only on their resource endowment (land and labor) but also on the returns that can be obtained from alternative uses of labor and land and the time profile of these returns. Many of the small farmers undertaking gum production are relatively poor and face significant opportunity costs of obtaining funds for investment. Therefore, the rate of time preference of farmers affects their decisions.

Moreover a stable market price is essential for the producers. In Figure 2.4, data on production are compared to the real market price[6]. There are however several middlemen and the price received by farmers may be lower than the values in Figure 2.4. During the last three decades, the price has experienced three peaks, with increasing amplitude (1975, 1987 and 1994/5), yet the real price of gum arabic has generally followed a downward trend. The real price in 2000 is only 22% of the value in 1970.

Gum arabic provides the farmers with important sources of income during its harvest period in the dry season, at times when income from other agricultural crops is low. Therefore gum harvest provides a way for

[6] The nominal prices were adjusted to real prices with the Consumer Price Index (World Bank 2001). The year 1995 is the base year (=100) when US$=58.9 Sudanese Dinar (SD).

farmers to diversify their livelihoods and to alleviate the risk for subsistence crises. However, it has to be born in mind that gum arabic can only alleviate this risk if the money received can be used to buy food. For example, during and after the severe drought and famine in the mid 1970s and 1980s, it became obvious that the supply of food through local markets had failed. Even though there was no net shortage of food at the national level and Sudan continued to export food (Olsson 1993). To farmers, this implies food markets can not be trusted in times of crisis and producing food has therefore, become a priority.

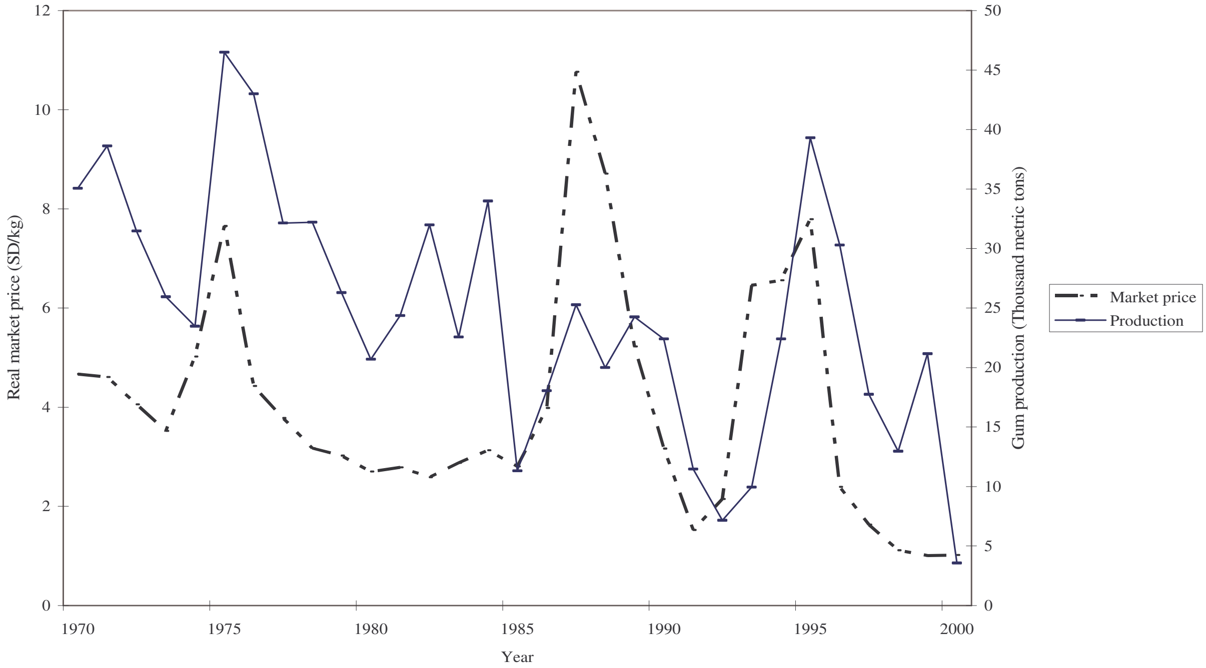

Figure 2.4 Real market price (SD/kg) (SD= Sudanese Dinar) of gum Arabic at El Obeid crop market and gum production for 1970-2000.
Source of data: prices (El Obeid auction market –annual statistics on agricultural crops trade 1960-2001) and production (Gum Arabic Company 2000).

2.5 Motivation of the study choices

The analysis of this study mainly focuses on factors operating at the farmer level and the international level. As we reviewed the literature we found that a recent survey on incentives structure and the socioeconomic and institutional factors influencing gum production is lacking. Previous studies on gum arabic show contradicting results as regard to the profitability of the gum arabic system. Sharawi (1986) calculated a positive financial net present value for the gum land use system. Pearce (1988) estimated the financial internal rate of return from gum, fuel wood and fodder production to be around 36%. A study of the economics of gum arabic (Barbier 1992) found that because of a decline in the real producer price of gum arabic relative to other crops the private profitability of gum arabic was lower than that of other crops except in the Tendelti system of the White Nile where field crop damage occurs frequently.

We therefore start our analysis in Chapter 3 using farmer level survey data to identify the most important factor affecting farmers' decision as regard to the discontinuity in gum production and gum land use system. While a large number of studies have considered factors determining the rate, timing and extent of adoption of agricultural innovations (Feder et al. 1985; Rogers 2003), only a few studies e.g. Neil and Lee (2001), have considered factors influencing disadoption. In Chapter 3 we use a micro econometrics technique to identify the effect of socio-economic factors assumed to influence the disadoption of gum production.

Existing studies on gum arabic also did not take the fluctuation of gum prices and the uncertainty over gum returns into account. Since *Acacia senegal* is a perennial tree, therefore, the gum land use system would imply a quasi-irreversibility in the land allocation decision. We therefore incorporate these two fundamental aspects in our analysis in Chapter 4 using a real option approach to study farmers' incentives to plant or deforest gum trees. Chapter 4 therefore merges the real options approach with agroforestry to analyze farmers' investment decision in the choice of either gum or agricultural production. The real options approach to studying investment under uncertainty relies on the concept of irreversibility (or equivalently sunk costs) and the possibility of delaying the investment. The basic notion of real options theory is that: when there is uncertainty over the investment returns, irreversibility (or partial irreversibility) and possibility of delaying the investment, then the value maximizing decision must consider the value of the option of delaying the investment when comparing the marginal benefits and cost of investing (or, equivalently when calculating the net present value). The existence of these three conditions (uncertainty, irreversibility and the flexibility in delaying the decision) generates a positive option value for waiting. While real option theory in general terms has been applied on the domain of deforestation (Albers et al. 1996; Bulte et al. 2002; and Mithöfer et al. 2004), to the best of our knowledge it has not been used to analyze agroforestry system.

Many commentators have focused on the critical role played by Sudan domestic policy under the monopoly power of the GAC on the decline in gum production and deforestation of the gum belt (Larson and Bromley 1991). However, in this study we did not focus on the domestic policy and the factors at the meso level. Nevertheless as there is an apparent interrelation between factors at the national level and the farmer level as can be seen in Figure 2.2, Chapter 4 partly deals with factors at the meso level e.g. marketing and pricing of gum arabic, output prices and gum price stabilization.

Few studies have qualitatively discussed the recent changes in the international gum market after the Sahel drought (Macrae and Merlin 2002; and Elmqvist et al., 2005). This study attempts to fill this gap in the literature. A theoretical scheme of Stackelberg model (non-cooperative oligopoly model) is deployed to analyse the competition in the gum export market for high and low quality gum between the (leader) Sudan and the followers (Chad and Nigeria). It attempts to investigate the effects of market interventions-such as international subsidies on gum market equilibrium and leader's (Sudan's) long run performance of profits from the gum export.

2.6 Conclusion

This chapter discusses natural resources and environmental problems in the Sahelian countries with particular reference to Sudan. FAO statistics on deforestation suggest a relatively high deforestation rate in Sudan and the literature on forest cover change in Sudan suggests that deforestation in Sudan is generally attributed to three factors. First, the expansion of agricultural land in response to population growth and low land productivity, for instance during the period 1961-1991 crop land has increased at annual average rate of 4% and forest land has declined at annual average rate of 2%. The second factor is burning to create grazing pastures. The third cause of deforestation in Sudan is the inefficient method in the consumption and use of fuel woods.

The gum belt in the Sahel-Sudan zone is considered a forest of particular importance because of it's various environmental and economics roles most important of which is providing a buffer against desertification. Nonetheless, the gum belt is suffering from increased degradation and some studies in the early nineties suggested that the gum land use system is moving towards a collapse. In this chapter we discuss the main factors driving the deforestation of the gum belt using a generic framework to categorize the factors into three different levels (the macro level, the meso level and the micro level. In the last Section of this chapter we provided a motivation to the methodological choices in our study.

CHAPTER 3

EXAMINING DISADOPTION OF GUM ARABIC PRODUCTION

Gum arabic production in Sudan has developed over the years in a well-established traditional bush-fallow system in which the gum tree (*Acacia senegal*) is rotated with annual crops. Following the Sahel drought the gum area has suffered from deforestation and gum production has declined. Several programs have been developed to boost gum production; however, many original adopters have disadopted gum production and the bush-fallow system. In this paper we apply a logit model to study the decision making behavior of farmers in west Sudan and to identify the socio-economic factors influencing disadoption of gum production and gum agroforestry system. Variables that measure farmer's wealth were found significant in explaining the disadoption behavior. Off-farm work was also found to positively influence the disadoption decision. Results show that a higher level of income from annual crops decreases the probability of disadoption, which suggests that annual crops and gum production do not compete but rather complement one another in the household farming economy. Therefore, policy measures aiming to boost the production of annual crops in the region can reduce seasonal labor migration and accordingly stimulate gum production.

Key words: Acacia senegal; Bush-fallow; Deforestation; Drought; Socio-economic

3.1 Introduction

The importance of farmers' adoption of improved agricultural technology has long been of interest to agricultural extensionists and economists. Quantitative and qualitative studies that explored farmers' adoption behaviors suggested several factors to explain the observed differential adoption behavior (Feder et al. 1985; Rogers 2003). These factors include among others demographic variables, technology characteristics, information sources, knowledge and awareness, attitude and group influence.

Earlier evidences led to the categorization of adoption behavior into innovators, early adopters, early majority, late majority and laggards. This is based on validated studies that adoption behavior of any agricultural technology would follow a normal distribution curve in a given social system (Rogers 2003). However an important component of the innovation decision-making process that has received little recent research is the discontinued adoption behavior which is the decision to reject an innovation after having previously adopted it. Rogers (2003) reported two types of discontinuance these are: replacement discontinuance where farmers reject the technology in order to adopt a better one that supersedes it. The second one is disenchantment discontinuance where a decision to reject the technology results from dissatisfaction with its performance.

Nevertheless analysis of the factors that predisposes farmers to discontinue adoption behavior of agricultural technology is not given due attention in the literature and failure to take disadoption into consideration implies an implicit assumption that adoption choice is irreversible. Such assumption does not hold in the case of gum agroforestry in Sudan, where it is estimated that more than 40% of the producers have disadopted gum production during the period 1993-1998 (Awouda 1999). This chapter aims to identify the socio-economic and institutional factors that are likely to explain the reasons behind discontinuing gum production and gum agroforestry in Sudan. The chapter contributes to agroforestry adoption literature, since it focuses on the disadoption of sustainable technology by farmers who adopted the technology in the past. Analysis of this aspect provides additional insight for policy makers and helps in identifying factors that stimulate gum production.

We use primary data obtained from a farm-level survey in Kordofan region and apply a logit model to analyze the disadoption of gum arabic production. Empirical results from survey data are summarized, and the socioeconomic and institutional factors influencing disadoption of gum arabic and the gum agrorforestry are discussed. The structure of the chapter is as follows. Section 3.2 highlights the various role of gum production to farmers in the dry lands of Sudan, sketches the background of declining gum production in Sudan and describes the study area. In Section 3.3 we describe the survey design and this is followed by Section 3.4 that gives a discussion on the reasons behind gum disadoption and the different disadoption layers in our sample. Section 3.5 explains the methodology and empirical model used to analyze gum production disadoption. In Section 3.6 we provide the summary statistics for the main variables included in our model. Section 3.7 contains the empirical results and the discussion. The final Section 3.8 provides policy conclusions.

3.2 Background information

3.2.1 Gum production: the promise and the problem

The dry lands in general are characterized by high variations in rainfall, which place agriculture at great risk. Risk spreading by diversification becomes essential and one important way to diversify in the Sahel has been through production of gum arabic. In West and Central Sudan, the production of gum arabic has at times been a totally dominant component of the farming system, and remains so for some parts. Gum arabic is a resin collected from several species of Acacia but in this study we focus on the gum collected from *Acacia senegal*. The first known uses for gum arabic were in ancient Egypt as an adhesive agent in food and paints (Seif el Din and Zarroug 1996). One of its major uses today is an emulsifier for citrus oil in fruit-based soft drinks and cola drinks

(Anderson 1993 and Chikamai 1996). Other uses are in confectionary, pharmaceutics and photography (Barbier 2000).

The land use system for gum production is a bush fallow system. Under this system each plot of land is used to cultivate crops for about 4-6 successive years followed by a period of 15-20 years of fallow under regenerating *Acacia Senegal.* In order for the tree to produce gum the tree has to be tapped or injured about 3-6 weeks before collection. When the production of gum arabic declines, the trees are cut and used for fuel wood and the land is put under cultivation and during this period the tree regenerates naturally. Gum harvest provides the small farmers with an important source of income during the dry season when there is no income from other agricultural crops. As the labor input and financial output occurs during a different time compared to other crops, gum represents away to diversify the livelihood and to alleviate the risk.

The tree is known to offer a number of environmental benefits, the most important are that its extensive lateral root system reduces soil erosion and run off and as a leguminous tree it fixes nitrogen which is a limiting nutrient in the dry lands and thereby improves soil fertility (Breman and Kessler 1997 and Barbier 2000). Deans et al. (1999) predict nutrient and organic matter accumulation in *Acacia senegal* fallow over 18 years in northern Senegal and record a substantial increase of N and K in surface soil with plantation age. Their study concluded that N accumulated in 15 years of fallow provides good sorghum yields for at least four cropping cycles. Based on these benefits *Acacia senegal* is a preferred species in the semi arid areas of the Sahel and is used on a large scale as a buffer zone against desertification. The trees also had many important local uses, such as fuel-wood, building materials for huts, wells, and fences, and animal fodder. Nonetheless, the gum arabic belt is suffering from increased deforestation due to drought, population movement and the recent changes in the international market structure of gum arabic (IEED and IES 1990; Keddeman 1994 and Barbier 2000).

The Sahel drought had resulted in large number of *Acacia senegal* tree mortality and accordingly gum production had declined as well as the income for the local farmers (Keddeman 1994). In order to sustain the level of gum production in Sudan and the environmental benefits associated with *Acacia senegal*, a number of development projects have been sponsored in 1980s by international donors to rehabilitate the gum belt in Kordofan and Darfur region. Most important are the restocking programs and the promotion of gum trees planting, which took place during the period 1980-1995, where seedlings produced in central nurseries were delivered to farmers free of charge supported by extension service. Estimates of the number of *Acacia senegal* seedlings distributed during this period exceed 15 millions seedlings (Awouda 1999).

Despite these efforts, gum production remained low and many original adopters have disadopted gum production and the gum agroforestry system. In our view, climatic factors can explain seasonal variation in gum production, but they are not the only reason for the declining trend in production. Particularly after all these rehabilitation efforts, other factors related to the incentive structure and the behavior of farmers must have contributed to the continuous decline in gum production and the observed disadoption behavior.

3.2.2 The study area

The gum belt in Sudan is divided into two main distinct areas. Mainly sandy area, in the west, consists of North Kordofan, West Kordofan, South Kordofan, North Darfur and South Darfur states. The second is clay land in the east, which is formed by provinces of Kassala, Blue Nile and White Nile. For the purpose of this study we selected Kordofan region since it is the main producing area of gum arabic in Sudan with a share of more than 50% of the total gum production. In addition the area has been a major focus of the gum belt restocking activities which were implemented by the Sudan government with the collaboration of international donor organizations during the 1980's and early 1990's.[7]

[7] At least 10 internationally financed projects had been undertaken during the 80s and 90s in Kordofan region focusing on desertification control by reforestation of Acacia Senegal; the largest one (Restocking the Gumbelt for Desertification Control)-under the direction of UNSO and the Dutch government-ceased in 1994 (Keddeman 1994).

Kordofan is a vast semi-arid region in mid-west Sudan, and its agricultural sector contributes significantly to Sudan's export crop portfolio netting nearly one third of the country foreign exchange earnings (Elamin et al. 1997). Furthermore, it spouses the largest gum arabic market in Sudan in Elobeid city. Figure 3.1 show the location of the study area in Sudan and the different land use system in the study area.

The majority of the populations in Kordofan are rural farmers. The region is well endowed with cultivable land even though only 20% of the total arable land is actually being exploited (El-Dukheri 1997). The traditional agriculture of the region, in the past was often described as subsistence rain-fed agriculture combined with limited amount of cash cropping. At present the practice of cash cropping is considerable in amount and increasing in importance. The bush fallow cultivation, which primarily involves the use of *Acacia* tree during the fallow period, has changed in recent decades to more or less continuous cropping (Olsson and Ardö 2002). The principal production alternatives in this system include millet and sorghum as stable food crops; and gum arabic, groundnut, sesame and Roselle (*Hibiscus sp.*) as the most important cash crops. Other food crops include cowpea and okra, while a minor cash crop is watermelon seeds. Two or more crops are often grown in one field so as to spread risks and to adjust labor demand during peak periods. Weeding tools, seeds and seed dressing are the main variable inputs used for agricultural production. Livestock, provides needed products to the household, and acts as a form of insurance against poor crops harvest, and is therefore also a principal production activity.

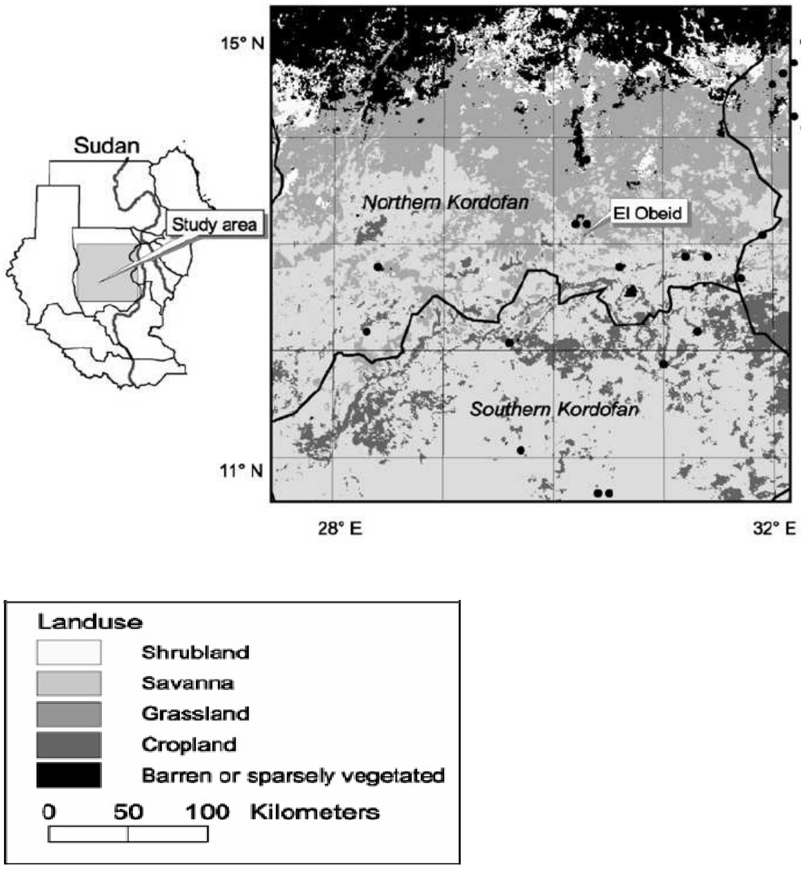

Figure 3.1 Study area

Source: Ardö and Olsson (2003).

The majority of labor demand is met with family labor supplemented with hired and communal labor in case of labor shortage. Seasonal labor migration is also an important income earning activity in the region. Migrating agricultural laborers head to destinations including the Gezira and other irrigation schemes in central Sudan, for cotton picking and sugar cane cutting, and to the mechanized farming schemes in Eastern Sudan mainly for sorghum and sesame harvest operations (El-Dukheri 1997). In addition to these major activities there are local employment opportunities including wage labor in market centers within the area.

3.3 Survey design

The main objective of this chapter is to investigate factors that contributed to disadoption of gum production and gum agroforestry in Kordofan region. We collected data from a field survey conducted between January and July 2003 in Kordofan region (West Sudan). Kordofan was selected due to its long history of gum production. In addition this area has been a major focus of the gum belt restocking activities which were implemented after the Sahel drought by the Sudanese government in collaboration with international donor organizations. Kordofan region is administratively divided into three states: north, south and west Kordofan. First, 20 villages were purposefully chosen based on past restocking activities. In the absence of an official census and in order to generate a sample of households, a household roster was compiled by asking each village headman to name all the household heads under their authority. The household census provided the sampling frame within which we stratified households in each village into three categories: 'adopters' (who are currently producing gum), 'disadopters' (who had previously produced gum but who had discontinued the practice for at least 3 years before the survey time), and 'non-adopters' (who had not produced gum before). Then a 1-in-5 random sample was drawn from each stratum in each village making a total sample size of 377 households, during data processing, however, 9 were dropped out because of missing data and inconsistencies, leaving 368 households for which data was available. The number of farm households interviewed from each state classified by adoption category is shown in Table 3.1.

The questionnaire covered various socio-economic characteristics of the farm household and its surrounding institutional environment. Socio-economic factors include land holdings, family size, age and education of the household head, and income composition. Institutional factors are the distance to the nearest town market, formal exposure to extension and credit as well as problems encountered with gum production. Before the questionnaire was administered it was pre-tested in one of the study villages in north Kordofan to evaluate validity of the questions and the structure of the questionnaire and to verify pre-coded responses included in the questionnaire. The purpose was to check clarity, relevance and sequence of the questions and identifying missing items. After the pre-testing, the questions were revised and the questionnaire finalized.

Table 3.1 Number of farm households interviewed from each state

State	Administrative unit	No. of villages selected	No. of households interviewed	Sample size based on adoption category		
				Adopter	Non-adopter	Dis-adopter
North Kordofan	Um Rawaba	3	63	38	17	8
	Sheikan	3	55	36	15	4
	Bara	3	60	39	15	6
	Subtotal	*9*	*178*	*113*	*47*	*18*
West Kordofan	Nuhud	3	60	28	19	13
	Gabaish	3	52	25	10	17
	Subtotal	6	112	53	29	30
South Kordofan	Jadid-Abu Nawara	3	37	29	2	6
	Al Sarajia	2	41	33	3	5
	Subtotal	*5*	*78*	*62*	*5*	*11*
	Total (sample)	*20*	*368*	*228*	*81*	*59*

3.4 Disadoption layers

The final dataset consist of 228 adopters, 81 non-adopters and 59 disadopters. Because adoption took place on average 20 years ago and as we have information only at the time of sampling, it will be difficult to analyze why non-adopters did not adopt (e.g. farm size as well as other variables that affected the adoption process in the past might have changed). We therefore dropped the non-adopters category from the sample and analyzed only continuous adoption *versus* disadoption decision using a total sample of 287 respondents.[8] Furthermore as mentioned earlier disadopters are defined as those who stopped gum production for at least three years as from the survey period; however,

[8] In an earlier stage of the analysis we have used a bivariate probit model to study both the initial adoption and the subsequent disadoption, however, because of the possible selection bias in measuring past behavior using current data we decided to remove the adoption stage and focus only on the continuous adoption stage.

discontinuing gum production does not necessarily mean abandoning the gum agroforestry system as it depends on whether or not the farmer still maintains the gum trees. Therefore the sample of disadopters could further be divided into *partial disadopters.* These are those who have stopped gum production but retained the tree and therefore may eventually re-adopt gum production. *Full disadopters* are those who stopped gum production but did not maintain the tree. Furthermore not having the tree is not necessarily an active choice for those who had fully disadopted as 15 disadopters lost their trees due to external factors i.e. mainly through drought and/or displacement. Figure 3.2 shows the different disadoption layers and their percentage in our sample.

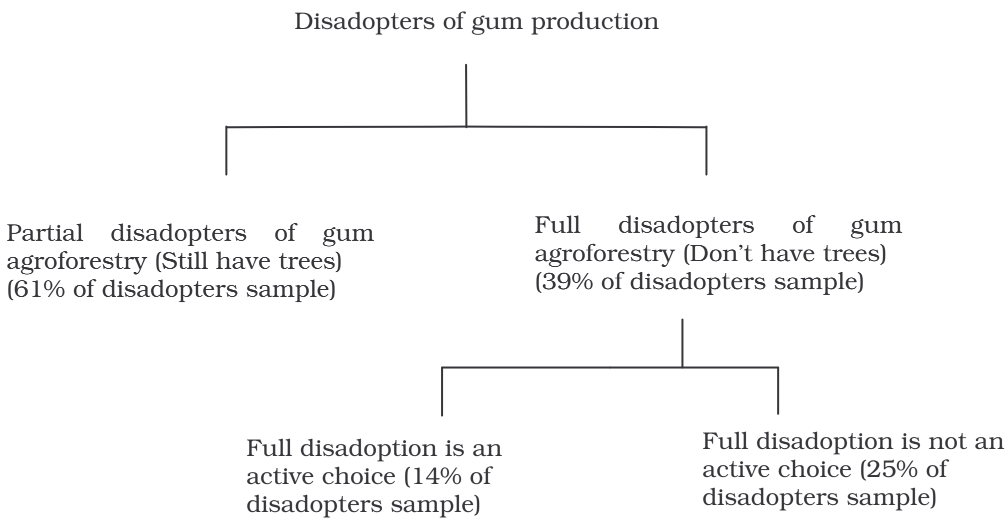

Figure 3.2 The different disadoption layers

Unfortunately the small sample of disadopters and the disproportionate split of the sample in the subsequent disadoption layers as shown in Figure 3.2 did not allow us to investigate the partial and the full disadoption decision in more detail, instead we removed from the sample those who lost their trees by drought and displacement (15 cases and 25% of the sample) because their full disadoption decision is not necessarily an active choice. This leaves us with a sample of 44 disadopters out of which 36 cases are partial disadopters and 8 cases of full disadopters for whom abandoning gum agroforestry is an active choice. The limited number of full disadopters in our sample suggests that partial disadoption whereby farmers abandon harvesting the gum but maintain the trees is the rule rather than the exception. As mentioned earlier gum production represents an important way to diversify income sources and the gum tree acts as a form of insurance and provides hedging against risk inherent in monocropping for poor farmers. This explains why farmers do not tend to fully abandon the gum agroforestry. Also farmers might maintain the tree in anticipation of an increase in the gum prices.

Table 3.2 shows farmers' stated reasons for disadoption. A high percentage of the respondents (50 %) mentioned low gum returns as main reason for abandoning. Gum tapping and gum production are highly elastic to prices and little gum is produced when prices are low and when prices are high the trees are over-tapped and sometimes killed in the process (Larson and Bromley 1991). The gum marketing and pricing policy are controlled by the Gum Arabic Company (GAC) which was established by the government to control gum trade and ensure fair returns to the gum producers by operating a minimum price mechanism. The policy on the minimum floor price is, however, not properly functioning and creates a dis-incentive for gum production and the planting of trees.

Table 3.2 Farmers' stated reasons for disadoption

Reason for disadoption	Proportion of disadopters[#]
Low gum returns	50 %
Have off-farm work	23 %
Insufficient land	14 %
Production of other crops	11 %
Lack of finance	9 %
Other reasons	5 %

[#] Due to multiple responses in some cases, percentages do not sum to 100.

Most farmers sell their gum to intermediate merchants, although the direct cash they receive is less than the announced floor price. About 86% of the surveyed producers do not sell their product in the GAC auction markets due to lack of cash, transport and small quantity produced and 64% sold their gum at prices lower than the floor price.

Other important reasons for disadoption stated by the farmers are engagement in off farm work (23%), insufficient land (14%) and production of other crops (11%).

3.5 The model

In most empirical applications, probit and logit models are used for modelling the relationship between a binary dependent variable and a set of continuous and/or discrete independent variables. The probit and logit models differ in the specification of the error term distribution, in the logistic model the error component follows a cumulative logistic distribution, while for probit models the error terms follows the cumulative normal distribution. The results obtained from the two models are therefore comparable except for very large samples. However, the estimates of coefficients (β) differ from each other, although they are related via a transformation (Maddala 1999).

For the purpose of this paper we use a logit model and following Neil and Lee (2001) we assume that the dependent variable is dichotomous such that: $y=1$ if the farmer continues to produce gum and $y=0$ if the farmer disadopts gum production. We are interested in the probability that the farmer continues to produce gum: $P(y=1|x)$, where x is a vector of explanatory variables.

The logit model assumes an underlying latent variable y_i^* representing the utility the ith farmer receives from continuing to adopt gum production, for which we observe the binary variable y_i where:

$$y_i = 1 \text{ if } y_i^* > 0 \text{ and } y_i = 0 \text{ if } y_i^* < 0 \qquad (3.1)$$

The underlying response variable y_i^* is defined by the following regression equation:

$$y_i^* = \beta_0 + \sum_{j=1}^{k} \beta'_j x_{ij} + u_i \qquad (3.2)$$

Where x_{ij} is a set of explanatory variables affecting the i^{th} farmer decision and k number of explanatory variables included in the equation. β_0 is a constant, β'_j coefficients of the explanatory variables j and u_i is the disturbance term. From the relationships (3.1) and (3.2) we get

$$P_i = \text{Prob}(y_i = 1) = \text{Prob}\left[u_i > -\left(\beta_0 + \sum_{j=1}^{k} \beta'_j x_{ij}\right)\right]$$

$$= 1 - F\left[-\left(\beta_0 + \sum_{j=1}^{k} \beta'_j x_{ij}\right)\right] \tag{3.3}$$

where F is the cumulative distribution function of u. In this case the observed values of y are realizations of a binomial process with probabilities given by (3.3) and varying from trial (depending on x_i). Hence the likelihood function is given by (Maddala 1999)

$$L = \prod_{y_i=0} F\left[-\left(\beta_0 + \sum_{j=1}^{k} \beta'_j x_{ij}\right)\right] \prod_{y_i=1} 1 - F\left[-\left(\beta_0 + \sum_{j=1}^{k} \beta'_j x_{ij}\right)\right] \tag{3.4}$$

The functional form of F (the cumulative distribution function of u) depends on the assumption made about u_i in (3.2). If the cumulative distribution of u_i is the logistic distribution, we have the *logit* model and in this case,

$$\text{Prob}\left(y_i = 0\right) = F\left(-\beta' x_i\right) = \frac{\exp\left(-\beta' x_i\right)}{1 + \exp\left(-\beta' x_i\right)} = \frac{1}{1 + \exp\left(\beta' x_i\right)} \tag{3.5}$$

Hence, the probability that the farmer will continue to produce gum is:

$$\text{Prob}\ \left(y_i = 1\right) = 1 - F\left(-\beta' x_i\right) = \frac{\exp\left(\beta' x_i\right)}{1 + \exp\left(\beta' x_i\right)} \tag{3.6}$$

3.6 Hypothesis and summary statistics

Several factors such as farm size, farm fragmentation, distance of plot from the homestead, engagement in off-farm work, income from annual crops, experience in gum production, etc. were hypothesized to influence disadoption of gum production. Farm size is expected to be positively associated with continued adoption as farmers with small holdings are more likely to convert the *Acacia* land either for the production of food crops or for the production of other cash crops that give relatively higher returns. On the other hand farmers, with large holdings are in a better position to follow the traditional gum rotation. Similarly, farm fragmentation is expected to have a positive effect on continued adoption as farmers who have large number of plots can leave some plots under *Acacia senegal* stand and cultivate annual crops on the other plots in order to reduce the time of commuting to and from plots. We expect that average distance of plots to the homestead will have a negative effect on continued adoption as smaller distance would imply less commuting time.

Studies have shown that off-farm income positively influences adoption of agricultural technologies (Adesina et al. 2000), as off-farm incomes may allow farmers to meet the inherent costs of new technologies (such as seeds and hiring of labor). We expect a negative association between engagement in off-farm work and continued gum adoption, as off-farm work competes with gum production for labor during the dry season and it also might imply a decline in farmers' dependence on gum as a dry season income.[9]

Farmer's gross revenue from other annual crops[10] is expected to have a negative effect on continuous adoption as it might imply horizontal expansion of agriculture into *Acacia* areas. We also expect a negative relation between groundnuts harvest and continued adoption because of overlap in harvest timing and competition on labor use.

The influence of livestock units on disadoption is less clear. Gum agroforestry provides fodder for animals; livestock otherwise, might also imply less reliance on gum as source of income and therefore, both positive and negative influence are possible. As the category of assets excludes agricultural land holding and Acacia trees, and only includes items used for off-farm work (such as animals' carts and small shops) we

[9] Because a major part of the household's off farm income comes from remittances of migrating family members and is not necessarily earned by the household head from working off farm, we therefore did not include off farm income in our analysis but rather included a dummy indicating whether the household head works off farm or not.

[10] The dimension of the farm gross revenue is one agricultural year (and represents the returns from crops for the agricultural season preceding the survey period i.e. 2001/2002). We have excluded gross revenue from gum because disadopters don't have returns from gum and we have excluded groundnut revenue because we have included the quantity harvested from groundnut as a variable in our analysis.

expect, *a priori*, that the variable 'current asset values' will have a negative influence on continued adoption. The effect of farmer's age on the decision on continuing to produce gum arabic can be taken as a composite effect of farming experience and planning horizon. While the longer farming experience amongst older farmers is expected to have a positive effect on adoption, younger farmers may have a longer planning horizon and, hence, may be more likely to adopt sustainable technology practices (Lapar and Pandey 1999). Previous research revealed a positive relationship between age and the likelihood of agroforestry adoption (Pattanayak et al. 2003). We also hypothesized that age is positively related to continued adoption as older farmers are less likely to opt for other off-season income sources, specially those involving seasonal migration. In a similar way we expect that farmer's experience in gum production to have a positive effect on the probability of continued adoption.

Educated farmers have been found to have greater likelihood of adopting conservation technologies (Adesina et al. 2000). We hypothesize education of the household head to be positively associated with continued adoption. The effect of family size on disadoption is difficult to predict. On one hand family size, is a proxy of household labor supply which implies a positive relationship. On the other hand, large families have more persons to feed and will strive to secure food requirements first; therefore a negative relationship is also possible.

Literature on adoption of agricultural technology suggests that extension and credit services bear a positive sign in explaining the likelihood of adoption. However, it is not clear if they will have the same effect on the disadoption decision. The effect of market distance on adoption and disadoption of gum agroforestry is ambiguous; in case the farm gate prices are fairly uniform, the distance variable could capture the price effect and may, therefore, be negatively related to continuous adoption as long distance to the market imply a longer marketing chain and a lower price incentive. However, the further away the farmer from the market the lower the probability of having access to off-farm work and thus a positive expected relationship is possible. Table 3.3 summarizes the variables that were hypothesized to influence gum disadoption.

Table 3.3 Description of explanatory variables and expected signs.

Explanatory variable	Description	Expected sign for continued adoption
Age	Age of household head (years);	+
Agesq	Age square	-
Educ	Education level of household head (years);	+
Exp	Farmer's experience in gum production (years of adoption)	+
Expsq	Experience square	?
Plotdist	Average distance of plots from the house in Km;	_
Frag	Farm fragmentation (number of farm plots);	+
Farmgrv	Farm gross revenue obtained from other crops (excluding gum and groundnut) in 000SD per year;	-
Gnut	Quantity harvested of groundnut in Kgs;	-
Creddum	1 if the farmer received credit during the last 3 years, 0 otherwise;	+/-
Extndum	1 if the farmer has received extension services during the last 3 years, 0 otherwise;	+/-
Astcv[11]	Current value of assets owned by the household (000 SD);	-
Lunit	Livestock units (index where livestock numbers are aggregated using following weighing factors; camel = 1, horse=0.9, cow=0.8, donkey=0.8, sheep=0.4, goat=0.4);	+/-
Mktdist	Distance to the nearest town market in Km;	+/-
State1	Dummy variable equals 1 if the farmer lives in south Kordofan, 0 otherwise;	+/-
State2	Dummy variable equals 1 if the farmer lives in west Kordofan, 0 otherwise;	+/-
Fmsz	Family size;	+/-
Farmsz	Farm size (hectares);	+
Offdum	1 if the farmer works off-farm, 0 otherwise;	-

[11] The current value of the asset was calculated by deducting an annual depreciation expense of 2.5% for buildings and 10% for other fixed (durable) assets e.g. radios and agricultural machines. For land and jewelry the current value is the purchase price, as these assets do not loose value by use.

Table 3.4 represents summary statistics from surveyed farm households, divided into two groups: adopters of the gum production and disadopters. Adopters appeared to have larger farm size land compared to disadopters. This is not surprising, as shown by the stated reasons for disadoption, where 14% of the disadopters mention insufficient land as a reason for discontinuing gum production. Adopters have high non-gum income which may suggest adopters are more dependent on farming activities in general. Also a higher percentage of adopters have received credit and extension services as compared to disadopters.

Table 3.4 Mean comparisons of adopters and disadopters

	Adopters N = 228 (84%)	Disadopters N= 44 (16%)
Age of household head (years)	44.49	44.93
Age square of the household head (years)	2203.19	2189.29
Experience in gum production	35.97	11.95
Experience square	44171.87	274.14
Education level of household head (years)	2.73	2.89
Family size	7.36	8.32
Farm size (hectares)	53.63	40.66
Average distance of plots from the house in Km	9.21	16.53
Farm fragmentation	2.74	2.02
Farm gross revenue (000 SD per year)	256.18	99.93
Quantity harvested of groundnut in Kgs	405.05	470.19
Credit (%)	16.23	4.55
Extension (%)	21.49	11.36
Current value of assets owned by the household (000 SD)	140.54	160.13
Livestock units	9.89	6.32
Distance to the nearest town market in Km	66.57	55.89
Off farm dummy (%)	32.46	61.36
Number of farmers in the sample living in South Kordofan (%)	26.75	22.73
Number of farmers in the sample living in West Kordofan (%)	21.93	56.82

3.7 Determinants of disadoption

We estimated the logit model using the statistical software package Limpdep 7.0 was used to generate the maximum likelihood coefficients, standard errors, marginal effects and measures of goodness-of-fit (chi-square statistics (χ^2) and the number of cases that are correctly predicted). The equation below represents the general form of the decision modeled:

$$
\begin{aligned}
y^* &= \beta_0 + \beta_1 AGE + \beta_2 AGE^2 + \beta_3 EXPER + \beta_4 EXPER^2 + \beta_5 EDU + \beta_6 FMSZ \\
&+ \beta_7 FRMSZ + \beta_8 PLOTDIST + \beta_9 FRAG + \beta_{10} FARMGRV \\
&+ \beta_{11} GNUT + \beta_{12} CREDDUM + \beta_{13} EXTNDUM \\
&+ \beta_{14} ASTCV + \beta_{15} LUNIT + \beta_{16} MKTDIST \\
&+ \beta_{17} OFFDUM + \beta_{18} STATE1 + \beta_{19} STATE2 + U
\end{aligned}
$$

Table 3.5 presents the results of the logit model, variables that appear significant with negative sign are: experience square, asset current value, livestock units, off farm dummy, groundnut harvest, family size and the dummy for state2. Variables that are significant with positive sign are: experience, farm fragmentation and farm gross revenue.

The logit estimates show that the variable experience is positive and the squared term of the variable is negative and both are significant at 1 %, indicating that the probability of continued adoption increases with experience though it increases at a decreasing rate. The data suggest that variables that measures farmer’s wealth (livestock units and asset current value) are important determinants of disadoption. Livestock and assets provides farmers with alternative income sources, for instance, livestock provide the needed insurance and supplement income in case of harvest failure, and assets can either be liquidated to smooth income or used for running small-scale entrepreneurial business at the village level (such as animal drawn carts). This implies that relatively wealthier farmers might depend less on gum as an income source. Results also indicate farm fragmentation has a positive effect on continuous adoption since operating more fragmented farms enables farmers to follow the traditional gum cultivation cycle. A marginal increase in farm fragmentation increases the likelihood of continuous adoption by 2%. A similar finding was reported in the Philippines, where farm households with more fragmented holdings are found to achieve higher levels of conservation (Pattanayak 1998).

Table 3.5 Binomial logit model results for continuous adoption

Variable	Coefficient estimate	SE	Marginal effect
Constant	4.4412*	2.4062	
Age	-0.0979	0.1021	
Age square	-0.0001	0.0011	
Experience	0.1427***	0.0306	0.0033
Experience square	-0.0000***	0.0000	-0.0000
Education	-0.0328	0.0684	
Family size	-0.14833*	0.0814	-0.0034
Farm size	0.0015	0.0043	
Plot distance	-0.0159	0.0226	
Farm fragmentation	0.8552***	0.2884	0.0196
Farm gross revenue	0.0089***	0.0030	0.0002
Groundnut harvest	-0.0005*	0.0003	-0.0000
Credit	1.4074	1.0840	
Extension	0.5557	0.7238	
Asset current value	-0.0022**	0.0011	-0.0000
Livestock units	-0.0506***	0.0185	-0.0012
Market distance	-0.0033	0.0079	
Off farm work (dummy)	-1.4553***	0.5146	-0.0334
State 1	-0.5541	0.7735	
State 2	-1.4121**	0.6268	-0.0324
Log likelihood	--64.7781		
Log likelihood ratio index	0.4619		
Model chi-square	111.21***		
Correct predictions (%)			
Continue to adopt (n= 228)	96.49		
Abandon (n= 44)	50.09		
Overall (N = 272)	90.44		

*** Significant at the α = 0.01 level (p<0.01)

** Significant at the α = 0.05 level (p<0.05)

* Significant at the α = 0.1 level (p<0.1)

The dummy for off-farm work is significant at 1 % level and the probability of continuing gum production decrease by 3.5 % for household heads who work off-farm. This was expected because 23 % of the adopters mentioned having off-farm income as a key reason for disadoption. During the 1970's gum production was the second important income source after annual crops but recently income from labor wage migration has gained increasing importance in most parts of the gum belt (Awouda 1999). Labor is frequently cited in the adoption literature as a constraint to agroforestry systems, because in many cases labor demand for tree management operation coincides with labor demand for other agricultural operations (Current et al. 1995). However, in the case of gum agroforestry most labor input for the production of gum occurs during the dry season when there is little work in other agricultural crops. The dry season is also the period when most off-farm labor takes place and most of the seasonal migration occurs. Macrae and Merlin (2002) stated that migration of labor during the gum collection season to the irrigated and mechanized schemes and other urban centers where better wages are provided is one of the factors behind the decline in gum production. The result that off-farm dummy negatively influences the continuity in gum production supports the above explanation for the decline in gum production.

The negative and significant effect of family size on the probability of continuous adoption have two intuitive interpretations, first large family size are likely to have more labor which in turn increase the possibility that part of the family members can work off farm and earn income through seasonal labor migration and therefore decrease the dependence of household on gum as off season income source. The other interpretation is that large family size implies more people to feed and a priority for the production of food crops i.e. more land will be devoted to food crops.

Interestingly and contrary to expectations we found that farm gross revenue from annual crops increases the probability of continuous adoption. The intuitive interpretation for this result is that a high income from annual crops will lead to a strong inducement for labor to remain in the villages and reduce migration. This in turns increases the availability of labor in the dry season for gum harvest and therefore, low income from annual crops could be the cause of migration in search for off-farm income. As expected the quantity harvested of groundnut, which is a proxy of opportunity cost of labor during the gum collection season, decreases the probability of continuous adoption.

Another significant variable in our result is the dummy for West Kordofan and this reflects the structure of our sample as a large number of disadopters are drawn from West Kordofan (50%). The variables 'extension' and 'credit' that are found to be significant factors for adoption of technology in several other studies (Feder et al. 1985) were not found to be significant determinants of continuous adoption of gum production. Generally, economic instability and government budget constraint limited the influence of formal institutions in remote areas of Sudan; this explains why extension and credit were not found to be significant determinants for the continuity in gum adoption. Finally, our model has a highly significant chi-square and high percentage of correct predictions. The numbers of households that are correctly classified into their actual adoption category are 90 %.

3.8 Conclusion

Gum arabic production in Sudan has developed over the years in a well-established traditional bush-fallow system in which the gum tree (*Acacia senegal*) is rotated with annual crops. Following the Sahel drought the gum area in Sudan has suffered from deforestation and gum production has declined. Several programs have been developed to boost gum production; however, many original adopters have dis-adopted gum production and the gum agroforestry system. In this paper we distinguish between partial disadopters (those who discontinue gum production but maintain the tree) and full disadopters (those who discontinue gum production and do not maintain the tree). Our survey sample shows that partial disadoption is the rule rather than the exception (81 % of our final sample are partial disadopters). Gum trees act as a form of insurance and provide hedging against the risk inherent in monocropping for poor farmers, and therefore, farmers might be reluctant to uproot the tree and fully disadopt the agroforestry system.

We applied a logit model to study the decision making behavior of farmers in west Sudan and to identify the socio-economic factors influencing disadoption of gum production and gum agroforestry. Results show that variables that measure farmer's wealth (livestock units and asset current value) were significant determinants of disadoption. Both livestock and assets can be liquidated to smooth income in case of poor annual crops harvest; therefore, wealthier farmers are more likely to abandon gum production. The factors that affect the opportunity cost of labor during the gum collection season such as the quantity of groundnut harvested and off-farm work were found important in explaining the disadoption decision. Therefore, policies that consider the returns of investments in gum production relative to alternative labor investment opportunities is likely to have a higher impact on continuous adoption of gum agroforestry.

Results also reveal that farm gross revenue from annual crops has a positive effect on continuous adoption. This can be explained as follows, on the one hand, the positive effect of the income from annual crops might indicate that adopters devote a large proportion of their labor time for the production of annual crops and gum whereas disadopters tend to work more off-farm. On the other hand, low income from annual crops could be a reason to abandon gum production and to migrate or search for off-farm work. This specific result suggests that gum arabic and other agricultural crops (except groundnut because of overlap in harvest time) do not compete but rather complement one another in the household farming economy, and good return from annual crops is a pre-requisite for gum production. Policy measures that aim to improve agricultural production in the region will induce farmers to settle in their villages and reduce the seasonal labor migration trend which will in turn increase the availability of labor for gum production.

CHAPTER 4

ECONOMIC INCENTIVES FOR ENTRY AND EXIT: THE GUM AGROFORESTRY

The gum tree (*Acacia senegal*) in the Sahel-Sudan zone has many environmentally beneficial functions. These important functions include improving soil fertility and controlling desertification. In this paper we use the real options approach to analyze farmers' economic incentives to exit gum production or enter by creating new plantations. Our results indicate that agricultural crops currently provide higher economic benefits as compared to gum agroforestry. However as land is abundant, gum arabic is produced during the dry season and agriculture crops mainly during the wet season and dry season opportunity costs for labor are low, the incentive for gum producers to exit gum production is low and, hence, an increase in deforestation of gum forests in the near future is not expected. Also, an expansion of gum forests and/or agroforests in the near future is not expected. The analysis shows that an increase in the prices of gum arabic of about 315 per cent is needed to induce entry into gum agroforestry and a shift in land use system from continuous agricultural production to gum agroforestry system. Price policies to improve incentives for expanding gum forests are discussed.

Key words: Gum arabic, Deforestation, Entry and Exit, Real options

4.1 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. Deforestation within the gum belt has lead to an increase in desert encroachment and threatens agricultural production (IEED/IES 1990, Keddeman 1994 and Olsson and Ardö 2002). Following the Sahel drought of the 1970s and 1980s a southward shifts in the tapping of gum has been reported (IIED/IES 1990), as people moved from the more fragile environment in the northern parts of the gum belt to the less fragile and better environment of the south. Over the last three to four decades the land use practices have moved from a rotation with long fallow periods (15-20 years) of gum cultivation interspersed with short period of cultivation (4-6 years) towards a more or less continuous cultivation (Olsson and Ardö 2002). The low and highly volatile producer prices of gum arabic over the previous decades have also accelerated the gum deforestation process (Barbier 2000).

An important question is if it can be expected that the observed deforestation of gum arabic will continue. Previous studies on gum belt deforestation show contradictory results with regard to the profitability of gum production. Ahmed (2000) estimates the financial internal rate of return of cultivating gum forest for 16 years to be around 15 percent. Barbier (2000) uses an economic analysis of six representative cropping systems containing gum arabic to estimate the net present value. He finds that because of a decline in the real producer price of gum arabic relative to other crops, the relative profitability of gum arabic is lower than that of other crops except in areas where field crop damage occurs frequently. But he also concludes that the inclusion of the environmental benefits of gum arabic and the role of the gum belt in controlling desertification meant that its social profitability is much higher than its private profitability.

The previous studies have assumed that gum arabic production directly competes with agriculture. We have observed that agriculture production mainly takes place during the rainy season while the tapping of gum arabic mainly takes place during the dry season. Furthermore labor is often considered as the most important constraint to agriculture for traditional farmers in the gum belt area (Elmadih 1992 and El-Dukheri 1997) as well as in the dry-lands generally (Visser et al. 2003 and Warren et al. 2003). As long as labor is relatively scarcer than land, comparing gum production in the dry season with agriculture production in the wet season can provide misleading results. In this study we analyze the incentives for abandoning gum production by comparing the benefits on the basis of the opportunity costs for labor.

The prices of gum arabic over the last few decades exhibit considerable fluctuation (Barbier 2000 and Elmqvist et al. 2005). The Discounted Cash Flow (DCF) technique used so far in the literature to examine the profitability of gum cultivation does not consider the fluctuation in gum prices and the uncertainty over gum return. DCF analysis assumes that either the investment opportunity is reversible or, if irreversible, is a now-or-never opportunity. 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 the 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). These real option values can be substantial (Mithöfer et al. 2004) and ignoring them results in under estimation of entry and exit costs. The contribution of the chapter to the literature on deforestation in the gum belt is analyzing the incentives for abandoning and extending gum production using a real option approach.

In summary, the two main objectives of this chapter are to analyze the economic incentives: first, for preserving the existing gum forest to understand if in the near future further deforestation of gum arabic can be expected and, second, for establishing new plantations at farm level to assess whether expansion of gum forest by farmers can be expected in the near future. More specifically this chapter will answer the following research questions: first, how much do the opportunity costs of labor have to rise to induce farmers to abandon their gum forest? And second, how much do gum prices have to rise in order to induce an expansion of the area under gum forest by converting either agricultural or bare land to gum production?

The remainder of the chapter is structured as follows. The next Section presents the theoretical framework of the chapter and introduces the gum production and management system. Section 4.3 describes the model we use for the analysis. Expected average annual net-benefits (annuities) from gum agroforest, gum forest and permanent agriculture systems are introduced and compared to identify critical conditions for continuation and expansion of gum arabic production. Section 4.4 presents the data base and the parameters of the model. The expected annuities for the different systems are calculated based on the data obtained from a farm level survey. Uncertainty is considered by using a Monte Carlo simulation. Secondary time series data are used for the estimation of the coefficients of the real option model. Section 4.5 presents and discusses the results and compares the expected annuities under uncertainty and irreversibility for the different systems with the critical values for expansion. In Section 4.6 we provide a discussion of the choice of the discount rate and sensitivity analysis with respect to the discount rate. The conclusion of the chapter is drawn in Section 4.7. The last Section summarizes the chapter and discusses its shortcomings.

4.2 Theoretical framework

From the perspective of private profit maximization, economic gain is a necessary but not a sufficient condition for preserving or planting the gum trees. Expected returns from the trees depend on the value of the services the trees provide. These in turn are determined by economic and biophysical factors such as costs, output prices and growth and yield functions. As long as alternatives for allocating either land or labor exist (e.g. off-farm income), preservation and plantation of gum arabic has an opportunity cost. However, farmers do not face a now-or-never dichotomous choice of either abandoning the gum business or planting trees as they can postpone the decision. They also face uncertainty and irreversibility about future benefits and costs, which influence the optimal timing of the decision.

4.2.1 The bush-fallow cycle of gum cultivation

For the purpose of exposition we will model the bush-fallow cycle of gum cultivation which prevails in west Sudan. The bush-fallow cycle is an agroforestry system based on integrating annual crops with gum trees in a temporal sequence. There are, however, other ways in which gum arabic is cultivated or combined with field crops by farmers throughout the gum belt. Other forms of gum cultivation are: the agroforestry system based on a spatial mixture- where annual crops and gum are produced from the same land unit simultaneously – and pure stand gum forest used for the production of gum only. Based on our survey data 75% of the farmers mentioned to follow the bush-fallow cycle (agroforestry based on temporal sequence) either solely or together with a combination of spatial agroforestry or pure stand gum forest. 30% of the farmers mentioned to use spatial agroforestry either solely or in combination with the other two gum land use (Appendix A.4.1. shows the percentage of farmers practicing the different gum cultivation systems).

Figure 4.1 illustrates the bush-fallow cycle of gum cultivation. The cycle starts by coppicing old gum trees at 10 cm from the ground surface. The land is then used for the cultivation of field crops such as millet, sesame, groundnut, sorghum, watermelon and roselle (*Hibiscus sabdariffa* L.). The average duration of field crop cultivation is around 4-6 years. Once the land is abandoned and put under fallow the coppiced trees shoot up and regenerate. Gum harvest usually starts after the tree has re-grown for 5-6 years and continues up to 15-20 years. When gum trees cease to produce they are coppiced again for crop cultivation and the cycle is repeated (Ballal 2002). The final tree stand is mainly the result of coppice regeneration, besides some regeneration from seeds dispersed naturally and in few cases from deliberate enrichment planting. During the period of field crop cultivation the coppiced shoots re-growth is removed to allow for the establishment and growth of agricultural crops. The change in the soil fertility (which improves during gum fallow and declines during tillage) provides a motivation for the use of the land rotation cycle in the bush-fallow system.

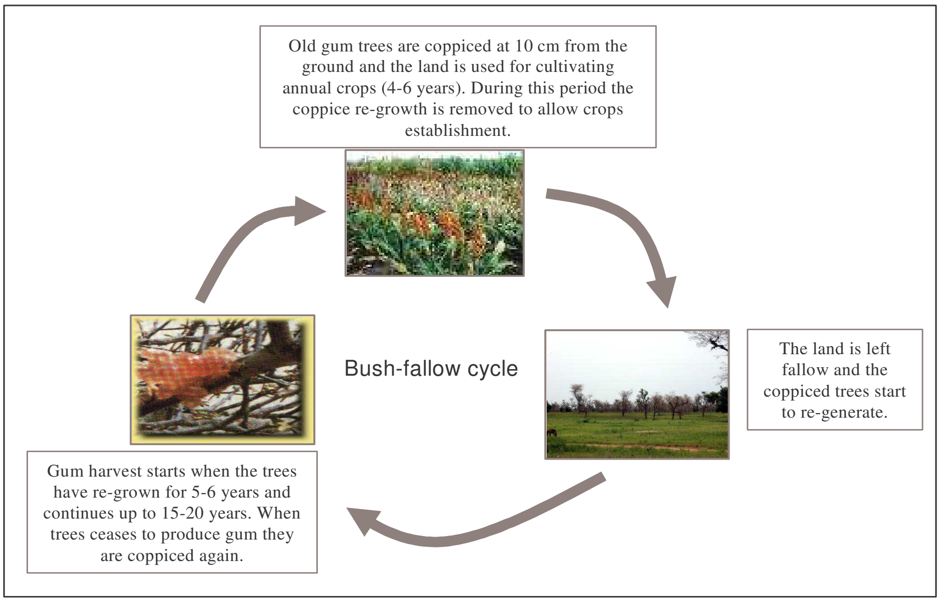

Figure 4.1 The bush fallow cycle of gum cultivation

4.2.2 Gum forest management options

We consider two options: the option to *abandon* (exit gum production) and the option to *expand* (enter gum production). The option to abandon implies either temporary suspension of gum harvesting or switching to a land use system of annual crops production. In the case of temporary suspension farmers abandon gum production but can leave the land idle and allow the tree to re-grow, whereas switching the land use system to agriculture requires either the complete removal or yearly coppicing of the tree.

Land in Sudan, however, is not a scarce resource, for instance only 20% of the total cultivable land is exploited in Kordofan region (El-Dukheri 1997). Moreover gum production takes place during the dry season and does not compete with agricultural crops for labor but rather competes with job opportunities during the dry season. One important trade-off to consider therefore is between the income from gum harvesting which takes place during the dry season versus the income from off-farm work during that same season. If farmers decide to continue the gum business they will receive a stochastic flow of benefits from gum harvesting during the dry season. Furthermore if they follow the bush-fallow cycle they may also receive returns from agriculture crops during the first 4-6 years.

More formally, we can say a gum farmer will continue cultivating gum trees down to a critical *value of abandoning* below which stopping gum tree cultivation (exit) becomes economically viable.

Similarly, the option of expanding (entering) will be exercised if planting of gum trees either as a forest or agroforest (including production of annual crops during the first four years) generates a higher economic value than using the land and labor for alternative purposes e.g. agriculture production during the rainy season and off-farm work during the dry season.

In the following section we explain the economic model to analyze incentives for abandoning gum forest production and incentives for expanding gum forest production in more detail.

4.3 Model setting

Assume that a risk neutral farmer owns one hectare of land which is used for gum agroforestry. The farmer is deciding whether to preserve this land use system or abandon the gum business. One option is to neglect the land and let the trees re-grow. In this case abandoning gum arabic production does not entail any extra costs and includes the possibility to start cultivating gum trees again, e.g. if the economic situation improves such as by an increase in the price of gum. The other option is to switch the land use to permanent agriculture and produce a portfolio of annual crops. But this option would only be applicable if land would be scarce. As this is not very relevant in our case, we do not pursue further analyzing this option.

4.3.1 Benefits from gum arabic agro forests and agriculture

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} [12] of length T is:

$$TGM_{AGF1} = \left(\int_{t=0}^{t=4} R_A.e^{-\mu t} dt + \int_{t=4}^{T} R_G(t).e^{-\mu t} dt + S.e^{-\mu t} \right)$$

$$- \left(\int_{t=0}^{t=4} VC_A.e^{-\mu t} dt + \int_{t=4}^{T} VC_G(t).e^{-\mu t} dt \right) \qquad (4.1)$$

where $R_A = P_A Y_A$ is the gross revenue and VC_A the variable costs from annual agricultural crops with P_A, Y_A and VC_A being the price, yield and variable cost vectors, respectively. The gross revenue of gum production is given by $R_G = P_G Y_G$ (t) where P_G is the price per unit of gum, $Y_G(t)$ the yield of gum and VC_G the variable cost vector of the gum crop. S is the net benefit of harvesting the timber, the stumpage value, at the end of the rotation cycle T. Further, μ represents 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 interval, 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).[13]

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

$$TGM_{AGF} = \frac{TGM_{AGF1}}{1 - e^{-\mu T^*}} \qquad (4.2).$$

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

[12] AGF stands for Gum AgroForestry system and the subscript (1) on the present value terms indicates the number of rotation. Note that gum revenue may occur from t = 4, but its value in years 4-8 will be zero and gum harvesting starts when revenue exceeds variable costs.

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

$$TGM_{A1} = \left(R_A - VC_A \right) \int_{t=0}^{t=T^*} e^{-\mu t} dt \quad . \tag{4.3}$$

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

$$TGM_A = \frac{TGM_{A1}}{1 - e^{-\mu T^*}} \quad . \tag{4.4}$$

The incremental total gross margin of abandoning the gum agroforestry system over an infinite time horizon TGM_{ABG} is measured as the incremental benefit of annual crops. [14] This is the difference between the present value of annual crops TGM_A and the present value of gum agroforestry TGM_{AGF} :

$$TGM_{ABG} = TGM_A - TGM_{AGF} \tag{4.5}$$

4.3.2 Irreversibility

Dixit and Pindyck (1994) show that entry and exit under irreversibility; uncertainty and flexibility create option values that add additional costs to entering or expanding an activity as well as additional costs for exiting an activity. As mentioned earlier 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. The costs of deforestation are denoted by *DF*. However, as land is not scarce resource in Sudan farmers can abandon gum production and leave the forest behind, we assume that there are no irreversible costs for exiting gum arabic production as the land can just be left idle. That is, *DF* is considered to be zero and there is no extra value of waiting to exit the gum arabic production.

Under this situation 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 of labor (OC), $TGM_{AGF} < OC$.

The situation looks different if a farmer considers to enter or to expand gum arabic production. In this case farmers will face irreversible

[14] ABG refers to Abandoning Gum Agroforestry.

afforestation costs, denoted by *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[15]

$$R_{AGF} = \frac{\left[\dfrac{\left(\int_{t=0}^{t=4} R_A . e^{-\mu t} dt + \int_{t=4}^{T} R_G(t) . e^{-\mu t} dt\right)}{1 - e^{-\mu T^*}}\right] - TGM_A}{e^{\mu} - 1} \qquad (4.6)$$

follow a geometric Brownian motion 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. The assumption of geometric Brownian motion implies that the current value of the annual incremental benefit from gum agroforestry is known but future values are log normally distributed with a variance that grows linearly with time, i.e. R_{AGF} is uncertain. Identification of the correct stochastic process the revenues follow (whether e.g. geometric Brownian motion or mean reverting) is difficult using econometric techniques to test the time series data. Dixit and Pindyck (1994) pointed out that the results can be ambiguous and depend on the time frame used. They recommended choosing the stochastic process not based on testing stationarity assumption for time series data but on theoretical grounds. From an empirical point of view the choice of the stochastic process may be important if different processes lead to different results and policy recommendations. According to Hassett and Metcalf (1995), however, the choice of stochastic process (geometric Brownian motion versus mean reversion) has no significant effect on the results; hence the more tractable geometric Brownian motion process can be used without significant loss of realism.[16]

---

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

[16] The main advantage of using geometric Brownian motion is that it leads to tractable solutions and closed form expressions that can be readily analyzed (Dixit and Pindyck 1994).

Following Dixit and Pindyck (1994, pp. 186-195) in solving for the critical incremental annual value of gum agroforestry R^*_{AGF}, where expanding the gum agroforestry system would be beneficial, provides the following two non-linear equations for an optimal solution:

$$A_1 {R^*_{AGF}}^{\beta_1} = B_2 {R^*_{AGF}}^{\beta_2} + R^*_{AGF} / \delta - \left(C_{AGF} - S_a\right) / \mu - AF \qquad (4.7)$$

$$\beta_1 A_1 {R^*_{AGF}}^{\beta_1 - 1} = \beta_2 B_2 {R^*_{AGF}}^{\beta_2 - 1} + 1/\delta \qquad (4.8)$$

where $\beta_{1,2}$ [17] is

$$\beta_{1,2} = \frac{1}{2} - (\mu - \delta)/\sigma^2 \pm \left[\left((\mu - \sigma)/\sigma^2 - \frac{1}{2}\right) + 2\mu/\sigma^2\right]^{1/2}, \qquad (4.9)$$

Here δ is the convenience yield and given by $\delta = \mu - \alpha$ [18]. C_{AGF} is the sum of the weighted average cost of production of annual crops and production of gum. S_a is the average annual timber benefits based on $S_T e^{-\mu T}$ for an infinite horizon.[19] $A_1 {R^*_{AGF}}^{\beta_1}$ 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 i.e. the right-hand-side of equation 4.7. $R^*_{AGF} / \delta - (C_{AGF} - S_a)/\mu$ 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, however, restart without any additional irreversible costs. B_2 is defined as $B_2 = \frac{(C_{AGF} - S_a)^{1-\beta_2}}{\beta_1 - \beta_2}\left(\frac{\beta_1}{\mu} - \frac{\beta_1 - 1}{\delta}\right)$ (Dixit and Pindyck 1994, pp. 189). Equation 4.8 is another optimality condition, the so-called smooth

---

[17] 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.

[18] We assume that $\delta > 0$ implying $\mu > \alpha$ this assumption is made to ensure the existence of an optimum otherwise waiting is always optimal. The convenience yield is the opportunity cost of not holding the project i.e. only those who own the gum forest can obtain a flow of benefits from harvesting the gum.

[19] The gum arabic timber at the end of the rotation is mainly used as fuel wood or for charcoal production. As the gain from fuel wood is relatively small, in our analysis we assume for simplification that the benefits equal the costs and set $S_a = 0$.

pasting condition that needs to be met at the optimum. Solving equation (4.7) and equation (4.8) for A_1 gives the following equation:

$$(\beta_1 - \beta_2) B_2 (R^*_{AGF})^{\beta_2} + (\beta_1 - 1) R^*_{AGF} / \delta - \beta_1 ((C_{AGF} - S_a) / \mu + AF) = 0 \qquad (4.10)$$

As B_2 is known Equation (4.10) can be solved numerically to give the critical incremental annual value of gum agroforestry R^*_{AGF} 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 idle land into gum agroforestry or by switching the land use system from annual crops to gum agroforestry. Computing the current values of R_{AGF} requires calculating the average annual revenues and costs for the annual crops portfolio, the gum agroforestry and for a pure stand gum forest. In the following section we will describe the data and the calculation procedure in more detail.

4.4 Data and calculation

The data for undertaking the analysis of this chapter were drawn from the field survey that was conducted between January and July 2003 in Kordofan region (West Sudan) and described in Chapter 3. For the purpose of this chapter, however, we only consider the adopters category (a sample of 228 households) as we are interested in analyzing the economic incentives for preservation and expansion of gum forests by farmers who are already planting the gum trees either as agroforest or forest. Furthermore, focus group discussions were held in each of the surveyed villages to obtain information about the minimum and maximum selling prices for the various crops, variable inputs required for the agricultural operations per unit of land, input costs and the cost of planting trees. Using the farm level questionnaire we obtained information regarding the proportion of land allocated to each crop and the yield of the different crops per unit of land. To calculate the gross margin of the annual crops we constructed a portfolio of the three major cash crops in the study area based on the average proportion of land allocated to each, as found in the farm level survey. The portfolio includes a 50 per cent share of sesame, a 20 per cent share of groundnut and a 30 per cent share of roselle.

The farm level survey also included hypothetical questions designed to measure the rate of time preference, μ, for the surveyed farmers in the study area following Holden et al. (1998). Respondents were asked to show their preferences for current PV_i versus future values FV to be obtained in a year time. The rate of time preference for individual i was then computed as $\mu_i = \ln\left(FV / PV_i \right)$. We use the maximum, minimum and mean computed farmers' real rate of time-preference as the discount rate in the different models. The summary statistics of the data used in this chapter are given in Table 4.1 and Table 4.2.

We estimated the age-yield function of gum trees using the Hoerl function $y = vg^{\xi} e^{kg} u$ and following others such as Haworth and Vincent (1977), Wesseler (1997) and Mithöfer et al. (2004). The functional form assumes that yield y in a given year depends on age g. It also includes a multiplicative disturbance term u which implies that the distribution of yield for any given age is log normal. The coefficients v, ξ and k can be estimated using ordinary least squares. Figure 4.2 shows the age-yield function estimated using data from Pearce (1988). Production of gum starts when the tree is six years old; after which a sigmoid growth portion follows up to the age of about 14 years then production starts to decrease. The estimated age-yield function for a gum forest of 400 trees gives a maximum yield of 1400 kg of gum arabic per hectare at age 14. [20]

[20] Appendix A.4.2 shows the costs and benefits for using one hectare of land to produce the crop portfolio in SD. The costs and benefits for the crop portfolio are shown for one year. Calculations are given for the expected values for the uncertain parameters: rate of time preference 0.33 and portfolio price 166.05 SD. SD refers to Sudanese Dinar. 1 USD was equivalent to 250 SD during the survey period. Appendix A.4.3 shows the costs and benefits for one hectare of gum forest with 400 trees in Sudanese Dinar (SD). Calculations are given for the expected values of the uncertain parameters: rate of time preference 0.30 and gum price 89.87 SD.

Table 4.1. Summary statistics of land allocation, portfolio ratio, annual crop yield, average crop farm gate price and rate of time preference.

	Minimum	Maximum	Mean	Standard deviation
Land allocation for the different cash crops				
Total farm size in ha (N=228)	4.20	153.20	53.63	36.93
Size of land allocated to sesame cultivation in ha (N=228)	0.00	18.30	2.70	2.77
Size of land allocated to groundnut cultivation in ha (N=228)	0.00	29.00	1.10	2.39
Size of land allocated to roselle cultivation in ha (N=228)	0.00	7.30	1.51	1.23
Total size of land under the 3 crops i.e. portfolio area in ha (N=228)	0.60	32.70	5.32	3.95
Portfolio ratio				
Ratio of sesame area in the portfolio (N=228)	0.00	1.00	0.499	0.28
Ratio of groundnut area in the portfolio (N=228)	0.00	0.89	0.20	0.24
Ratio of roselle area in the portfolio (N=228)	0.00	0.69	0.299	0.18
Annual crop yield				
Sesame yield in kg/ha (N=228)	0.00	1937.14	680.633	493.70
Groundnut yield in kg/ha (N=228)	0.00	2860.00	1200.49	844.12
Roselle yield in kg/ha (N=228)	0.00	1828.57	600.44	465.99
Farm gate price for the different crops (SD/Kg)[1]				
Sesame	80	170	NA	NA
Groundnut	50	125	NA	NA
Roselle	100	300	NA	NA
Portfolio	80	200	NA	NA
Gum[2]	65	140	NA	NA
Rate of time preference[3]				
Present value equivalent in SD (N=92)	5886	8270	7144.18	754.95
Rate of time preference (N=92)	0.19	0.53	0.34	0.11

Source: Based on survey data (2003).

[1] The farm gate prices represent the average maximum price at which farmers sell their crops early in the season and the average minimum price at which farmers sell their crops late in the season. Data on prices are based on the interview of key informants at the village level. The average minimum and maximum price is calculated from the values reported by the 20 surveyed villages.

[2] The modal price for gum (the most common selling price for gum among the surveyed villages based on key informants' interview) is 70 SD/kg.

[3] To measure the rate of time preference farmers were asked the following question: if you have the choice between an amount of money today (PV) and 10000 SD (FV) to be received in one year with certainty, how large will the amount to be received today (PV) have to be for you to prefer it instead of the FV in one year?. The response rate to the hypothetical questions for measuring the rate of time preference among the adopters category is 40%, therefore the sample size included in the above statistics is 92 respondents.

Table 4.2. Labor requirements for crop production per hectare of land in hours and the cost of labor man-days in SD[1].

	Labor hours required per operation for one hectare of the crop					Labor cost (SD/man-days)
Agricultural operation/crop	Sesame	Groundnut	Roselle	Portfolio	Gum arabic	
Land clearance and preparation	32	32	32	32	NA	400
Seeding and planting	28	56	21	32	NA	300
First weeding	63	84	63	67	NA	300
Second weeding	24	49	21	28	NA	300
Early harvesting	98	84	70	87	NA	1000
Late harvesting	63	77	56	64	NA	1000
Other labor requirements (post-harvest cleaning, seed separation…Etc.)	18	28	14	19	NA	400
Gum tapping	NA	NA	NA	NA	52	300
Gum collection	NA	NA	NA	NA	77	300
Total labor required (hours/ha)	326	410	277	328	129	

Source: Based on survey data (2003).

[1] Data are based on the interview of key informants at the village level. One labor man-day is equal to 7 working hours.

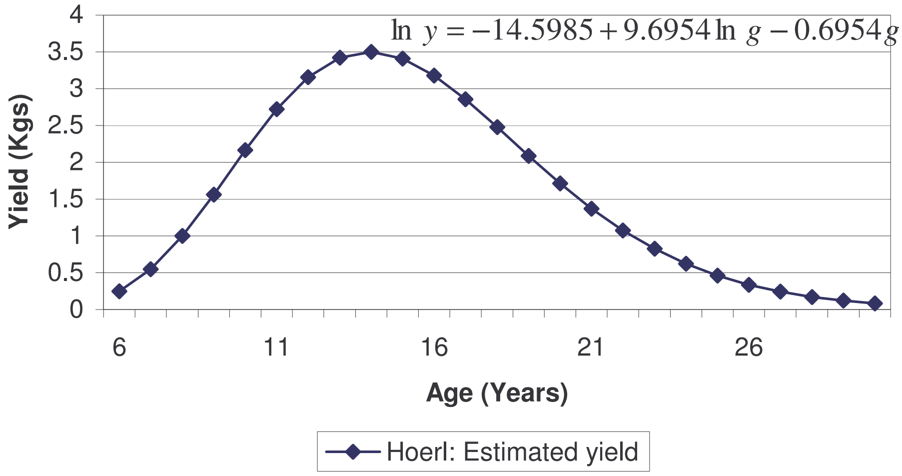

Figure 4.2 Age yield function of gum arabic tree

The average value of one hectare of gum agroforestry V_{AGF} for one production cycle over an infinite time horizon is calculated from the results of a Monte Carlo simulation and following Wesseler (1997). The

Monte Carlo simulation approach adopted involves making probability distribution assumptions for the parameters of the model. In our analysis we only considered uncertainty with regard to gum prices, agricultural portfolio prices and farmers' rate of time preference. Gum prices are modeled as a triangular distribution with minimum, maximum and modal farm gate prices of 65, 140 and 70 SD/kg for the 2002/03 season. Portfolio prices are assumed to follow a uniform distribution between 80 and 200 SD/Kg, which are the minimum and maximum prices farmers received based on the survey data. The private rate of time preference is also considered to be uniformly distributed between 0.19 and 0.53, which are the minimum and maximum farmers' rate of time preference obtained from the survey. Then a multiple simulation (1000 iterations) of the outcomes of the model are generated by randomly sampling the uncertain parameters. Using the Monte Carlo simulation results we then calculate the average annuity of revenues and costs from agriculture and from a pure stand of gum forest trees. Figure 4.3 sketches the schematic representation of the Monte Carlo simulation.

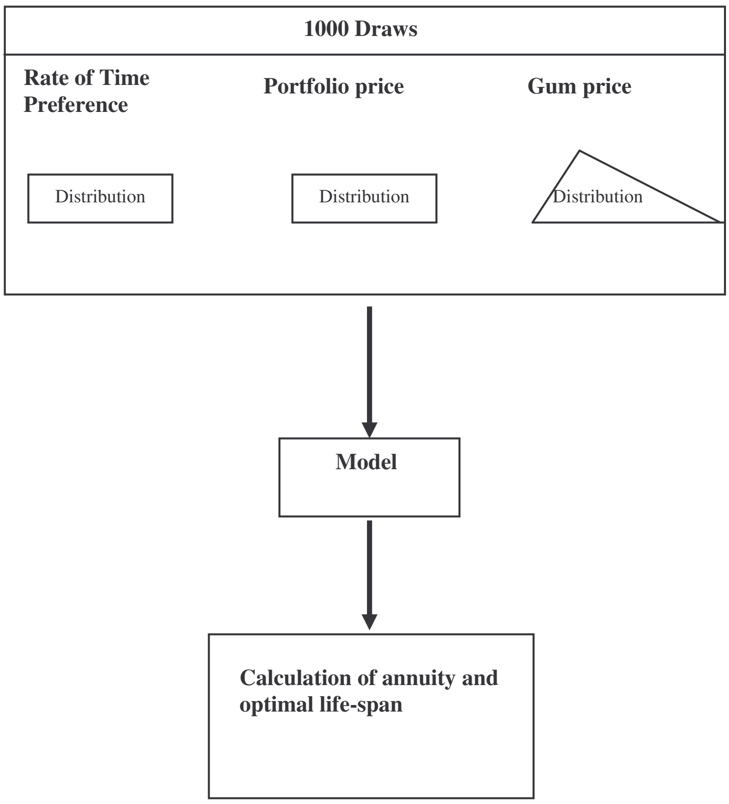

Figure 4.3 Schematic representation of the Monte-Carlo simulation

As mentioned before we assume that the annual incremental revenues from gum agroforestry R_{AGF} follow a geometric Brownian motion. Unfortunately, only time series data for prices and amounts of gum arabic and other agricultural crops traded at El Obeid auction market are available. This does not allow us to calculate a time series for R_{AGF}. Instead, we estimate the drift and variance rates of gum agroforestry revenues from the real prices and real total gross revenue time series data of the crop portfolio and gum arabic. We then use the different variance and drift rates to calculate the critical $R^{*}{}_{AGF}$ following Campbell et al. (1997, Chapter 9).

4.5 Results and discussion

The results of the Monte-Carlo simulation are presented in Table 4.3. The three columns show the expected annuities for using one hectare of land either for agriculture, for gum arabic agroforestry or pure stand of gum arabic trees. Table 4.4 shows the estimated drift and variance rates of gum arabic, the three major cash crops considered in the portfolio, and the weighted average for the portfolio. The various drift and variance rates were calculated using two data sources for agricultural crops (prices and gross revenues of crops traded at El Obeid auction) and three for gum arabic (prices and gross revenues of gum arabic traded at El Obeid auction and gum arabic floor price). The drift and variance rates are used to calculate the critical values for establishing gum arabic agroforest or a forest system.

Table 4.5 reports the critical incremental annual value of gum agroforestry R^{*}_{AGF} needed for switching land use either to gum arabic agroforest or forest system calculated using different drift rates, variance rates and discount rates μ (minimum, mean and maximum). These values can be compared with the expected annuities for gum agroforest reported in Table 4.3.

Table 4.3. Expected annuities for agriculture, gum arabic agroforestry, and gum arabic forestry for one hectare of land in SD#. (Maximum rate of time preference 0.53 and minimum 0.19).

	Agriculture	Gum arabic agroforest	Gum arabic forest
Annuity reversible benefits	107409	76412	5270
Annuity reversible cost	62600	43573	555
Annuity reversible net-benefits	44809	32839	4716
Annuity irreversible afforestation costs	0	360	360

SD refers to Sudanese Dinar – 1 USD was equivalent to 250 SD during the survey period. Results were simulated using maximum rate of time preference 0.53 and minimum 0.19.

4.5.1 Abandoning gum arabic production

The results in Table 4.3 show that agriculture currently provides the highest expected economic benefits. The average annual reversible net-benefits from agriculture are about 27 per cent higher than from the gum arabic agroforestry and about 90 per cent higher than from the gum arabic forests. We mentioned earlier that gum arabic does not directly compete with agriculture but with off-farm labor opportunities during the off-season. The observed cultivation of gum arabic can therefore be explained by the non-overlapping labor requirement and under such situation farmers might abandon gum production while leaving the forest land idle if they find better off-farm opportunities. The economy studied here is traditional and stagnant with limited off-farm labor opportunities. Based on our results the forest will be left behind 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 will have to increase by about nine to ten times (5270/555). Therefore, diversification of the economy and increasing off-farm and non-agricultural employment in relatively larger villages in the gum belt zone can result in the abandonment of the gum forest and reduce the deforestation pressure. At the same time it can have an adverse effect on gum production and the Sudanese exports of gum arabic. As the increase in off-farm income has to be substantial, it can be expected that abandoning of gum arabic production may not happen in the near future.

Table 4.4. 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 El Obeid 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).

The current situation of agricultural land abundance and labor scarcity prohibits the expansion of agricultural production by deforesting gum arabic trees. Because of this, the conversion of gum forests to agricultural production only becomes a problem if the population density in Sudan would increase and the labor constraint is relaxed.

Table 4.5. Critical values for entering gum arabic production for a selection of various drift (α) and variance (σ) rates for the geometric Brownian motion and using different discount rates (μ).

	Minimum discount rate $(\mu = 0.19)$	Mean discount rate $(\mu = 0.36)$	Maximum discount rate $(\mu = 0.53)$
	Drift and variance rate based on real total gum revenue		
Critical values			
Gum agroforestry (R_{AGF}^{*})	58336	58918	59440
Gum forest (R_{GF}^{*})	3747	4014	4269
	Drift and variance rate based on real gum price		
Critical values			
Gum agroforestry (R_{AGF}^{*})	48204	48775	49215
Gum forest (R_{GF}^{*})	1306	1497	1678
	Drift and variance rate based on real floor price for gum		
Critical values			
Gum agroforestry (R_{AGF}^{*})	48235	48774	49194
Gum forest (R_{GF}^{*})	1678	1312	1497
	Drift and variance rate based on real total revenue of the portfolio		
Critical values			
Gum agroforestry (R_{AGF}^{*})	53418	54085	54643
Gum forest (R_{GF}^{*})	2407	2660	2896
	Drift and variance rate based on real price of the portfolio		
Critical values			
Gum agroforestry (R_{AGF}^{*})	49556	50237	50764
Gum forest (R_{GF}^{*})	1558	1780	1985

4.5.2 Expanding gum arabic production

The second research question we consider in our analysis is when can we expect farmers to expand the gum arabic forest? There are two options that we need to consider. The first option is converting idle land with zero opportunity costs and the second is to convert agricultural land into land for gum arabic production. Both types of land can either be converted to an agroforestry system, including agricultural production during the initial years, or a pure stand of gum trees without agricultural production.

4.5.2.1 Converting idle land to a gum arabic forest

Table 4.5 shows the critical incremental annual values for gum agroforestry R^*_{AGF} and gum forestry R^*_{AGF} calculated based on a selection of drift rates, α, variance rates, σ, and using different discount rates μ. The critical incremental annual values for gum agroforestry range from about 48200 to 59500 Sudanese Dinar (SD) per hectare, whereas the critical values for gum forestry range from 1300 to 4200 SD per hectare. The current incremental average annual benefits of gum arabic agroforests and the forest system, as shown in Table 4.3, are 76412 and 5270 SD per hectare respectively. Since the opportunity cost of idle land is zero both values are above the calculated critical values reported in Table 4.5. Given this, we would expect farmers to expand gum arabic production; however, this is not seen in practice. 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 an individual farmer, as marginal costs of labor per farmer are difficult to observe. It is reasonable that the marginal opportunity cost of labor for some farmers might be 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, however, may force families to abandon their farms and move to a different place. This most likely will discourage long-term investments such as the decision to plant trees.

4.5.2.2 Converting agricultural land to a gum arabic forest

The current incremental average annual benefits for converting agricultural land to a gum arabic forest or a gum arabic agroforest are about 5270 – 44809 = - 39539 or 76412 – 44809 = 31603 respectively. The difference between the two values can simply be explained by the higher expected benefits from agriculture during the first four years of the bush-fallow cycle. Both values are below the calculated critical values reported in Table 4.5. Currently, we can not expect farmers to convert permanent agricultural 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 4.5 we observe that the average annual benefits from the gum arabic agroforest have to increase by at least 53 per cent. This is equivalent to an increase in the prices of gum arabic of at least about 315 per cent (48204-31603)/5270. Even much higher price increase is needed to induce a shift to gum arabic forests, i.e. the price for gum arabic has to increase by at least 775 per cent. These results indicate that even if the constraints on the labor market will be reduced and political uncertainty is resolved, conversion of agricultural land to gum arabic forests is very unlikely to happen in the near future without any additional support to farmers in the form of improving the price incentive.

The farm gate price of gum arabic results from a complex combination of domestic and international factors. The marketing of gum arabic is controlled by the Gum Arabic Company (GAC), who has monopoly over raw gum exports from Sudan and also plays an important role in the local marketing of gum arabic[21]. The GAC sets not only the international price for gum arabic because of its large market share but also announces and is assumed to supervise a fixed minimum price at the gum auction markets as a mechanism to ensure that producers are adequately remunerated.[22]

One policy option for increasing the farm gate price is to increase the export price level. Given the recent changes in the international gum

---

[21] As a result of pressure and belief that the GAC monopolistic arrangement should be de-regulated to allow free entry into the industry, the system has currently been partially liberalized and the export of semi-processed gum by private companies is now permitted by the Sudanese government.

[22] At the theoretical level the assumption of a trader paying the minimum adequate price if he could pay less is not realistic. Driven by profit maximization motives traders will always attempt to pay a lower price.

market and the decline in Sudan market share (Macrae and Merlin 2002), however, increasing the gum export price is likely to be difficult to achieve. Even if an increase in export price level is feasible it would be difficult to sustain; it is very likely that international demand will decrease as a response to higher prices and further development of gum manufactured substitutes will be triggered. A high and abrupt increase in producer price, on the other hand, may encourage over-tapping. Over-tapping and the concomitant death of the trees in the process took place in the 1970s when the GAC increased the domestic market price considerably (by 300% in nominal terms in a period of 2 years-1973-1974 season) in an attempt to introduce incentives for boosting gum production after the Sahel drought (Larson and Bromley 1991). Stabilization of both domestic and international market prices is therefore important for sustaining the gum forest as well as Sudanese revenue from gum export.

Another policy instrument that can give farmers long term confidence and the incentive necessary to induce tree planting and investment is to adopt measures that will remove the distortions in the domestic pricing and marketing of gum. Two features of the domestic market prevent producers from receiving a higher remuneration for their production. These are high levels of profits margins and taxes charged by the GAC and the Sudanese government and the predominance of informal money lending institutions at the village level.[23]

Regarding the former (excessive level of profit and taxation by the government) despite the fact that the GAC is under majority private ownership (70% of the company share are owned by individuals and the gum producers association), over 20% of the FOB value of gum arabic currently ends up in the public treasury via various types of taxes, fees and export duties. [24] The farm gate prices, depending on the extent to

[23] The informal money lending institution is known locally as the *Sheil* system whereby village merchants or intermediate traders provide loans to farmers in anticipation of their harvest. Credit is paid in the form of consumer goods or in cash. Because farmers who resort to the *sheil* system generally have low bargaining power they sell their future harvest at lower prices than what they could obtain if they sell their product directly to the merchants after harvest.

[24] This figure is calculated based on information provided by the GAC annual reports and it does not include GAC profit, which accounts for 9% of the FOB price.

which farmers are able to sell at the official announced prices, may be as low as 21% of the FOB value.[25] Accordingly, improving the returns to producers could be feasible in case policy makers are willing to reduce the level of profits and taxation that end up in the GAC or the public treasury. Nevertheless, the fact that the Sudanese gum market has been de-regulated to some extent might have some positive effect on producers' future price levels.

The second feature that distorts the domestic gum market is the predominance of informal credit institution i.e. the *sheil* system. It is assumed that gum producers sell their product at the local auction markets in order to receive the officially announced minimum price. Most producers, however, are often prevented from selling their product at the auctions due to transport problems. Only 6% of the interviewed farmers sold their gum at the auctions market, 86% sold their gum to the village merchants (who in most cases are the money lenders themselves) and 64% mentioned that they sold their gum at a price lower than the announced floor price. Formal credit facilities within the agricultural sector in Sudan are extended only to farmers who are able to provide a guarantee to the bank, mainly in the form of stored products and land titles (IEED/IES 1990). Because small farmers are seldom able to provide guarantees, they are greatly dependent on the *sheil* system. This dependency acts as a constraint and prevents farmers from receiving better prices for their gum harvest. Therefore, promoting a mechanism that will reduce the effect of the *sheil* system (e.g. extending formal credit to gum farmers through cooperative schemes) can remove the distortions at the local credit market and help in providing the producer with the right signal.

---

[25] In 2003 (survey period), the announced floor price was 3500 SD/kantar, and the export FOB price was 1480 USD/MT. Using the prevailing exchange rate during the period, which is one USD is equivalent to 250 SD and as one Kantar is equivalent to 45 Kgs, one can calculate that the floor price represents 21.02% of the FOB value. Macrae and Merlin (2002) report that producers in Sudan are estimated to receive one fifth of the final gum export price.

4.6 Sensitivity analysis and the choice of the discount rate

In a theoretical economy with a perfectly functioning market and if unlimited borrowing and saving at a single riskless rate of interest is possible, individuals optimally would discount future consumption and production at the market interest rate (Fisher 1930). In the real world, however, and in particular in rural areas of developing countries, markets are far from perfect. As a result individuals' discount rates may be quite different from the observed interest rates.

Market imperfections are particularly common in relation to land resources, labor, credit, risk and insurance (De Janvry et al. 1991 and Hoff et al. 1993). Of particular interest in this chapter is the market imperfection with regard to credit as there is wide spread empirical evidence that small farmers in most developing countries face credit constraints (Holden et al. 1998). For example Hoff et al. (1993) report that only 5 per cent of farmers in Africa and 15 per cent of farmers in Asia and Latin America have had access to formal credit. Moreover, informal credit markets in rural areas of developing countries are characterized by very high interest rate which may be explained by the lender's risk hypothesis (Bottomley 1975) or his/her monopoly power (Bottomley 1964). The majority of small farmers in the rural areas of Sudan resort to the informal credit institutions (*Sheil* system) and the implicit rate of interest differs according to location and time of borrowing but reported to be extremely high, perhaps in the order of 50 % to 75 % (Kevane 1993).

High interest rates found in the informal credit market in the rural areas of Sudan provide an indicator as to why the surveyed farmers tended to show a high rate of time preference (maximum 53%). Furthermore, empirical evidence from other studies also suggests that the poor tend to have a high rate of time preference; Pender (1996) estimates high rates of time preference (over 50 %) through an experimental game for a small sample of poor farmers in India. Using hypothetical questions to estimate the rate of time preference of farmers in Indonesia, Zambia and Ethiopia Holden et al. (1998) find high rates of time preference among the surveyed farmers (an average rate of time preference of 93 % in Indonesia, 1.04 % in Zambia and 52 % in Ethiopia). Based on their study Holden et al. (1998) suggest that poverty and/or liquidity scarcity leads to high rate of time preference.

While the above discussion supports the high discount rate we used in our analysis, nevertheless, we undertook sensitivity analysis in order to check the robustness of our results with respect to the discount rate. We calculated the expected average annual net-benefits (annuities) from gum agroforest, gum forest and permanent agriculture using maximum discount rate of 15 % and minimum of 10 %. Results for the expected annuities are shown in Table 4.6 and results for the critical value of gum agroforestry are shown in Table 4.7.

The results in Table 4.6 show the same pattern obtained with a high discount rate. The average annual reversible net-benefits from agriculture are about 29 per cent higher than from the gum arabic agroforestry and about 48 per cent higher than from the gum arabic forests. The current incremental average annual benefits of gum arabic agroforests and the forest system, as shown in Table 4.6, are 55343 and 24620 SD per hectare respectively. Since the opportunity cost of idle land is zero both values are above the calculated critical values reported in Table 4.7 implying that conversion of idle land to gum agroforest or forest should be expected. The current incremental average annual benefits for converting agriculture land to a gum arabic forest (24620-43454 = -18834) or a gum arabic agroforest (43454-55343 = 11889), however, are below the calculated critical values reported in Table 4.7. Results using a low discount rate also show that an increase in the prices of gum arabic of at least about 65 per cent, i.e. (27789-11889)/24620, is needed to convert an agricultural land to gum agroforestry. A higher price increase (81 per cent) is needed to induce a shift to gum arabic forests.

The results obtained using high discount rate and low discount rate, however, were counter intuitive with regard to the expected annuities for permanent agriculture and gum agroforest as lower values are obtained when a low discount rate is used. The lower average annuity values obtained for agricultural are a result of negative net present values when portfolio prices are low. The counter intuitive result for gum agroforestry can be explained by the nature of the benefit stream of gum agrofrestry, as high returns are obtained during the first four years of annual crops, followed by a period of no benefits during fallow until harvesting of gum starts.

Table 4.6. Expected annuities for agriculture, gum arabic agroforestry, and gum arabic forestry for one hectare of land in SD#. (Maximum rate of time preference 0.15 and minimum 0.10).

	Agriculture	Gum arabic agroforest	Gum arabic forest
Annuity reversible benefits	1060540	55343	24620
Annuity reversible cost	62600	24582	2045
Annuity reversible net-benefits	43454	30761	22575
Annuity irreversible afforestation costs	0	125	125

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

4.7 Conclusion

This chapter focuses on the analysis of the economic incentives for entry and exit in gum arabic agroforestry (forestry) systems in Sudan using a real options approach. Conversions of land use system from gum agroforestry (forest) to a continuous annual cropping system and vice versa imply a quasi-irreversible nature of land allocation. In addition the benefits and opportunity costs of such actions are uncertain, therefore, the decision to deforest or to plant gum trees generates an option value.

We show that agriculture currently provides higher expected economic benefits than the gum agroforestry (forestry) system. However, in Sudan land is not a relatively scarce resource, whereas labor is a relatively scarce factor. Gum arabic is produced during the dry season and it does not compete with other agricultural crops for labor demand. Because of the aforementioned reasons farmers might abandon gum production, leave the tree on the land and pursue off-farm income. Our results show that an increase of about nine to ten times on the average opportunity costs of labor would be needed in order for farmers to abandon gum arabic production, neglect the gum forests and start working off-farm.

Table 4.7. Critical values for entering gum arabic production for a selection of various drift (α) and variance (σ) rates for the geometric Brownian motion and using different discount rates (μ).

	Minimum discount rate $(\mu = 0.1)$	Mean discount rate $(\mu = 0.125)$	Maximum discount rate $(\mu = 0.15)$
	Drift and variance rate based on real total gum revenue		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	35767	35847	35925
Gum forest $(R_{GF}{}^{*})$	6351	6396	6441
	Drift and variance rate based on real gum price		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	27789	27890	27982
Gum forest $(R_{GF}{}^{*})$	1314	1302	1292
	Drift and variance rate based on real floor price for gum		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	27837	27930	28015
Gum forest $(R_{GF}{}^{*})$	1305	1294	1286
	Drift and variance rate based on real total revenue of the portfolio		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	31821	31920	32016
Gum forest $(R_{GF}{}^{*})$	4625	4674	4721
	Drift and variance rate based on real price of the portfolio		
Critical values			
Gum agroforestry $(R_{AGF}{}^{*})$	28772	28890	28999
Gum forest $(R_{GF}{}^{*})$	1133	1120	1109

As for the entry decision or the expansion of gum forest we analyzed two options: converting idle land into gum forest and converting agricultural land into gum forest. 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 explanations for the observed non-conversion of idle land into gum forest: 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 into a 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 315 per cent and 775 percent is 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 forests is unlikely to happen in the near future without an increase in the gum price .

4.8 Summary and caveats

In this chapter we used a system modeling approach to analyze the economic incentive needed for an average gum farmer to conserve the existing gum forest or plant gum trees. We did not test empirically how the model relates to the behavior of farmers in reality but we can link our analysis to our findings in the previous chapter. In Chapter 3 we have examined the reasons behind the disadoption of gum production and we have discussed the mechanism behind disadoption of gum production in relation to the disadoption of gum agroforestry as shown in Figure 3.2. In our survey sample we found that 81 per cent of those who disadopted gum production are partial disadopters of gum agroforestry (i.e. they abandoned gum production but still maintained the tree). This supports our modeling approach that farmers might abandon gum production but not necessarily deforest the tree. This occurs mainly because land is not scarce resource but labor is the relatively scarce factor.

In Chapter 3 we observed that farmers disadopt (abandon) gum production, while our analysis and results here suggest low incentive for abandonment for an *average farmer*. We mentioned earlier labor has been priced in our model at average costs over all farmers and not at marginal costs of an individual farmer. Therefore, not necessarily no abandonment will happen as the marginal opportunity cost of labor for some farmers might be higher than the one we used here.

Moreover, we might have underestimated the benefits from gum agroforest as we did not take full account of all the environmental and social benefits of the tree. A major benefit of the tree which is widely mentioned in the literature and acknowledge by farmers is nitrogen fixation and improving the soil fertility. This has been partly captured in our analysis as the data on crop yield are obtained from a cross section of farmers who are at different stage of the bush fallow cycle. Nevertheless, the unavailability of scientific data that quantifies the nitrogen fixing ability of the tree as well its other environmental benefits (soil stabilization and desertification control) did not allow us to take full account of these benefits in our analysis.

Appendix A.4.1. The percentage of farmers practicing the different gum cultivation systems.

Gum cultivation system (s)	No of farmers practicing the system (s)	Percent from the total sample (228 farmers)
Temporal agroforestry (bush-fallow)	108	47
Temporal agroforestry + spatial agroforestry	48	21
Temporal agroforestry + pure stand gum forest	15	7
Total number of farmers practicing temporal agroforestry	171	75
Spatial agroforestry	16	7
Spatial agroforestry + pure stand gum forest	4	2
Total number of farmers practicing spatial agroforestry	68	30
Pure stand gum forest	37	16

Source: Based on survey data (2003)

Appendix A.4.2. Costs and benefits for one hectare of crop portfolios.

Annual crops portfolio	
Portfolio yield (kg/ha)	760
Portfolio revenue (SD/ha/year)	86249
Portfolio cost	
Portfolio seed cost (SD/ha/year)	1000
Land clearance cost (SD/ha/year)	1900
Seeding cost (SD/ha/year)	1400
First weeding cost (SD/ha/year)	2800
Second weeding cost (SD/ha/year)	1200
Harvesting cost (SD/ha/year)	22000
Cost of coppicing the shoot (SD/ha/year)	1000
Portfolio labor cost (SD/ha/year)	30300
Portfolio other variable costs (SD/ha/year)	1000
Total portfolio cost (SD/ha/year)	62600
Annuity agriculture Benefits	126194
Annuity agriculture costs	62600
Annuity agriculture net benefit	63594

Source: Based on survey data (2003)

Appendix A.4.3. Costs and benefits for one hectare of gum forest with 400 trees.

Year	0	1	2	.....	6	7	.....	9	10	...	28	29	30	31
Gum forest														
Planted trees/ha	0	400	400		400	400		400	400		400	400	400	400
Gum yield (kgs/tree)	0	0	0		0.003	0.02		0.25	0.55		0.46	0.34	0.24	0.17
Gum Yield (kgs/ha)	0	0	0		1	8		99	220		184	134	97	69
Gum revenue in SD/ha/year	0	0	0		0	0*		8873	19731		16558	12082	8691	6169
Gum production costs														
Labor tapping cost (SD/ha/year)	0	0	0		0	0		2200	2200		2200	2200	2200	2200
Labor collection cost (SD/ha/year)	0	0	0		0	0		3200	3200		3200	3200	3200	3200
Cost for rejuvenating the trees (SD/ha/year)	0	0	0		0	0		0	0		0	0	0	0
Total cost (SD/ha/year)	0	0	0		0	0		5400	5400		5400	5400	5400	5400
Total cost discounted (SD/ha/year)	0	0	0		0	0		504	387		3.4	2.6	1.9	1.5
Gum revenue -total cost (Gross margin from gum forest)	0	0	0		0	0								
Discounted gross margin from the gum forest (SD)	0	0	0		0	0		324	1027		6.9	3.2	1.2	0.2
Accumulated discounted gross margin from gum forest (SD)	0	0	0		0	0		324	1350		18084.7	18087.8	18089.1	18089.3
Annuity gum forest (SD)	0	0	0		0	0		108	439		5458.21	5458.39	5458.15	5457.75
Maximum annuity gum forest (SD)	5458													
NPV gum forest (SD)	18088													
Annual discounted cost for gum forest (SD)	2166													
Average annual discounted cost for gum forest (SD)	654													
Optimal life span	29													

Source: Based on survey data (2003).

*Note that there is yield in year 6 and 7, but the value of the revenue is zero as gum harvesting starts when revenue exceeds variable costs.

CHAPTER 5

COMPETITION IN THE GUM MARKET: POLICY IMPLICATIONS TO SUDAN

Gum arabic is mainly produced from two Acacias that are found in the gum belt of Sub-Saharan Africa. These are *Acacia senegal* that produces high quality gum and *Acacia seyal* that produces low quality gum. In recent years the gum market structure has changed and Sudan lost its near monopoly position. In order to understand the best strategy for Sudan to pursue we model the competition between Sudan, Chad and Nigeria in the export of high and low quality gum arabic using a von Stackelberg model with interdependent markets. Whereas Sudan (the leader) has a comparative cost advantage in the export of high quality gum, Chad and Nigeria (the followers) have a cost advantage in the export of low quality gum. We determine the market equilibrium outcomes and study the impact of subsidies to promote either the high or low quality gum. Our results suggest that the three countries are better off if they adopt an export coordination strategy and if Sudan makes side payments to Chad and Nigeria.

Key words: Sub-Sahara; Gum arabic; Oligopoly; Interdependent markets; Stackelberg; International subsidies.

5.1 Introduction

Gum arabic or gum Acacias[26] trade is a market of vital importance to Sub-Saharan African countries' economy and environment. Gum export represents a source of foreign exchange earning and gum harvest is an additional income source for the poor farming population in the Sub-Saharan area. Moreover, Acacia trees also contribute to protecting the soil against erosion, enriching the soil by improving its water and nutrient levels, and thereby help to combat desertification, which is a major environmental problem in the region. Gum arabic is mainly produced from two Acacias that are found to a varying intensity in the gum belt of Sub-Saharan Africa. These are: *Acacia senegal* that produces hard gum and *Acacia seyal* that produces friable gum. Hard gum is known as *hashab* in Sudan, *Kitir* in Chad, first quality in Mali and grade 1 in Nigeria and friable gum is known as *talha* in Sudan and Chad, second quality in Mali and grade 2 in Nigeria.

At present the world market is divided more or less equally between hard and friable gum, nonetheless, friable gum is considered to have a relatively low quality and is only used for a price advantage or when supplies of hard gum are low (Macrae and Merlin 2002). It is worth mentioning that trade in friable gum is relatively new and more recently increasing whereas, trade in hard gum dates back to the Pharaoh's civilization and was used by the ancient Egyptians for the preparation of ink, water colors and dyes.

Gum arabic generally has no or few uses in the producing countries but is demanded on the international market mainly by the pharmaceutical and food industry. The main uses of gum arabic are based upon its properties of emulsification, adhesiveness, thickening, binding and stabilization. The precise chemical and molecular structure of gum arabic and as a result the functional properties and uses to which gum arabic can be put and its commercial value differ according to the botanical origin of the gum i.e. *Acacia senegal* or *Acacia seyal* (FAO 1995). Friable

[26] The term gum arabic is often used the gum from any Acacia species and is sometimes referred to as gum Acacias.

gum has inferior emulsifying properties and sometimes forms dark solutions in water due to the presence of tannins and others impurities (*ibid*).

The market for gum arabic is dominated by few countries in terms of exports, re-exports and imports. The European Union is the biggest importer of gum arabic (over 70 percent) and within the EU, France, UK and Germany are the major re-exporters of processed gum. The United States is the second major importer. Figure 5.1 shows gum imports by the EU and USA over the period 1990-2003.[27] An upward trend in imports can be observed and the market is projected to grow at an annual rate of 5% reaching a level of 90,000 Metric Tons by the year 2010 (Macrae and Merlin 2002).

Export of gum arabic is almost exclusively of African origin and mainly produced in the Nile River basin (Sudan, Ethiopia), the Lake Chad region (Chad, Nigeria, Cameroon, Niger, Central African Republic) and the Senegal River basin (Senegal, Mali, Mauritania). Historically Sudan has dominated world production and trade of gum arabic. During the period 1925-85 exports from Sudan accounted for around 80 percent of world exports (Macrae and Merlin 2002).

This domination, however, has become less marked in recent years. Years of the Sahel drought (1970s-1980s) have led to erratic and low supplies of gum from Sudan and a huge rise in price that have choked off the demand for gum arabic. As a result many clients turned to manufactured substitutes such as modified starches and celluloses and many importers began an effort to expand the available sources of gum arabic in order to build a reliable and affordable supply. The technical properties of a sample of gum arabic from other African countries was assessed and the quality of gum arabic from Chad and Nigeria is found to be good and some importing companies started to be active in supporting the promotion of gum development in these countries (Coppen 1999).

[27] Data is drawn from two sources, Coppen 1999 and COMTRADE database. Therefore, in order to give self-consistent time-series data the import figures refer to the imports of 11 EU members (France, UK, Germany, Italy, Denmark, Belgium, Netherlands, Ireland, Spain, Greece and Portugal).

In the meantime a technique was developed to decolorize the naturally dark friable gum without damaging its attractive natural properties (ISC undated). This development has opened new markets for friable gum in food and pharmaceutical applications which require colorless solutions. Market studies on gum arabic suggest that the demand for friable gum has increased in recent years and is expected to increase further following the recent specification of gum arabic by the joint FAO/WHO Expert Committee on Food Additives (JECFA) which consolidates the position of gum from *Acacia seyal* as a food additive (JECFA 1999). The new definition of gum arabic according to the JECFA is the dried exudates from the trunk and branches of *Acacia senegal* or *Acacia seyal*, of the family leguminosae. The old definition confines gum arabic to the exudates of *Acacia senegal* and closely related species.

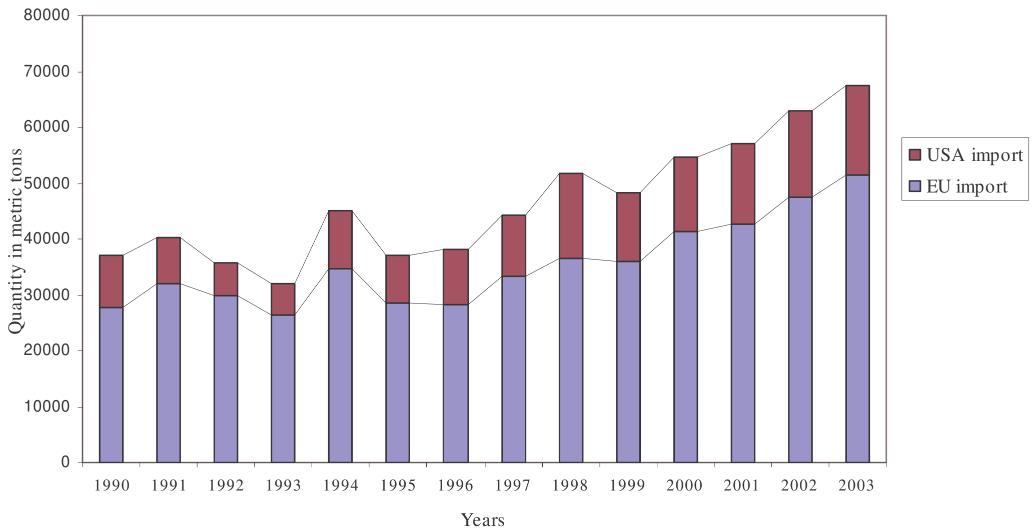

Figure 5.1 Imports of gum arabic (EU and USA 1990-2003)

Source of data: Coppen (1999) and United Nations Statistics Division, *COMTRADE* database

The increased demand for friable gum further opened the way for other African exporters that are specialized mostly in the export of friable (low quality) gum and Sudan currently faces a growing competition from Chad and Nigeria. Figure 5.2 shows gum export from Sudan, Chad and Nigeria during the period 1990-2003 and the percentage share of Sudan on the world export market for gum. It can be seen that Chad's exports have increased since 1993 and started to decline again since 2001.

Current international interest in gum arabic can be gauged from the fact that the world market for gum arabic was the subject of several recent commercial reviews (Parker 2005). In light of the increased demand for gum arabic and the instability in the gum arabic supply which is caused by natural calamities along with political unrest in the producing countries[28] a number of governments, entrepreneurs and international gum stakeholders are embarking on supporting the promotion of gum production in sub-Saharan Africa.

The main objective is to diversify the supply base and stabilize prices of gum arabic other complimentary objectives stated by donors to support development assistance and promotion of gum production in the Sahel include among others desertification control, local employment and increased income for farmers as well as increased foreign exchange earning for the producing countries. Acacia tree is important for the livelihoods of many rural populations and its incorporation into farming systems will diversify agriculture, enhance income generation and contribute to land improvement, replenish soil fertility and mitigate desertification (ACACIAGUM 2005).

In addition reducing dependence on Sudanese gum is also on the agenda of some donor organizations not only because of the natural calamities and the political upheavals that adversely affects gum production in Sudan but also because of Sudan's political link to terror. Macrae and Merlin (2002 pp. 11) report:

"As a result of the bombing of the World Trade Centre in September 2001, the United States have put into action a program designed to reduce their dependence on the Sudan, considered to be too close to terrorism for comfort. As regard gum arabic, Nigeria has been singled out as a possible replacement for the Sudan and currently the USAID is in the process of

[28] This is particularly in the case of Sudan as the current war in Darfur one of the major producing region of gum arabic in west Sudan has adversely impacted the collection and exportation of gum arabic (Purcell 2005).

mounting an important program of assistance to the gum arabic sector in this country"

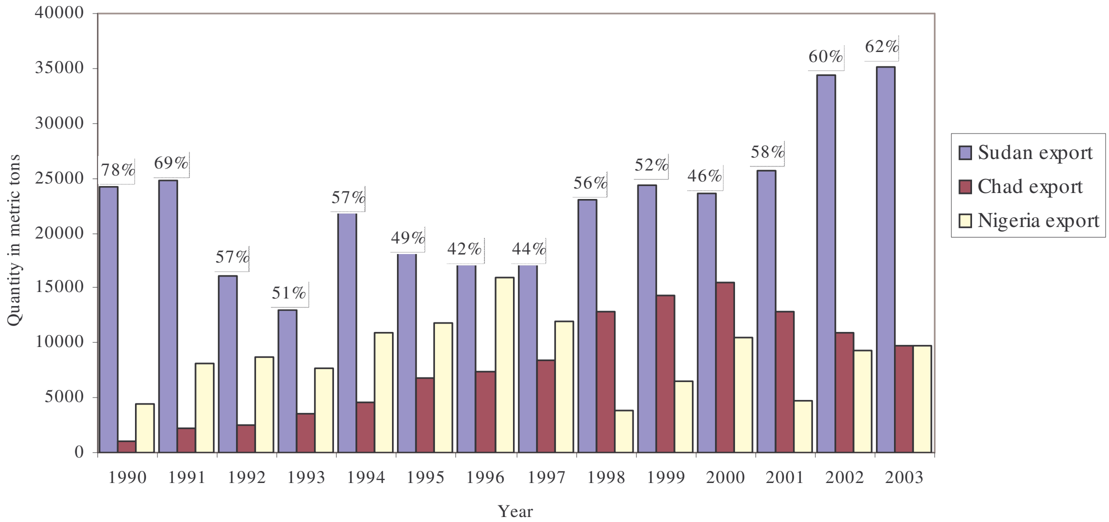

Figure 5.2 Export of gum arabic (Sudan, Chad and Nigeria 1990-2003)

Source of data: Coppen (1999) and United Nations Statistics Division, *COMTRADE* database

It is apparent from the preceding that strategic and political interest in reducing the volatility of the gum arabic supply and stabilizing the gum price level along with the positive economic and environmental externalities associated with gum production have triggered proposals to subsidize gum production in Sub-Saharan Africa. In order to understand the best strategy for Sudan to pursue in light of the recent changes in gum market structure and the proposed policies we assess the impact of subsidizing the major producing countries on gum arabic output, prices and welfare in the respective countries. The analysis is based on a von Stackelberg model to represent the gum market structure with Sudan as leader and Chad and Nigeria as the followers and investigating the effect of different subsidy scenarios on market equilibrium.

To our knowledge it is the first time the Stackelberg model has been applied to the gum market and the paper makes a novel contribution to the literature by introducing interdependent markets of vertically differentiated gum qualities (high and low quality gum) in the Stackelberg model. We start with the base case in which Sudan is assumed to have a comparative cost advantage over the followers in the production and export of the high quality gum and vice versa.

We then compare the market equilibrium outcomes under two different subsidy scenarios to promote gum production as currently on the agenda of international stakeholders in the gum arabic business. In the first scenario we introduce an international subsidy to the leader which will be either used to promote the production and export of high quality or low quality gum. In the second scenario the followers receive a subsidy and allocate it to promote either high quality or low quality gum. In both scenarios we assume that the subsidy will lead to 10% reduction in the marginal cost of production and export of the gum quality for which the subsidy is allocated.

The remainder of the paper is structured as follows. The next Section further motivates the choice of a Stackelberg model to represent the gum market structure and understand the relevant policy options. Section 5.3 describes the model we use for analysis followed by Section 5.4 that presents the data and the parameter calibration. Section 5.5 presents the different scenarios and section 5.6 discusses and compares the scenario results. In Section 5.7 we present the sensitivity analysis and Section 5.8 contains the conclusion.

5.2 Theoretical background

The international gum export market can be characterized as an oligopoly market where three major producing countries (Sudan, Chad and Nigeria) represent over 95% of the world gum export market (ITC 2000) while other minor producing countries serve different niche markets. Amongst the three major players Sudan is a dominant exporter. In oligopoly models, one side of the market typically consists of either price or quantity setters, with price takers on the other side. With a homogenous product the Cournot model is most often chosen to describe market interaction, and with differentiated products, the Bertrand model is usually applied.

For each of these static simultaneous decision models of oligopoly there is a sequential decision counterpart. These sequential decision models are the progeny of von Stackelberg's (1934) strategic analysis of quantity setting. Stackelberg models rely on leadership by one of the rivals and extend the Cournot model to include leadership behavior (Varian 1999). Stackelberg leader's output choice influences the output choices of its rival and the leader chooses output in full recognition of its follower's reactions. Von Stackelberg's insight has also been adapted to the Bertrand pricing model. In this case the leader would choose a price that its followers would respond to (Higgins 1996).

In Stackelberg models, the decisions of followers and the choice of output or price by the leader are made sequentially in two stages (Shapiro 1989). In stage 1 the leader chooses to maximize profit anticipating how his choice affects his rivals' choices. In stage 2 the followers independently maximize their profit functions taking the decisions of the leader as given. In this regard, the choice between price-setting (Bertrand) and quantity-setting (Cournot) models usually depends on the relative heterogeneity of the products for sale in the market to be analyzed. The original Stackelberg model consists of two firms, a leader and a follower. Subsequently, researchers have generalized the model to include more than two firms (Anderson and Engers 1992, Church and Ware 1996).

Most existing work that extends the Stackelberg model to include more than two firms always assumes identical cost functions for all firms (Pal and Sarkar 2001). This assumption, however, is rather restrictive, since the firms' costs may actually differ. Here we introduce a cost advantage for the leader (Sudan) for the high quality gum and a cost advantage for the followers (Chad and Nigeria) for low quality gum.

Our model mimics the international market for gum arabic using von Stackelberg's model of non-cooperative oligopolistic behavior where Sudan is a leader and Chad, Nigeria are followers. This seems a natural representation of the gum arabic export market since Sudan is not only a dominant exporter for gum but also its quality and classification for the hard gum is used as yardstick on the world market.[29] The countries' decision variables are output levels for the two gum qualities and the output decisions are made sequentially: the dominant firm (Sudan) has the first mover advantage while all other firms take the decision of the leader as given (Carlton and Perloff 2000).

In this approach each country is represented by one firm. This is a natural assumption because for Sudan the gum arabic trade is controlled by the Gum Arabic Company (GAC). While in the case of Chad and Nigeria, though there are few companies involved in the gum arabic business, the industry is coordinated by central bodies (Société Commerciale du Chari et du Logone (SCCL) in Chad and the Nigerian Gum Arabic Association in Nigeria..[30] We use the model to examine the impacts of market interventions like the subsidies proposed by the USAID, EU and other international donors to promote gum arabic production in Sub-Saharan Africa.

5.3 The model

The gum arabic market sector in the Stackelberg gum model is divided into two segments: the high quality gum and the low quality gum hereafter indicated by q $(q = 1,2)$ respectively. We assume that the utility from the consumption of the two gum qualities is quadratic and strictly concave

$$U(X_1, X_2) = \alpha_1 X_1 + \alpha_2 X_2 - 1/2\left(\beta_1 X_1^2 + \beta_2 X_2^2 + 2\gamma X_1 X_2\right).$$

Following the analysis of Singh and Vives (1984) this utility function generates a linear system of inverse demand functions

$$P_1 = \alpha_1 - \beta_1 X_1 - \gamma X_2 \qquad (5.1a)$$

$$P_2 = \alpha_2 - \beta_2 X_2 - \gamma X_1 \qquad (5.1b)$$

[29] Sudan has established a detailed classification for its hard gum, known as Kordofan classification-Kordofan is the main producing area for hashab gum in Sudan. This classification has become a reference on the world market.

[30] There are six major companies controlling the gum industry in Chad and The Société Commerciale du Chari et du Logone (SCCL) holds over 35% of the market.

where P_1, P_2 are the prices of high and low quality gum respectively. Parameters $\alpha_1, \alpha_2, \beta_1$ and β_2 are positive constants and X_1, X_2 are the total world demand for, respectively, high and low quality gum. The parameter γ measures the level of substitutability (i.e. the degree of product differentiation) between the two gum qualities and we assume that $\gamma > 0$.[31] Furthermore, $X_q = x_q^S + x_q^C + x_q^N$ where x_q^S is the output of Sudan (the leader) and x_q^C, x_q^N are the outputs of Chad and Nigeria respectively where $q \in \{1,2\}$ is a quality index.

We assume that in each country i the high and low quality gum are produced under constant marginal cost of production equal to c_1^i and c_2^i respectively. The assumption of constant marginal cost is made as our analysis is based on static model. In the short run production of gum is constrained by the size of gum plantation in each country, therefore one would expect the marginal cost to be constant as each country has to produce within its natural capacity. In the long run if the country decides to increase production and put more land under gum plantation then it will incur increasing marginal cost. The marginal cost of producing the high quality gum is greater than the marginal cost of producing the low quality gum ($c_1^i \geq c_2^i$) because the high quality gum is usually exported after cleaning, sorting and grading while the low quality gum only undergoes a cleaning process. In addition the production of the high quality gum is stimulated by "tapping" the *Acacia senegal* tree whereas the low producing gum tree (*Acacia seyal*) does not require tapping and exudes its gum naturally.

Furthermore, for simplification, we assume identical marginal costs for Chad and Nigeria equal to c_q^f where f refers to the fringe and quality $q \in \{1,2\}$.

For historical and institutional reasons we consider Sudan to be the incumbent with first mover advantage, so the countries choose their quantities as follows: Sudan chooses its high and low quality gum

[31] If $\gamma = 0$, then the two products are independent and can be modeled as separate markets.

quantity setting strategy (x_1^S, x_2^S) incorporating the reaction functions of Chad and Nigeria which specify their profit maximizing quantities as a function of Sudan's output choice. Chad and Nigeria observe x_q^S, for $q \in \{1,2\}$ and simultaneously choose x_q^C and x_q^N respectively, for $q \in \{1,2\}$.

Given that Sudan chooses x_q^S and Chad chooses x_q^C, then Nigeria will choose x_q^N to maximize:

$$\Pi^N(X_1, X_2) = P_1 x_1^N + P_2 x_2^N - c_1^f x_1^N - c_2^f x_2^N .$$

Substituting the inverse demand functions in (5.1a) and (5.1b) into the profit function of Nigeria gives

$$\Pi^N(X_1, X_2) = \left[\alpha_1 - \beta_1\left(x_1^S + x_1^C + x_1^N\right) - \gamma\left(x_2^S + x_2^C + x_2^N\right)\right] x_1^N$$
$$+ \left[\alpha_2 - \beta_2\left(x_2^S + x_2^C + x_2^N\right) - \gamma\left(x_1^S + x_1^C + x_1^N\right)\right] x_2^N - c_1^f x_1^N - c_2^f x$$

Nigeria will maximize its profit with respect to its output choice of the high quality and low quality gum by setting marginal revenues equal to marginal costs that is

$$\alpha_1 - \beta_1 x_1^S - \beta_1 x_1^C - 2\beta_1 x_1^N - \gamma\left(x_2^S + x_2^C + 2x_2^N\right) = c_1^f . \qquad (5.2a)$$

$$\alpha_2 - \beta_2 x_2^S - \beta_2 x_2^C - 2\beta_2 x_2^N - \gamma\left(x_1^S + x_1^C + 2x_1^N\right) = c_2^f . \qquad (5.2b)$$

Solving equation (5.2a) and (5.2b) to derive Nigeria with respect to Sudan's and Chad's outputs we get

$$x_1^N = \frac{\beta_2\left(\alpha_1 - c_1^f\right) - \gamma\left(\alpha_2 - c_2^f\right) - \left(\beta_1\beta_2 - \gamma^2\right)\left(x_1^S + x_1^C\right)}{2\left(\beta_1\beta_2 - \gamma^2\right)} . \qquad (5.3a)$$

$$x_2^N = \frac{\beta_1\left(\alpha_2 - c_2^f\right) - \gamma\left(\alpha_1 - c_1^f\right) - \left(\beta_1\beta_2 - \gamma^2\right)\left(x_2^S + x_2^C\right)}{2\left(\beta_1\beta_2 - \gamma^2\right)} . \qquad (5.3b)$$

Likewise, by symmetry, the output maximizing quantity for Chad with respect to each gum quality is also given by (5.3a) and (5.3b) when superscripts *N* and *C* are exchanged.

Substituting the output maximizing quantities for Nigeria in (5.3a) and (5.3b) for the high and low quality gum respectively into the expression for Chad maximizing output quantities and rearranging gives the reaction functions of Chad as a function of Sudan output choice which is by symmetry equal to the reaction functions of Nigeria.

$$x_1^{C*} = x_1^{N*} = \frac{1}{3}\left[\frac{\beta_2\left(\alpha_1 - c_1^f\right) - \gamma\left(\alpha_2 - c_2^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)} - x_1^S\right]. \qquad (5.4a)$$

$$x_2^{C*} = x_2^{N*} = \frac{1}{3}\left[\frac{\beta_1\left(\alpha_2 - c_2^f\right) - \gamma\left(\alpha_1 - c_1^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)} - x_2^S\right]. \qquad (5.4b)$$

Sudan will maximize its profit with respect to output choice incorporating the reaction functions of Chad and Nigeria shown in equation 5.4a and 5.4b.

$$\Pi^S(X_1, X_2) = \left[\alpha_1 - \beta_1\left(x_1^S + x_1^{C*} + x_1^{N*}\right) - \gamma\left(x_2^S + x_2^{C*} + x_2^{N*}\right)\right]\cdot x_1^S$$
$$+\left[\alpha_2 - \beta_2\left(x_2^S + x_2^{C*} + x_2^{N*}\right) - \gamma\left(x_1^S + x_1^{C*} + x_1^{N*}\right)\right]\cdot x_2^S - c_1^S x_1^S - c_2^S x_2^S.$$

From the first order conditions we get Sudan's profit maximizing quantities for the high and low quality gum

$$x_1^S = \frac{3}{2\beta_1}\left(\alpha_1 - c_1^S\right) + \left(\frac{\gamma^2}{\beta_1} - \beta_2\right)\frac{\left(\alpha_1 - c_1^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)} - \frac{\gamma}{\beta_1}x_2^S. \qquad (5.5a)$$

$$x_2^S = \frac{3}{2\beta_2}\left(\alpha_2 - c_2^S\right) + \left(\frac{\gamma^2}{\beta_2} - \beta_1\right)\frac{\left(\alpha_2 - c_2^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)} - \frac{\gamma}{\beta_2}x_1^S. \qquad (5.5b)$$

Substituting x_2^S from (5.5b) into (5.5a) and vice versa and simplifying we get

$$x_1^S = \frac{1}{\left(\beta_1\beta_2 - \gamma^2\right)}\left[\begin{array}{l}\frac{3}{2}\beta_2\left(\alpha_1 - c_1^S\right) + \frac{(\gamma^2\beta_2 - \beta_1\beta_2^2)\left(\alpha_1 - c_1^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)} \\ -\frac{3\gamma}{2}\left(\alpha_2 - c_2^S\right) - \frac{\left(\gamma^3 - \gamma\beta_1\beta_2\right)\left(\alpha_2 - c_2^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)}\end{array}\right]. \qquad (5.6a)$$

$$x_2^S = \frac{1}{\left(\beta_1\beta_2 - \gamma^2\right)}\left[\begin{array}{l}\frac{3}{2}\beta_1\left(\alpha_2 - c_2^S\right) + \frac{(\gamma^2\beta_1 - \beta_2\beta_1^2)\left(\alpha_2 - c_2^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)} \\ -\frac{3\gamma}{2}\left(\alpha_1 - c_1^S\right) - \frac{\left(\gamma^3 - \gamma\beta_1\beta_2\right)\left(\alpha_1 - c_1^f\right)}{\left(\beta_1\beta_2 - \gamma^2\right)}\end{array}\right]. \qquad (5.6b)$$

In order to get Chad's and Nigeria's output of high and low gum quality we substitute the profit maximizing quantity for Sudan in equation (5.6a) and (5.6b) into the reaction functions of Chad and Nigeria (4a) and (4b).

5.4 Data and parameters

Generally the scarcity and unreliability of time series data for gum arabic pose special difficulties for empirical analysis and to our best knowledge no empirical study has been carried out on the differentiated gum market. This is caused probably by the fact that custom statistics do not distinguish between the two varieties (hard and friable gums) and both are recorded under the same Harmonized System-code, exception being Sudan as the annual reports published by the Gum Arabic Company distinguish Sudan's gum export by variety.[32]

Since the three countries represent over 95% of world export, the world demand is taken to be equivalent to the supply from these countries. In addition since the production is almost entirely exported and local use of gum arabic is insignificant in relation to the amount exported (Seif el Din and Zaroug 1996 and Macrae and Merlin 2002), the export figures are a good proxy for the level of production in the different countries.

Given the lack of time series data on the export by variety for Chad and Nigeria we could not estimate the demand equations given in (5.1a) and (5.1b). For the purpose of our comparative static analysis we therefore made a rough estimate on the relative share of each variety on the total gum export of Chad and Nigeria. We used information mentioned in the literature (Coppen 1999 and Macrea and Merlin 2002) on the relative breakdown of Chad's and Nigeria's export into the two varities and data for the years 2001-03 on gum export value and export quantity for Chad and Nigeria obtained from ITC and COMTRADE data bases. We used the three years average total export of each variety (X_1, X_2) and the

[32]In order to obtain information on Chad's and Nigeria's export by variety and the export price we have contacted several gum stakeholders (organizations and individuals) including among others –FAO database on NWFP, International Trade Center (ITC), CNI (largest importer of gum arabic at www.cniworld.com), Nigerian Gum Association and Association Françaises des Volontaires de Progrés-Tchad -Ndjaména. Unfortunately it appears that obtaining the needed statistics is difficult as these organizations either don't have the required information or are reluctant to give it.

corresponding weighted average price (P_1, P_2) in the equations for own price elasticities and cross price elasticity. In order to calibrate the model we made the following assumptions for own and cross price elasticties, production and export costs and firm's output:

5.4.1 Own price elasticities

Few empirical studies have estimated gum arabic price elasticity of demand. Abdelgalil (2004) reports an elasticity of demand for gum arabic of – 1.78. Because of a lack of better information and as a starting point for our analysis we consider this elasticity to be the average price elasticity for both qualities. Based on our understanding of the gum arabic market we start by assuming that the demand for hard gum is more inelastic as compared to the friable gum since it has been mentioned in the literature that the price of hard gum depends on a much tighter market (ITC 2000). Industries that use high quality gum in their applications might be reluctant to switch to friable gum at least in the short run This is because changing product formulations has major cost implications in the short term (e.g. costs of changing the machinery, procedures, labeling in addition to considerations of whether the consumer will accept the newly formulated product), this makes switching decision difficult at least in the short run. In the long run hard quality gum can either remain price inelastic as compared to the low quality gum in case no effort is carried out to further improve the quality of friable gum so that it can easily substitute the high quality gum.

Therefore, in our base case we start with elasticties of demand for high and low quality gum of -1.2 and -2.2 respectively. Given the uncertainties about these values we perform a sensitivity analysis. The stylized demand functions of the two gum varieties are shown in Figure 5.3.

5.4.2 Cross price elasticity

We assume that a change in a variety's price impacts more its own quantity demanded than on the quantity of the other variety. We also expect a strong substitution effect between the demand for high quality with respect to a low quality price change as end-users can opt for the lower grades from the hard gum (such as the siftings, dust and red gum (see Table 5.1)) in case the price of the low quality increases. We calibrated the model to reflect as close as possible the export quantity and export value tuning the cross price elasticity of the high quality gum with respect to the low quality gum price at 0.6 ($\varepsilon_{12} = 0.6$), which reflects a fair but not excessive level of substitutability.

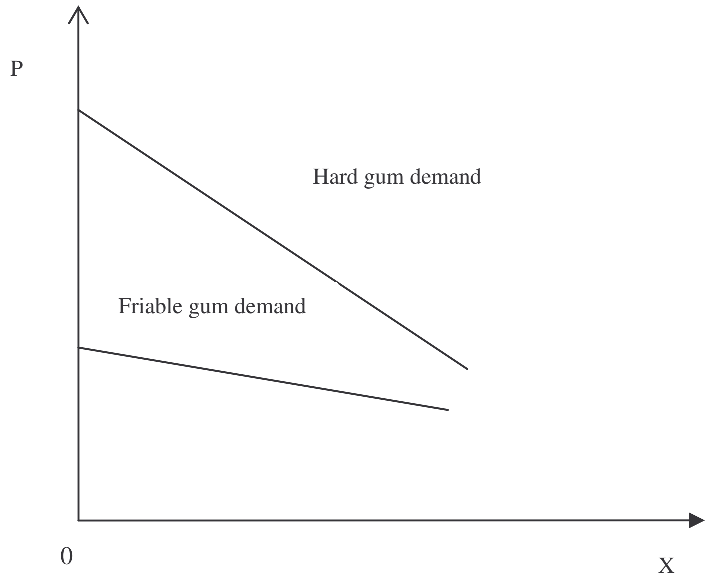

Figure 5.3 Stylized demand system for hard gum and friable gum demand

We then derive the parameters $\alpha_1, \alpha_2, \beta_1, \beta_2$ and γ for the base case of our analysis from the inverse demand equations given in (1a) and (1b) and the following equations for the elasticities:

$$\varepsilon_1 = \frac{-\beta_2}{\beta_1\beta_2 - \gamma^2}\frac{P_1}{X_1}, \quad \varepsilon_2 = \frac{-\beta_1}{\beta_1\beta_2 - \gamma^2}\frac{P_2}{X_2} \text{ and } \varepsilon_{12} = \frac{\gamma}{\beta_1\beta_2 - \gamma^2}\frac{P_2}{X_1}$$

where ε_1 is the price elasticity for the high quality gum, ε_2 is the price elasticity for the low quality gum and ε_{12} is the cross price elasticity of the high quality gum with respect to the low quality gum price.

5.4.3 Production and export cost

Before reaching the importer or end-users, most gum arabic from the producer countries will have gone through some sort of cleaning, sorting and grading. Gum quality is certainly an important factor in determining the price which the exporters can obtain. There are two aspects to quality: (i) intrinsic quality, which is outside the control of the producer and is determined by the botanical source of the tree (affecting in turn its functional properties) as mentioned earlier and (ii) the quality which is determined by the treatment and post-harvest handling subsequent to exudation from the tree. With regard to the latter it has been stated that the quality of hard gum from Chad and Nigeria is compromised by collecting and mixing gums from different botanical sources reflecting the less rigorous and efficient methods of harvesting and post-harvest treatment practiced in Chad and Nigeria compared to Sudan (FAO 1995).

In our base case, therefore, we consider Sudan to have a comparative cost advantage over the followers in the production and export of high quality gum i.e. $c_1^S < c_1^f$.[33] Two main reasons, besides its long history and experience in the trade, are behind Sudan's comparative cost advantage in high quality gum harvest and post-harvest handling: First the distribution of *Acacia senegal* in Sudan is uniform and the species is found in pure stand, whereas in other African producing countries *Acacia senegal* is found mixed with other species (Macrae and Merlin 2002). Therefore, separation of mixtures of hard gum from different botanical sources during the harvest and post-harvest cycle requires less labor input. Second since 1991 the last operation of post-harvest handling (re-cleaning, sorting and grading) for the hard gum in Sudan has been mechanized using a system of conveyor belt and shaking and sieving machines. In addition Sudan has developed a standardized grading system for hard gum while other countries export their hard gum only as cleaned grade. Table 5.1 gives a description of the different grades of Sudanese hard gum ranked according to the purity and desirability of the grade.

[33] The assumption of Sudan's cost advantage for the hard gum can be seen as a premium for Sudanese gum export price because of its better hard gum quality. As stated earlier Sudanese hard gum set the standard by which others gum are judged and the quality of Kordofan gum is regarded as the best quality. A similar argument goes for the low quality cost advantage for Chad and Nigeria i.e. the cost advantage can be seen as a price premium for their quality as the followers get a higher price in the gum export market for their friable gum as compared to Sudan.

Table 5.1 Grades of Sudanese Hard Gum

Grade	Description
Hand-picked selected	Large nodules which have been carefully selected. Cleanest and lightest in color.
Cleaned (standard)	The material that remains after hand-picked selected and siftings are removed. Comprises whole or broken nodules varying in color from pale to dark.
Siftings	Fine particles remaining following sorting of the standard grade. Contains some sand, bark and dirt.
Dust	Very fine particles collected after the cleaning process. Contains sand and dirt.
Red	Dark gum removed by hand from the other nodules.

On the other hand, all the three countries export their friable gum only in standard and cleaned form. Nevertheless, the quality of friable gum from Chad and Nigeria is thought to be better than the product from Sudan, which gives a darker solution in water (Coppen 1999). In addition the friable gum export of Chad and Nigeria is rarely mixed with other types of gum (*ibid*); accordingly we assume that the followers have a comparative cost advantage over the leader in the production and export of low quality gum i.e. $c_2^f < c_2^S$.

We have data for Sudan's cost structure obtained from the Gum Arabic Company, however, for Nigeria and Chad the cost structure is not well documented and despite all our attempts it was not possible to obtain the needed information for these countries. Based on the information we obtained from Sudan we start by assuming that the cost of production and export of each variety is 65% of its weighted average market price for the years 2001-03 and the followers' marginal cost for the low quality gum is less than the leader's marginal cost by 15% and vice versa for the high quality gum.

5.4.4 Firm's output

We assume that in equilibrium each firm will produce a positive output quantity of both varieties This assumption together with the above assumption on own and cross price elasticities implies: $\alpha_1 > \alpha_2 > c_q^i$ and $\beta_1 > \beta_2 > \gamma$.[34]

Table 5.2 reports the base case values of the parameters that we derived. All the parameters used for the base case are in accordance with the constraints and assumptions described above.

Table 5.2 Derived Parameters Values for the Base Case ($\varepsilon_1 = -1.2, \varepsilon_2 = -2.2, \varepsilon_{12} = 0.6$)

Parameter	Value	Parameter	Value
α_1	3682.45	c_1^S	772.28
α_2	2071.13	c_2^S	517.35
β_1	0.0644	c_1^f	908.57
β_2	0.0293	c_2^f	439.75
γ	0.0258		

5.5 Scenario analysis

5.5.1 Scenario 1: Leader subsidy

Under this scenario Sudan receives an international subsidy and is considering whether to become more competitive in production and export of hard gum or use the subsidy to develop and promote production and export of its friable gum as the demand for the latter has increased recently and friable gum is now accepted as a certified food additive. For the purpose of comparison we will assume that once the decision is made on which quality to target, the subsidy will lead to 10% reduction in the marginal cost of production of the targeted quality.

Scenarios 1a and 1b indicate that the subsidy is allocated for the high quality and low quality gum, respectively. Cost reduction can be achieved by adopting mechanical systems of cleaning, sorting and grading for all the stages of post-harvest handling. The amount of subsidy needed to achieve 10% reduction in the marginal cost of either quality is equal to cost difference from the base case times the export quantity increase under the subsidy scenario. We expect, however, promotion of the high quality gum to be more profitable for Sudan as compared to promoting low quality gum because Sudan already has competence and cost advantage in the production and export of high quality gum.

5.5.2 Scenario 2: Followers subsidy

Under scenario 2 the followers receive an international subsidy and are deciding which gum quality to promote and develop further. They try to catch up with Sudan's cost advantage in the production and export of high quality gum, for instance by undertaking extension services to disseminate advice to the farmers and traders involved in the gum industry in order to improve their cleaning and quality control procedures. Alternatively the followers can use the subsidy to become more competitive in the low quality market and take advantage of the surge in the demand for friable gum. The subsidy is supposed to lead to 10% reduction in marginal cost for the production of either quality. We refer to these scenarios as scenario 2a and 2b, respectively, to indicate that the subsidy is used for the high or low quality gum sector.

5.6 Scenario results and discussion

Table 5.3 shows the percentage change in market parameters under the different scenarios. We fix the cross price elasticity ε_{12} at 0.6 and calculate the market parameters for two plausible values on own price elasticity for the high and low quality gum $(\varepsilon_1 = -1.2, \varepsilon_2 = -2.2)$ and $(\varepsilon_1 = -1.5, \varepsilon_2 = -1.8)$. Table 3 also shows the amount of subsidy in US

---

[34] When $\alpha_1 = \alpha_2$ and $\beta_1 = \beta_2 = \gamma$, the goods are perfect substitutes (Singh and Vives 1984). In addition $\beta_1 > \beta_2 > \gamma$ implies that $\beta_1\beta_2 - \gamma^2 > 0$ which is the sufficient condition for the strict concavity of the utility function.

dollars needed to achieve a 10% reduction in marginal cost for the leader or follower in the production and export of either quality. Numbers in brackets under scenario 2 indicate the total amount of subsidy needed for the two followers.

A comparison of the proportionate change in the gum price level and total gum export when the subsidy is granted to Sudan (scenario 1) or the followers (scenario 2) is shown in Table 5.3. We can see that the reduction in the price of high and low quality gum is higher under scenario 1 than under scenario 2 and similarly the percentage change in total gum export is relatively higher under scenario 1 as compared to scenario 2. This is expected considering the dominant role Sudan plays in the gum arabic market and its high market share. The amount of subsidy required by Sudan in order to decrease its marginal cost for the high or low quality by 10% is on average less than the total amount of subsidy required by the followers, by 19% and 73% respectively for scenarios a and b.

Results in Table 5.3 suggest a proportionately larger increase in Sudan's profit when the subsidy is used to promote high quality gum under scenario 1a instead of promoting the low quality gum under scenario 1b (14.5% and 16.8% increase in profit compared to 2.1% and 1.8% increase). It is not surprising that Sudan will benefit more from using the subsidy to increase its competitiveness in high quality gum since Sudan already has a comparative cost advantage in the export of this gum variety. Total gum export from Sudan increases by 9.2% and 5.9% under scenario 1b and only by 1.3% and 3.6% under scenario 1a. The proportionately higher increase in Sudan's total gum export under scenario 1b as compared to scenario 1a arises from the larger increase in Sudan's export of low quality gum (123.1% and 122.6%) when the subsidy is used to promote low quality gum.

On the other hand whether the followers obtain a proportionately higher or lower profit when they use the subsidy to promote the high or low quality gum depends on the assumptions for the own price elasticties. A proportionately higher profit is obtained when the subsidy is used for the promotion of low quality gum (14.2% under scenario 2b compared to 12.1% under scenario 2a) when assuming own price elasicities $\varepsilon_1 = -1.2$ and $\varepsilon_2 = -2.2$. The followers profit is relatively higher when the subsidy is used for the promotion of high quality gum (14.3% under scenario 2a compared to 13.8% under scenario 2b) when we assume the own price elasticties to be -1.5 and -1.8 for the high and low quality gum, respectively. The intuitive interpretation for this specific result is that when the demand for the high quality gum becomes more elastic (ε_1 decreases from -1.2 to -1.5) then the followers can compete more aggressively with Sudan and increase their sale of high quality gum (the difference in the proportionate increase in followers sale of high quality gum when ε_1 is equal to -1.2 and -1.5 is about 11%).

Interestingly, our results show that if the followers use the subsidy to promote their high quality gum export then it will lead to a proportionately higher reduction in Sudan's profit than when the subsidy is used for the promotion of low quality gum (Sudan's profit decreases by 10.2% and 11.7% under scenario 2a but only by 0.5% and 0.4% under scenario 2b). Results also shows that under scenario 1 the followers's profit reduction is higher for scenario 1b as compared to scenario 1a (10.5% and 10.3% compared to 5.2% and 5.6%), suggesting that when Sudan uses the subsidy to promote low quality gum, then a proportionately higher reduction in the profit for the followers will occur.

The fact that Sudan receives a larger profit and that the followers suffer from smaller reduction in profits when Sudan use the subsidy to promote high quality gum suggests that it will not only benefit Sudan in case it directs its effort to the export of high quality gum, but it is also better for Chad and Nigeria. In a similar way Sudan will also benefit in case Chad and Nigeria focus on promoting low quality instead of high quality gum. However, in case the demand for high quality gum is more elastic, the followers prefer to promote the high quality gum. This causes substantial losses for Sudan. In light of these results the three exporters are better off if they adopt an export coordination strategy whereby Sudan focuses on promoting high quality gum and the followers promote low quality gum with some side payments to be paid by Sudan to the follower as a compensation lost for profits in case they curtail their export of high quality gum.

5.7 Sensitivity analysis

There are three major assumptions in our analysis: the level of the own price elasticity for the high and low quality gum $(\varepsilon_1, \varepsilon_2)$ and the cross price elasticity of the high quality gum with respect to the low quality gum price (ε_{12}). The latter affects the value of the parameter γ which measures the extent of product differentiation between the high and low quality gum.

Above in (Table 5.3) we presented results for two plausible values on own price elasticity for the high and low quality gum $(\varepsilon_1 = -1.2, \varepsilon_2 = -2.2)$ and $(\varepsilon_1 = -1.5, \varepsilon_2 = -1.8)$. In order to check the robustness of our results with respect to the assumption on cross price elasticity we also calculate the market parameters for a cross price elasticity level ε_{12} of 0.3 and two plausible values on own price elasticity for the high and low quality gum as before ($\varepsilon_1 = -1.2$ and $\varepsilon_2 = -2.2$ then $\varepsilon_1 = -1.5$ and $\varepsilon_2 = -1.8$). Results are shown in Table 5.4 and confirm the pattern shown on Table 5.3 for a cross price elasticity level of 0.6. That Sudan is better off promoting the high quality gum and the proportionate increase in the followers' profit in case they promote high or low gum quality is also sensitive to the assumption on cross price elasticity. Also promotion of low quality gum by Sudan leads to a proportionately larger reduction in followers' profit and promotion of high quality gum by Chad and Nigeria leads to a proportionately larger reduction in Sudan's profit.

5.8 Conclusion

Gum arabic is mainly produced from two Acacias that are found in the gum belt of Sub-Saharan Africa. These are: *Acacia senegal* that produces hard gum and *Acacia seyal* that produces friable gum. The demand for gum arabic, and particularly for friable gum, has increased in recent years. At present the world market is divided more or less equally between hard and friable gum. Nonetheless, friable gum is considered to have a relatively low quality and is only used for a price advantage or when supplies of hard gum are low.

Historically, Sudan was known to monopolize the gum trade exporting mainly the high quality hard gum. Following the drought that affected the Sahel the gum arabic market structure has changed not only because the position of friable gum is consolidated as a credible food additive but also because the shares of Chad and Nigeria in gum arabic export generally and friable gum specifically have increased substantially in recent years. Sudan that is known for its expertise in exporting high quality gum is now facing a growing competition from Chad and Nigeria who are specialized in the export of friable gum.

In order to understand the best strategy for Sudan to pursue in light of the recent changes in the gum market and the proposed donor policies, we model the international market for gum arabic using a Stackelberg model of non-cooperative oligopolistic behavior where Sudan is a leader and Chad and Nigeria are followers. We start with the base case in which Sudan is assumed to have a comparative cost advantage over the followers in the production and export of the high quality gum and vice versa. We then compare the market equilibrium outcomes under two different scenarios: Under the first scenario we introduce an international subsidy to the leader which will be either used to promote the production and export of high quality or low quality gum. Under the second scenario the followers receive a subsidy which is allocated to promote either high quality or low quality gum.

Our results show that the proportionate increase in Sudan's profit is higher when Sudan uses the subsidy to promote high quality gum than when it uses the subsidy to promote the low quality gum. We therefore recommend that in the short and medium term Sudan should direct its efforts basically to the export of high quality gum. In the case of Chad and Nigeria, however, the decision on which quality to promote appears to be sensitive to the levels of own and cross price elasticties.

The main finding of this paper is that, promotion of low quality gum export by Sudan is harmful for Chad and Nigeria and promotion of high quality gum by Chad and Nigeria is harmful to Sudan. Also our results suggest that the three countries are better off if they adopt an export coordination strategy whereby Sudan focuses on promoting high quality gum and the followers promote low quality gum with some side payments to be paid by Sudan to the follower as a compensation for the lost profits in case they curtail their export of high quality gum. We expect, however, that it will be difficult to achieve such international cooperation in the near future. As Sudan is still a key player on the gum market, a subsidy to Sudan will improve welfare in the importing countries more than a subsidy to Chad and Nigeria, because it leads to a stronger increase of gum output and larger reduction of price. Still it might be in the interest of donors to reduce volatility of supply through diversifying the sources of supply.

Table 5.3 Changes in Market Equilibrium under the Different Scenarios (in percent)

Cross price elasticity $\varepsilon_{12} = 0.6$

	Scenario 1: Leader subsidy				**Scenario 2: Followers subsidy**			
	Scenario 1a 10% reduction in c_1^S		Scenario 1b 10% reduction in c_2^S		Scenario 2a 10% reduction in c_1^f		Scenario 2b 10% reduction in c_2^f	
	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**
x_1^S	11.9	13.3	-7.0	-6.3	-9.3	-10.4	4.0	3.5
x_2^S	-73.5	-89.4	123.1	122.6	57.6	70.1	-69.8	-69.5
Sudan total export	1.3	3.6	9.2	5.9	-1.0	-2.8	-5.2	-3.4
$x_1^{C(N)}$	-31.8	-38.7	18.7	18.2	49.9	60.7	-21.2	-20.6
$x_2^{C(N)}$	10.1	11.4	-16.9	-15.6	-15.8	-17.9	19.1	17.7
Followers total export	-1.0	-3.4	-7.5	-5.6	1.6	5.3	8.4	6.4
X_1	3.2	3.6	-1.9	-1.7	2.5	2.8	-1.1	-1.0
X_2	-4.2	-4.8	7.0	6.6	-3.3	-3.8	4.0	3.7
Total gum export	0.2	0.7	1.7	1.2	0.2	0.5	1.0	0.7
P_1	-3.0	-3.1	0.0	0.0	-2.3	-2.4	0.0	0.0
P_2	0.0	0.0	-3.4	-3.4	0.0	0.0	-2.0	-1.9
Π^S	14.5	16.8	2.1	1.8	-10.2	-11.7	-0.5	-0.4
$\Pi^{C(N)}$	-5.2	-5.6	-10.5	-10.3	12.1	14.3	14.2	13.8
Subsidy in USD	214052	267541	210952	172597	131635	164548	67738	55423
Total subsidy for the followers					(263271)	(329095)	(135476)	(110847)

Table 5.4 Changes in Market Equilibrium under the Different Scenarios (in percent)

Cross price elasticity $\varepsilon_{12} = 0.3$

	Scenario 1: Leader subsidy				**Scenario 2: Followers subsidy**			
	Scenario 1a 10% reduction in c_1^S		Scenario 1b 10% reduction in c_2^S		Scenario 2a 10% reduction in c_1^f		Scenario 2b 10% reduction in c_2^f	
	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**	ε_1**=-1.2** ε_2**=-2.2**	ε_1**=-1.5** ε_2**=-1.8**
x_1^S	11.5	13.0	-3.4	-3.1	-9.0	-10.2	1.9	1.7
x_2^S	-15.2	-16.4	50.8	44.8	11.9	12.8	-28.8	-25.4
Sudan total export	4.8	6.6	10.2	7.4	-3.8	-5.2	-5.8	-4.2
$x_1^{C(N)}$	-23.5	-28.8	6.9	6.8	36.8	45.1	-7.8	-7.7
$x_2^{C(N)}$	5.0	5.6	-16.6	-15.3	-7.8	-8.8	18.8	17.4
Followers total export	-4.3	-6.7	-9.0	-7.5	6.7	10.4	10.2	8.5
X_1	2.9	3.3	-0.9	-0.8	2.3	2.6	-0.5	-0.4
X_2	-1.7	-1.8	5.6	5.1	-1.3	-1.5	3.2	2.9
Total gum export	0.9	1.3	1.9	1.5	0.7	1.0	1.1	0.8
P_1	-3.3	-3.4	0.0	0.0	-2.6	-2.7	0.0	0.0
P_2	0.0	0.0	-4.0	-3.9	0.0	0.0	-2.3	-2.2
Π^S	18.8	21.2	5.0	4.5	-13.3	-14.8	-1.9	-1.8
$\Pi^{C(N)}$	-9.9	-10.9	-14.4	-14.2	20.9	24.4	19.5	18.9
Subsidy in USD	251810	314756	179311	146708	111912	139890	79693	65203
Total subsidy for the followers					(223825)	(279780)	(159386)	(130407)

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1 Introduction

The gum belt in Sudan offered in the past an example of how environmental conservation and economic development could be achieved simultaneously as it generates a number of private and social benefits to gum producers and the country as a whole. The most important benefits from the gum based system are income from the gum harvest to the poor farmers and combating large scale desertification in the Sudan-Sahel zone. Two important gum arabic producing acacias are found in the gum belt: *Acacia senegal* that produces high quality gum and *Acacia seyal* that produces low quality gum. The analysis in this study focuses mainly on *Acacia senegal* and *Acacia senegal*- based agroforestry system.

Over the last few decades, however, the gum belt suffered from increased degradation, gum production decreased and Sudan lost its near monopoly position in the gum export market. The main purpose of this study is to obtain a better understanding of the factors underlying the decline in gum production in Sudan and the deforestation of the gum belt during recent years. To this effect, we developed research questions to guide our analysis and to assess the factors that are considered to have contributed to the decline of gum production and the degradation of the gum belt in Sudan.

This chapter gives a summary of the main conclusions drawn from the analysis and is structured as follow. Section 6.2 presents the main results in the context of the research objectives and questions as presented in Chapter 1. In Section 6.3 the main policy implications of these findings are discussed. Section 6.4 summarizes the most important limitations of this study and provides suggestions for future research.

6.2 Empirical results

In this section we summarize the empirical results obtained from our analysis in Chapters 3, 4 and 5 relating the results to the research question addressed per chapter. Research question 1:
What are the socio-economic factors that influence the farming strategy of the traditional gum producer and the conservation of the gum belt?

In *Chapter* 3, we used a micro econometric technique to study the decision making behavior of farmers in west Sudan and to identify the socio-economic factors influencing the disadoption of gum production and gum agroforestry. We distinguish between *partial disadopters* of gum agroforestry (those who discontinue gum production but maintain the gum tree) and *full disadopters* of gum agroforestry (those who discontinue gum production and do not maintain the tree). Our survey sample shows that partial disadoption is the rule rather than the exception.

The logit model estimates show that the variable experience in gum production is positive and the squared term of the variable is negative and both are significant, indicating that the probability of continued gum production increases with experience though it increases at a decreasing rate. The data suggest that variables that measures farmer's wealth (livestock units and asset current value) are important determinants of gum production disadoption. Livestock and assets provides farmers with alternative income sources, for instance, livestock provide the needed insurance and supplement income in case of harvest failure, and assets can either be liquidated to smooth income or used for running small-scale entrepreneurial business at the village level.

Results show that factors that affect the opportunity cost of labor during the gum collection season (such as the quantity of groundnut harvested and off-farm work) are important in explaining the observed disadoption behavior. Also the empirical results show that income from annual crops has a positive effect on continuous adoption of gum agroforestry. This specific result suggests that gum arabic and other agricultural crops (except groundnut because of overlap in harvest time) do not compete but rather complement one another in the household farming economy.

Research question 2:

Considering the uncertainty on prices, what are the costs and benefits of various agricultural systems to farmers including the gum agroforestry system and what are the economic incentives required for the preservation of the existing gum forest and for establishing new plantations at farm level?

In *Chapter 4* we considered the *uncertainty* over gum returns, the *quasi-irreversible* land allocation problem and the flexibility of postponing the investment decision of entry (planting trees) and exit (abandoning gum production) in gum agroforestry. We merged the real options approach with agroforestry and analyzed farmers' investment decision in the choice of either gum or agricultural production. The option approach has an advantage over the widely used cost benefit analysis as it considers the marginal cost of an investment not only include the initial investment outlay cost, but also the opportunity cost of keeping the option alive. The decision of allocating or not allocating the land to gum forest is quasi-irreversible. In addition the benefits and opportunity costs of entering or exiting gum agroforestry are uncertain. Moreover, farmers do not face a dichotomous decision of either abandoning the gum business or planting trees now-or-never, as they have flexibility of postponing the decision, therefore, the decision to abandon the gum forest or to plant gum trees generates an option value.

Results show that agriculture currently provides higher expected economic benefits than gum agroforestry (forestry) system. However, as gum arabic is produced during the dry season and it does not compete with other agricultural crops for labor demand. Moreover, since land is not scarce resource in Sudan but rather labor is the relatively scarce factor. Because of the aforementioned reasons farmers might abandon gum production, leave the tree on the land and pursue off farm work. Our results also show that an increase of about nine to ten times on the average opportunity costs of labor is necessary in order for farmers to abandon gum arabic production and neglect the gum forest.

As for the entry decision or the expansion of gum forest we analyzed two options: converting *idle* land into gum forest and converting agricultural land into gum forest. 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 could 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 found to be below the calculated threshold values needed for the investment. Results suggest that an increase in the prices of gum arabic respectively of about 315 per cent and 775 percent is needed to induce a shift in land use system from continuous agricultural production to gum agroforestry or forestry land use systems respectively.

Research question 3:

What is the role of the international market structure and what are the effects of market interventions- such as international subsidies, on the gum market equilibrium and Sudan's profits from gum export?

In *Chapter 5* we studied factors that affect the deforestation of the gum belt at the international level and we answered research question 3. Over the last few decades the gum market structure has changed and Sudan lost its near monopoly position not only because the position of low quality gum (the product of *Acacia seyal*) is recently consolidated as a credible food additive but also because of the increased competition from other African producers, particularly Chad and Nigeria.

In *Chapter 5* we analyzed the competition in the gum export market between the three major gum exporters (Sudan, Chad and Nigeria) in order to assess the best strategy for Sudan to pursue in light of the recent changes in the gum market structure and the proposed donor policies of subsidizing gum production in Sub-Saharan Africa. The analysis is based on von Stackelberg model and investigates the effect of different subsidy scenarios. Our result shows that the proportionate increase in Sudan's profit is higher when the leader (Sudan) uses a subsidy to promote high quality gum than when it uses the subsidy to promote the low quality gum. In the case of followers (Chad, Nigeria), however, the decision on which quality to promote appears to be sensitive to the levels of own and cross price elasticises. Moreover, the results suggests that it is in the advantage of Sudan, Chad and Nigeria to adopt an export coordination strategy with some side payments to be made by Sudan as compensation for Chad's and Nigeria's lost profits in case they agree to curtail their export of high quality gum.

6.3 Policy implications

Several policy implications can be drawn from the major findings of our study.

At the *farmers' level* price incentives plays an important role in shaping their decisions as regard gum harvest gum and conservation of the gum forest. As shown in Chapter 3 a large percentage of farmers stated low gum returns as the main reason for discontinuing gum production (50 per cent). For farmers, however, the decision as to whether to harvest gum and conserve the gum forest is not only influenced by the price of the gum but also the prices they can get from other crops and factors of production. Results in Chapter 4 suggest that farmers obtain higher expected economic benefits from other crops as compared to gum cultivation and inducing a shift in land use system from agricultural cropping to gum agroforestry land use system requires raising the gum prices by at least 315 per cent from its current level.

Increasing the gum price farmers obtain through an increase in the gum export price, however, is likely to be unfeasible and difficult to sustain. Not only because market power of Sudan in the international gum market has declined but also because it might trigger further development of gum manufactured substitutes. Stabilization of both domestic and international market prices is therefore important for sustaining the gum forest as well as Sudanese revenue from gum export. Improving the returns to producers, nevertheless, could be possible either through reducing the level of profits margins and taxes charged by the Sudanese government and the Gum Arabic Company or through extending formal credit to farmers so as to reduce the effect of high interest rate charged by the informal money lenders. Nevertheless income from annual crops is also found to have a positive effect on continuous adoption of gum agroforestry (see Chapter 3), suggesting a positive spillover effect of pricing policies at the regional level for gum production e.g. improving agricultural production in the region will induce farmers to settle in their villages and reduce seasonal migration, thus increasing the availability of labor for gum production and protection of the gum forest.

Moreover, our analysis in Chapters 3 and 4 shows that the opportunity cost of labor is a decisive factor in the decision to abandon gum harvesting and to neglect the gum forest. In Chapter 4 we analyzed the incentives for abandoning gum production by comparing the benefits on the basis of the opportunity costs of labor. Our results suggest that the incentives for gum producers to exit gum production is low as long as the opportunity cost of labor remains low. Furthermore several reasons might support our finding that farmers are less likely to deforest the gum tree but rather abandon gum production and neglect the gum forest:

- The low productivity level of land in the study area might render some land unsuitable for growing annual crops, resulting in very low and fluctuating yield; accordingly leaving the land under *Acacia senegal* might be more desirable.
- By the same token fallowing land may be important to maintain its fertility; *Acacia senegal*-based agroforestry is the ideal choice for such purpose and traditional farming community in the gum belt are aware of this benefit.
- Gum cultivation provides cash income to farmers outside the growing season for cash crops. Apart from late maturing varieties of groundnut there is no overlap or competition on labor time for gum harvest with other crops harvest.

- Risk averse farmers may desire some of their land being held under *Acacia senegal* because the harvest from gum may be less variable under stressful environmental and climatic conditions, although the expected economic benefits from gum is lower than that from other crops.

It is nonetheless important to adopt and maintain an adequate, and stable price incentive for gum vis-à-vis other crops to halt the deforestation of the gum belt and to ensure that farmers have appropriate incentives to rehabilitate and cultivate gum as part of their cropping system. If the *Acacia senegal* farming system should be able to provide the environmental benefits of improved soil fertility and the socio-economic benefits of dry season income to the farmers and the wider scale benefit of desertification control, then the prices passed to farmers must be stabilized at an adequate level. Moreover an adequate and stable price incentive is also essential for farmers to undertake investment decision to replant gum forest; otherwise, other profitable uses of the land may appear more attractive.

Our analysis at the *international level* aimed to understand the future trade potential for gum arabic and the competitive position of Sudan in the international gum export market particularly in light of the increased competition from Chad and Nigeria and the recent recognition of low quality gum as food additive by FAO. Several insights and policy implications can be drawn from this analysis: First the study shows that end-users' imports of gum arabic have increased in recent decades with a clear upward trend in the import level. Furthermore the increased consumers concern with food quality and the natural advantage of gum arabic over its competitive substitutes is likely to increase the demand for gum arabic. This could be taken to imply that the gum arabic market is less threatened by manufactured substitutes as suggested by some authors in the nineties (Larson and Bromley 1991 and Freudenberger 1993).

Second the results suggest that in the short run Sudan should direct its efforts basically to the export of high quality gum because the promotion of high quality gum export results in proportionately higher increase in Sudan's profit. Third it would also be advantageous to Sudan and to Chad and Nigeria as well if the three countries adopt an export coordination strategy with some side payments to be made by Sudan as compensation for Chad's and Nigeria's lost profits in case they agree to curtail their export of high quality gum. We expect, however, that it will be difficult to achieve such regional cooperation in the near future.

The policy recommendation that Sudan maintains expertise in high quality gum and further promotes it in the short run, can be supported also from an environmental concern point of view. As we mentioned in Chapters 1 and 2, *Acacia senegal* (the high quality gum producing tree) is known for its nitrogen-fixing ability and improving the soil fertility and its tolerance for temperature and rainfall variations. In addition to this *Acacia senegal* grows on the Northern part of the gum belt where rainfall level is lower and desertification threat is higher. *Acacia seyal*, on the other hand, grows on the gum belt where the rainfall is slightly higher compared to the regions populated with the *Acacia senegal* and is therefore affected at a later stage with the desertification process. Therefore, promoting the export of high quality gum generates positive environmental externalities in addition to the socio-economic benefits for the farmers who cultivate the tree. The position in the longer run with respect to possible movement towards greater low quality gum production should be assessed bearing in mind the ecological role of *Acacia senegal* in halting the desertification process.

6.4 Study limitations and research recommendations

The study contributes to the existing agroforestry literature particularly through the application of real option theory to farmers' investment decision to enter and exit gum agroforestry. The study did not focus only on the adoption (entry) but also on the abandonment (exit) of a sustainable technology by farmers who adopted the technology in the past. By modeling both parts of the sequential land use decision, the study revealed not only the factors that explain the adoption process, but also those that subsequently affect the sustainability of the land use pattern once it has been adopted. Moreover, in the assessment of farmers' behavior we have considered a multiplicity of factors affecting the adoption and the abandonment process e.g. the uncertainty on prices, the quasi-irreversibility of the land allocation problem as well the farmers' rate of time preference.

Another contribution of our study to the literature is the application of the Stackelberg model to the gum market. To our knowledge no previous study has applied a game theory model to the gum market and the study makes a novel contribution to the literature by introducing interdependent markets of vertically differentiated gum qualities (high and low quality gum) in the Stackelberg model.

The theoretical and empirical investigations in this thesis have limitations that provide opportunities for future research.

The standard cross-sectional analysis of a mixed sample of adopters and disadopters we used in Chapter 3 might suffer a selection problem associated with farmers' choice either to continue (or not to continue) gum production. Studying the permanent disadoption process, however, requires complementing the cross section approach with a longitudinal study. Panel data would have given more insights to our analysis. The limitation of cross section data and the modeling approach adopted in revealing the factors at work that affect the disadoption decision of farmers is clearly manifested by not capturing a major factor (gum prices) in the analysis. Longitudinal data would have allowed us to overcome these limitations and quantify the response of farmers to the price incentive.

In Chapter 4 we used a system modeling approach to analyze the economic incentive needed for an *average gum farmer* to conserve the existing gum forest or plant gum trees. We did not test empirically how the model relates to the behavior of farmers in reality. While our analysis and results in Chapter 4 suggest low incentive for abandonment for an *average farmer*, nevertheless, it is not necessary that '*no abandonment*' will happen as the marginal opportunity cost of labor for some farmers might be higher than the one we used in our analysis.

Moreover, we might have underestimated the benefits from gum agroforest as we did not take full account of all the environmental and social benefits of the tree. A major benefit of the tree which is widely mentioned in the literature and acknowledged by farmers is nitrogen fixation and improving the soil fertility. This has been partly captured in our analysis as the data on crop yield are obtained from a cross section of farmers who are at different stage of the bush fallow cycle. Nevertheless, the unavailability of scientific data that quantifies the nitrogen fixing ability of the tree as well its other environmental benefits (soil stabilization and desertification control) did not allow us to take full account of these benefits in our analysis.

So far no study has actually quantified the environmental benefits of gum agroforestry system and the discussion on the indirect environmental benefits of soil stabilization, nitrogen fixation as well as the wider external environmental benefits of dune fixation and anti-desertification so far remained qualitative. The lack of agro-ecological and biophysical data has made it impossible to measure these benefits. Further research into these indirect ecological benefits is needed to verify their significance.

The major shortcoming of Chapter 5 is the scarcity of relevant data for Chad's and Nigeria's export for each gum variety and their cost structure. Although we have made the best use of available data, the modeling exercise would have been improved with more and better quality data. Some of the model parameters could have been estimated econometrically, if the relevant data had been there. Due to data limitations, results of the policy recommendations are not necessarily precise quantitative measures. Other caveats of this chapter are the assumption of constant marginal cost and the static modeling approach applied in the analysis. Given the repeated nature of interactions among the exporters and the increased demand for low quality gum a dynamic modeling approach, with an increasing marginal cost or capacity constraints, may be an interesting avenue for further research.

Lastly, the study did not focus on the contribution of the GAC monopoly power to the decline of Sudanese gum trade and the degradation of the gum belt but partly discussed these aspects in Chapter 4. Nevertheless a study on the effect of the GAC monopolistic arrangement on gum belt deforestation as well as the effect of liberalizing the gum market in Sudan and allowing free entry into the industry is worth pursuing.

REFERENCES

Abdelgalil, E. A., 2004. "Deforestation in the dry lands of Africa: quantitative modelling approach". *Environment Development and Sustainability,* Vol. 6: 415–427.

Abdelgalil, E.A., 2000. "*Economic Policies for Sustainable Resource Development: Models Applied to the Sudan*". Ph.D. thesis, Erasmus University Rotterdam.

ACACIAGUM 2005. "*Innovative management of Acacia senegal trees to improve resource productivity and gum arabic production in the arid and semi-arid sub-Saharan Africa*". ACACIAGUM proposal submitted to EU. (Internal document).

ADB [African Development Bank]. 1994. "Country environmental profile: Sudan". *Environment and Social Policy Working Paper Series,* Abidjan, Cote d'Ivoire.

Adesina, A. A., Mbila D., Nkamelu, G.B. and Endamana, D. 2000. "Econometric analysis of the determinants of adoption of alley farming by farmers in the forest zone of southwest Cameroon". *Agricultural, Ecosystems and Environment,* Vol. 80: 255-265.

Albers, H.J., Fisher, A.C. and Hanemann,W.M. 1996. "Valuation and management of tropical forests: Implications of uncertainty and irreversibility". *Environmental and Resource Economics,* Vol.8: 39-61.

Alstad, G. 1991. "*The Influence of Acacia on Soil in Arid North-eastern Sudan*". Bergen, Norway: University of Bergen. 79 pp.

Amous, S. 1999 "The role of wood energy in Africa." *In Wood Energy Today for Tomorrow (WETT) Regional Studies*. FAO Forestry Department Working Paper FOPW/99/3, FAO, Rome.

Anderson, D.M.W. 1993. "Some factors influencing the demand for gum arabic (*Acacia senegal* L Willd) and other water-soluble tree exudates". *Forest Ecology. and Management*, Vol.58: 1–18.

Anderson, S. and Engers, M., 1992. "Stackelberg versus Cournot oligopoly equilibrium". *International Journal of Industrial Organization,* Vol. 10: 127-35.

Angelsen, A. and Kaimowitz, D. 1999. "Rethinking the causes of deforestation: Lessons from economic models". *The World Bank Research Observer,* Vol.14, No. 1:73-98.

Ardö, J. and Olsson, L. 2003. "Assessment of soil organic carbon in semi-arid Sudan using GIS and the CENTURY model". *Journal of Arid Environments*, Vol. 54: 633-651.

Awouda, E. H. M. 1999. "*Development of gum arabic production and marketing*". Rome, FAO.

Ballal, M., E., 2002. "*Causes of variability in gum arabic yield from Acacia Senegal as related to some environmental and managerial factors*". PhD thesis-Faculty of Forestry, University of Khartoum-Sudan.

Bottomley, A. 1975. "Interest rate determination in under developed rural areas". *American Journal of Agricultural Economics*, Vol.57, No. 2:279-291.

Bottomley, A. 1964. "Monopoly profit as a determinant of interest rates in under developed rural areas". *Oxford Economic Papers*, 16.

Barbier, E. B. 2000. "The economic linkages between rural poverty and land degradation: some evidence from Africa". *Agriculture, Ecosystems and Environment*, Vol. 82: 355-370.

Barbier, E. B. 1992. "Rehabilitating gum arabic in Sudan: economic and environmental implications". *Environmental and Resource Economics* 2: 341-358.

Barbier, E. Burgess, J. C. and Folke, C. 1994. "*Paradise lost? The ecological economics of biodiversity*". London: Earthscan.

Breman, H. and Kessler, J.J. 1997. "The potential benefits of agroforestry in the Sahel and other semi-arid regions". *European Journal of Agronomy*, Vol.7, No.9:25-33.

Beshai, A. 1984. "The economics of a primary commodity: Gum Arabic", *Oxford Bulletin of Economics and Statistics*, Vol.46, No.4: 371-381.

Bulte, E., van Soest, D.P., van Kooten, G.C. and Schipper, R.A. 2002. "Forest conservation in Costa Rica when nonuse benefits are uncertain but rising". *American Journal of Agricultural Economics*, Vol. 84, No. 1: 150-160.

Carlton, D.W. and Perloff, J.M. 2000. "*Modern industrial organisation*". 3rd edition, Reading, Addison Wesley.

Campbell, J.Y., Lo, A.W. and MacKinlay, A.C. 1997. "*The econometrics of financial markets*". Princeton, NJ: Princeton University Press.

Caviglia, J. L. 1999. "Sustainable Agriculture in Brazil: Economic Development and Deforestation". *New Horizons in Environmental Economics series*, Edward Elgar Publishing Limited, United Kingdom: Cheltenham.

Chang, P., Ji, L. and Li, H., 1997. "A decadal climate variation in the tropical Atlantic ocean from thermodynamic air-sea interactions". *Nature*, Vol.385:516-518.

Chikamai, B.N. 1996. "*A review of production, markets and quality control of gum arabic*". Technical co-operation programme (project no. TCP/RAF/4557). Food and Agricultural Organization, Rome.169 pp.

Church, J. and Ware, R., 1996. "Delegation, market share and the limit price in sequential entry models". *International Journal of Industrial Organization*, Vol. 14: 575-609.

Coppen, J.W. 1999. "*Gum arabic: its production and marketing opportunities and constraints to their improvement in Sudan*". FAO document TC:TCP/SUD/7821, Rome.

COMTRADE [United Nations Statistics Division]. 2005. COMTRADE Database via the homepage http://unstats.un.org/unsd/databases.htm

Current, D., Lutz E. and Scherr S. 1995. "The costs and benefits of agroforestry to farmers". *The World Bank Research Observer*, Vol. 10, No. 2: 151-180.

Dasgupta, S., Deichmann, U., Meisner, C., and Wheeler, D. 2003. "The poverty/environment nexus in Cambodia and Lao people's Democratic Republic". *World Bank Policy Research Working Paper*, WP/2960.

Deans, J.D., Diagne, O., Lindley, D.K., Dione, M. and Parkinson, J.A. 1999. "Nutrient and organic-matter accumulation in *Acacia senegal* Fallows over 18 years". *Forest Ecology and Managment*, Vol. 124:153-162.

De Janvry, A., Fafchamps, M. and Sadoulet, E. 1991. "Peasant household behaviour with missing markets: some paradoxes explained". *Economic Journal*, Vol. 101:1400-1417.

De Waal, A. 1989. "*Famines that kills Darfur*". Clarendon Press, Oxford.

Dixit, A., Pindyck, R. S., 1994. *"Investment under uncertainty"*. Princeton University Press, Princeton, NJ.

Dregne, H. 2002. "Land degradation in the dry lands". *Arid Land Research and Management*, Vol. 16:99-132.

Dufournaud, C.M., Quinn, J.T., Harrington J.J. and co-workers. 1995. "A model of sustainable extraction of non-timber forest products in subsistence societies". *Environment and Planning*, Vol. A 27: 1667-1676.

Elamin, E.M., Musa, H. and Rahim, I. 1997. "Reconciling the trade offs between domestic demand and export markets: The case of Sudan dry lands agriculture". *Research Reports Series/0406*. Economic Research Forum, Cairo, Egypt.

El-Dukheri, I. A. 1997. "*Past changes and future prospects of traditional rain-fed farming in north Kordofan state*". PhD thesis München, Technische Universitat München-Germany.

El Obeid Auction Market Bureau. Annual statistics on agricultural crops trade 1960-2001 in Arabic. Ministry of Agriculture and Natural Resources, Kordofan, Sudan.

Elmadih, M. A., 1992. "*Target MOTAD analysis of risk-income trade off, dry land farming in the Nuba mountains region of Western Sudan*". Unpublished M.Sc thesis, Department of Agricultural Economics, Washington State University.

Elmqvist, B. 2003. "*The vulnerability of traditional agroforestry systems: a comparison of the gum arabic livelihood strategy before the 1984 drought to that of the present in Kordofan-Sudan*". Paper presented on Environment, Place and Sustainable Natural Resource Management Conference. Uppsala, Sweden 2003.

Elmqvist, B., Olsson, L., Elamin, E.M. and Warren, A. 2005. "A traditional agroforestry system under threat: an analysis of the gum Arabic market and cultivation in the Sudan". *Agroforestry systems*, Vol.64:211-218.

Elnagheeb, A.H. and Bromley, D.W. 1994. "Extensification of agriculture and deforestation: empirical evidence from Sudan". *Agricultural Economics*,Vol. 10:193–200.

Eklundh, L and Olsson, L. 2003. "Vegetation index trends for the African Sahel 1982-1999". *Geophysical Research Letters*,Vol. 30, No.8.

FAO [Food and Agriculture Organization]. 2005. "*Forest Resource Assessment 2005".* FAO, Rome.

FAO [Food and Agriculture Organization]. 2000. "*Forest Resource Assessment 2000".* FAO, Rome.

FAO [Food and Agriculture Organization]. 1997. "*The State of the World's Forests 1997*". FAO, Rome.

FAO [Food and Agriculture Organisation]. 1995. "*Non-wood forest products: gums, resins and latexes of plant origin*". FAO, Rome.

Feder G., Just R. E. and Zilberman D. 1985. "Adoption of agricultural innovations in developing Countries: a Survey". *Economic Development and Cultural Change,* Vol. 33: 254-297.

Fisher, I. 1930. "*The theory of interest*". Macmillan, New York.

FOSA [Forestry Sector Outlook Studies for Africa]. 2000. "FOSA: Sudan". *FOSA Working Paper*, FOSA/WP/19.

Freudenberger, M.S. 1993. "Regenerating the gum arabic economy: local-level resource management in northern Senegal". pp. 231-252. In: Friedman, J. and Rangen, H. (eds) *Defense of livelihood: comparative studies on environmental action*. Kumarian Press, West Hartford, USA.

Fries, J. 1990. "*Management of natural forests in the semi-arid areas of Africa: Present knowledge and research needs*". IRDC, Swedish University of Agricultural. Science, Uppsala. 119 pp.

GAC [Gum Arabic Company]. "*Annual reports for the years 1970-2002*". GAC research unit, Khartoum, Sudan.

GAC [Gum Arabic Company]. 2000. "*Recent indicators for gum arabic production*". A study conducted by GAC research unit, Khartoum, Sudan.

Gaston, G., Brown, S., Lorenzini, M., and Singh, K. D. 1998. "State and change in carbon pools in the forests of tropical Africa". *Global Change Biology*, Vo. 4:97-114.

Geçgil, A.S., Yalabik, H.S. and Groves, M.J. 1975. "A note on tragacanth of Turkish origin". *Planta Med*, Vol. 27: 284-286.

Geist, H.J. and Lambin, E.F. 2001. "What drives tropical deforestation? A meta-analysis of the proximate and underlying causes of deforestation based on substantial scale case study evidence". *LUCC Report Series No.4*. Univesity of Louvain, Louvain-la-Neuve.

Grainger, A. 1993. "*Controlling tropical deforestation*''. London: Earthscan.

Harrison, H. and Jackson, D. 1958. "*Ecological classification of the vegetation in Sudan*". Forest Bulletin, No.2. Ministry of Agriculture, Khartoum.

Hassett, K. A., Metcalf, G.E. 1995. "Investment under alternative return assumption: comparing random walk and mean reversion." *Journal of Economic Dynamics and Control*, Vol. 19:1471-1488.

Haworth, J. M., and Vincent, P. J. 1977. "*Medium term forecasting of orchard fruit production in the EEC: Methods and analysis*". Brussels, Belgium, European Communities Commission.

Hellden, U. 1992. "Desertification-time for an assessment". *Ambio*, Vol.20:372-383.

Higgins, R.S. 1996. "An economic theory of leader choice in Stackelberg models". *Journal of Economic Studies*, Vol. 23, No. 5/6:79-95.

Hinderson, T. 2004. "Analysing environmental change in semi-arid areas in Kordofan, Sudan". *Seminar series No. 109,* Physical Geography and Ecosystems Analysis. Lund University, Sweden.

Hoff, K., Braverman, A. and Stiglitz, J.E. 1993. "*The economics of rural organization. Theory, practice and policy*". Oxford University Press, Oxford.

Holden, S, T., Shiferaw, B., and Wik, M., 1998. "Poverty, market imperfections and time preferences of relevance for environmental policy?". *Environment and Development Economics*, Vol. 3:105-130.

Hulme, M. 2001. "Climatic perspectives on Sahelian desiccation 1973-1998". *Global Environmental Change*, Vo.11:19-29.

Hulme, M. and Kelly, P.M. 1993. "Exploring the linkages between climate change and desertification. *Environment*, Vol.35, No.4-11:39-45.

IEED and IES. 1990. "*Gum arabic rehabilitation in the republic of the Sudan: stage 1 report volume 2. Main report and recommendations for action*". International Institute for Environment and Development (IEED), London, England and Institute of Environmental Studies (IES), University of Khartoum, Sudan.

ISC [Importers service corporation], undated., 233 Suydam Avenue, Jersey city NJ 07304, USA. Or via ISC homepage: http://www.iscgums.com/our.htm

ITC, 2000. "*Market brief on gum arabic: overview of world production and trade*". International Trade Centre UNCTAD/WTO, Geneva.

JECFA [FAO/WHO Expert Committee on Food Additives]. 1999. "*Compendium of Food Additive Specifications*". Appendum 7, Joint JECFA 53rd session, Rome. 1-10 June 1999. Rome, Italy.

Jewitt, T. N. and Manton, J. S. 1954. "*Soil exhaustion in the Goz sands of the Sudan*". Congress international de la science du sol, Leopodville, pp. 413–416.

Keddeman, W. 1994. "Restocking of the gum belt for desertification control in Kordofan, Phase III". Report of the evaluation mission (UNSO/SUD/89/X05). Netherlands Economic Institute, Agricultural and Rural Development Department, Rotterdam.

Kevane, M. 1993. "Is the *sheil* a shill? Informal credit in rural Sudan". *The Journal of Developing Areas*, Vol.27:515-534.

Lamprey, H. 1976. "*Survey of desertification in Kordofan province*". United Nations Environment Program (UNEP), Nairobi.

Lapar M. A. and Pandey S. 1999. "Adoption of soil conservation: the case of Philippines uplands". *Agricultural Economics*, Vol. 21, No. 2: 241-256.

Larson B. A. and Bromley D. W. 1991. "Natural resource prices, export policies and deforestation: the case of Sudan". *World-Development,* Vol. 19, No. 10: 1289-1297.

Macrae, J. and Merlin, G. 2002. "*The prospects and constraints of development of gum arabic in Sub-Saharan Africa*". Washington, D.C., World Bank.

Maddala G.S. 1999. "*Limited dependent and qualitative variables in econometrics*". New York, Cambridge University Press.

Mainguet, M. and Da Silva, G.G. 1998. "Desertification and dry lands development: what can be done?". *Land Degradation and Development*, Vol.9:375-382.

Mink, S. 1993. "Poverty, population and the environment." *World Bank Discussion Paper* 189. The World Bank, Washington, DC.

Mithöfer, D., Wesseler, J. and Waibel, H. 2004. "*R&D and private investment: how to conserve indigenous fruit biodiversity of Southern Africa*". Paper presented at the 14th Annual Meeting of the European Association of Environmental and Resource Economists, Budapest, Hungary.

MOED (Sudan's Ministry of Environment and Development). 2003. "*Sudan's First National Communications under the United Nations Framework Convention on Climate Change.*" Higher Council for Environment and Natural Resources, Ministry of Environment and Development, Khartoum, Sudan.

Mohamed, A.G. 2005. "*Improvement of traditional Acacia senegal agroforestry: ecophysiological characteristics as indicators for tree-crop interaction on sandy soils in Western Sudan*". PhD thesis, Faculty of Agriculture and Forestry, University of Helsinki.

Mortimore, M. and Turner, B. 2005. "Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human induced desertification?" *Journal of Arid Environments*, Vol.14: 508-24.

Movik, S., Dejene, S. and Synnevåg, G. 2003. "Poverty and environmental degradation in the dry lands: an overview of problems and processes". *Noragric Working Paper* No.29. Agricultural University of Norway.

NAS [National Academy of Science]. 1983. "*Firewood crops-shrub and tree species for energy production*". Washington, D.C.

Neil S. and Lee D. 2001. "Explaining the adoption and disadoption of sustainable agriculture: the case of cover crops in northern Honduras". *Economic Development and Cultural Change,* Vol. 49, No. 4: 793-821.

Njiti, C. F. and Galiana , A. 1996. "Symbiotic properties and Rhizobium requirements for effective nodulation of five tropical dry zone acacias". *Agroforestry Systems*, Vol. 43: 265–275.

Olsson L., Eklundh, L., and Ardö J. 2005. "A recent greening of the Sahel-trends, patterns and potential causes". *Journal of Arid Environments*, Vol. 63: 556–566.

Olsson L. and Ardö J. 2002. "Soil carbon sequestration in degraded semiarid agro-ecosystems – perils and potentials". *Ambio*, Vol. 31: 471–477.

Olsson, L. 1993. "*On the causes of famine-drought, desertification and market failure in the Sudan*". *Ambio,* Vol. 22: 395-403.

Olsson, L. 1985. "*An integrated study of desertification*". Geografiska Institution, University of Lund, Lund.

Olsson, K. 1984. "*Long-term changes in woody vegetation in North Kordofan, the Sudan: a study with special emphasis on Acacia senegal*". Lund University, Lund.

Pal, D. and Sarkar, J. 2001. "A Stackelberg oligopoly with non identical firms". *Bulletin of Economic Research,* Vol. 53, No. 2: 127-133.

Parker, P.M. 2005. "The world market for gum arabic: A 2005 world perspective". Icon Group International Inc. San Diego, Ca. USA. 72p.

Pattanayak S. and Mercer, D.E 1998. "Valuing soil conservation benefits of agroforestry: contour hedgerows in the eastern Visayas, Philippines". *Agricultural Economics,* Vol. 18: 31-46.

Pattanayak S., Mercer, D. E., Sills E., and Yang, J.C. 2003. "Taking stock of agroforestry adoption studies". Agroforestry Systems, Vol. 57: 173-186.

Pearce, D., E. Barbier and Markandya, A. 1990. "*Sustainable development: Economics and environment in the Third World*", England: Edward Elgar.

Pearce, D. W. 1988. "Natural resource management and anti-desertification policy in the Sahel-Sudan zone: a case of gum arabic." *Geojournal*, Vol.17, No. 3:349-355.

Pender, J.L. 1996. "Discount rates and credit markets: theory and evidence from rural India". *Journal of Development Economics*, Vol. 50:257-296.

Perman, R., Ma, Y., McGilvary, J. and Common, M. 2003. "*Natural resource and environmental economics*". Pearson Education Limited, Edinburgh Gate.

Place F., Franzel S., DeWolf, J., Rommelse, R., Kweisga F., Niang A. and Jama B. 2002. "Agroforestry for soil-fertility replenishment: evidence on adoption processes in Kenya and Zambia". pp. 155–168. In: Barrett C.B., Place F. and Aboud A. (eds) *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices*. CABI Publishing, Wallingford, UK.

Purcell, K., 2005. "Sudan war impacts availability of gum arabic, a key ingredient for many commercial products". *HerbalGram*: the Journal of the American Botanical Council, Vol. 65:25-27.

Reenberg, A., Nielsen, T.L., Rasmussen, K. 1997. "Field expansion and reallocation in the Sahel-land use pattern dynamics in a fluctuating biophysical and socio-economic environment". *Global Environmental Change*, Vol.8, No.1:309-327.

Rogers E. M. 2003. "*The diffusion of innovations*". Fifth Edition. New York, The Free Press.

Rowell, D.P., Folland, C.K., Maskell, K. and Ward, M. 1995. "Variability of summer rainfall over tropical North Africa (1906-92): Observation and Modeling". *Quarterly Journal of the Royal Meteorological Society*, Vol. 121:669-704.

Salih, S.A. 1994. "Sustainable ecosystem in Africa: managing national forests in Sudan". *Working Paper* No. 117, Helsinki, Finland: UNU/WIDER.

Shapiro, C. 1989. "Theories of oligopoly behaviour". In: Schmalensee, R. and Willig, R. (eds), *Handbook of Industrial Organization*, North-Holland, New York, NY. pp. 329-414.

Sharawi, H.A. 1986. "*Acacia senegal in the gum belt of Western Sudan: a cost benefit analysis*". MSc. Thesis, Department of Forestry, University College of North Wales, Bangor.

Seif el Din A.G. and Zarroug M. 1996. "Production and commercialization of gum arabic in Sudan". In: FAO (eds), *Report of the International Expert Consultation on Non-Wood Forest Products*: Yogyakarta, Indonesia, 17–27 January 1995. FAO [Food and Agricultural Organization], Rome. pp. 465, 1-7.

Singh, N. and Vives, X., 1984. "Price and quantity competition in a differentiated oligopoly". *Rand Journal of Economics*, Vol. 15, No. 4: 546-554.

Stackelberg, H., 1934. "*Marktform und Gleichgewicht*". Vienna: Springer.

Stebbing, E. P. 1935. "The Encroaching Sahara: The threat to West African Colonies." *Geographical Journal*, Vol.14: 508-24.

UNSO [United Nations Sudano-Sahelian Office]. 1983. "*The gum market and the development of production*". Geneva and New York, UNSO.

Varian, H. R. 1999. "*Intermediate microeconomics: a modern approach*". 5th edition. New York: Norton.

Verbeken, D., Dierckx, S. and Dewettinck, K. 2003. "Exudate gums: occurrence, production and applications". *Appl Microbiol Biotechnol*, Vol. 63:10-21.

Visser, S. M., Leenders, J.K. and Leeuwis, M. 2003. "Farmers' perception of erosion by wind and water in northern Burkina Faso". *Land Degradation and Development*, Vol. 14: 123-132.

Wardell, D.A., Reenberg, A., Tettrup, C. 2004. "Historical footprints in contemporary land-use systems: forest cover changes in savannah woodlands in the Sudano-Sahelian zone. *Global Environmental Change*, Vol. 13, No.4:235-254.

Warren, A., Osbahr, H., Batterbury, S. and Chappell, A. 2003. "Indigenous views of soil erosion at Fanou Beri, south-western Niger". *Geoderma*, Vol. 11: 439-456.

Wesseler, J. 1997. "*Die Ökonomik der Einführung von Obstkulturen in der Cordillera Central von Nordluzon, Philippinen*". Shaker-Verlag, Aachen.

World Bank. 2001. "*The 2001 World Development Indicators* CD-ROM", Win*STARS, version 4.2, 32 bit, International Bank for Reconstruction and Development, The World Bank.

SUMMARY

The gum arabic belt in Sudan offered in the past an example of how environmental conservation and economic development could be achieved simultaneously as it generates a number of private and social benefits to gum producers and the country as a whole. The most important benefits from the gum based system are income from the gum harvest to the poor farmers and combating large scale desertification in the Sudan-Sahel zone. Over the last few decades, however, the gum belt suffered from increased degradation, gum production decreased and Sudan lost its near monopoly position in the gum export market. The main purpose of this study is to obtain a better understanding of the factors underlying the deforestation of the gum belt and the decline in gum production in Sudan during recent years.

Two important gum arabic producing acacias are found in the gum belt: *Acacia senegal* that produces high quality gum and *Acacia seyal* that produces low quality gum. The analysis in this study focuses mainly on *Acacia senegal* and *Acacia senegal*-based agroforestry system in Kordofan region – a major gum production area in Sudan. Various methodological approaches including theoretical and empirical analysis are employed in the study. A micro econometrics technique is used to identify the effect of socio-economic factors assumed to influence the disadoption of gum production. The study merges the real options approach with agroforestry to analyze farmers' investment decision in the choice between three different land use systems (gum agroforestry, gum forestry and agriculture). Moreover a theoretical scheme of Stackelberg model (non-cooperative oligopoly model) is deployed to analyze the competition in the gum export market for high and low quality gum between the (leader) Sudan and the followers (Chad and Nigeria). It attempts to investigate the effects of market interventions-such as international subsidies on gum market equilibrium and leader's (Sudan's) long run performance of profits from the gum export.

The micro-econometric approach used to analyze the determinants of farmers' disadoption of gum production shows that factors which affect

the opportunity cost of labor and income from annual crops tend to influence the observed variation in the behavior of adoption practices in gum production. Income from annual crops has a positive effect on continuous adoption of gum agroforestry. This specific result suggests that gum arabic and other agricultural crops (except groundnut because of overlap in harvest time) do not compete but rather complement one another in the household farming economy. Policy measures that aim to improve agricultural production in the region will induce farmers to settle in their village and reduce the seasonal labor migration trend which in turn will increase the availability of labor for gum production.

The theoretical framework developed using a real options approach aimed to analyze the economic incentives for entry (planting gum tree) and exit (abandoning gum forest) in the gum arabic agroforestry. Monte Carlo simulation shows that higher economic benefit is observed from agricultural production than the gum production. Results also suggest that 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 expansion (plantation) of gum forest we analyzed two options: converting idle land into gum forest and converting agricultural land into gum forest. 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 could 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 found to be below the calculated threshold values needed for the investment. Results suggest that an increase in the prices of gum arabic respectively of about 315 per cent and 775 percent is needed to induce a shift in land use system from continuous agricultural production to gum agroforestry or forestry land use systems respectively.

The analysis of the competition in the gum export market between the three major gum exporters attempts to assess the best strategy for Sudan to pursue in light of the recent changes in the gum market structure and the proposed donor policies of subsidizing gum production in Sub-Saharan Africa. The analysis is based on von Stackelberg model and investigates the effect of different subsidy scenarios. Our result shows that the proportionate increase in Sudan's profit is higher when the leader (Sudan) uses a subsidy to promote high quality gum than when it uses the subsidy to promote the low quality gum. In the case of followers (Chad, Nigeria), however, the decision on which quality to promote appears to be sensitive to the levels of own and cross price elasticities. Moreover, the results suggest that it is in the advantage of Sudan, Chad and Nigeria to adopt an export coordination strategy with some side payments to be made by Sudan as compensation for Chad's and Nigeria's lost profits in case they agree to curtail their export of high quality gum.

SAMENVATTING (SUMMARY IN DUTCH)

De productie van Arabische gom in Soedan was in het verleden een voorbeeld van hoe milieubescherming en economische ontwikkeling samen konden gaan. Gomproductie genereerde baten voor zowel de producenten van Arabische gom als de maatschappij als geheel. De meest belangrijke baten zijn de inkomens van de oogst voor arme boeren en het tegengaan van verwoestijning op grote schaal in de Sudan-Sahel zone. De laatste decennia echter, is de productie van Arabische gom in het belangrijkste gom-gebied van Sudan gedaald als gevolg van degradatie van het milieu. Sudan heeft hierdoor haar bijna monopolie-positie op de wereldmarkt voor Arabische gom verloren. Het belangrijkste doel van dit onderzoek is het verkrijgen van inzicht in de verklarende factoren voor ontbossing van het gom-gebied en achteruitgang van gom-productie in Soedan in de laatste jaren.

Twee belangrijke boomsoorten die Arabische gom produceren komen voor in het gomgebied: de *Acacia senegal* produceert Arabische gom van hoge kwaliteit en de *Acacia seyal* produceert Arabische gom van lagere kwaliteit. Dit onderzoek richt zich met name op de *Acacia senegal* en daarop gebaseerde productiesystemen in de Kordofan regio – een belangrijk gom-gebied in Soedan. In dit onderzoek passen we een theoretische en een empirische benadering toe. Een micro-econometrische techniek wordt gebruikt voor het identificeren van de effecten van socio-economische factoren die, naar verwacht, de afname van gom-productie beïnvloeden. Het onderzoek combineert de real options methode met agroforestry om de investeringsbeslissing van agrariërs in hun keuze tussen drie verschillende mogelijkheden voor landgebruik (gom agroforestry, gom forestry and landbouw) te analyseren. Een theoretisch schema van het Stackelberg model (een non-cooperatief oligopolie model) wordt ingezet voor de analyse van concurrentie in de export van hoge kwaliteit- en lage kwaliteit gom tussen (de leider) Soedan en de volgers (Tsjaad en Nigeria). Het model onderzoekt de effecten van markt-interventies, zoals internationale subsidies, op het evenwicht in de markt voor gom en de lange termijn opbrengsten van de export van gom voor Soedan.

De analyse laat zien dat factoren die van invloed zijn op de alternatieve kosten van arbeid en inkomen uit jaarlijkse gewassen, de neiging hebben om de geobserveerde variatie in de toe- en afname van gom-productie te beïnvloeden. Inkomen uit jaarlijkse gewassen heeft een positief effect op de continue adoptie van gom agroforestry. Dit specifieke resultaat suggereert dat Arabische gom en andere landbouwgewassen (met uitzondering van aardnoten vanwege een overlappende oogsttijd) niet met elkaar concurreren maar eerder elkaar complementeren op zelfvoorzienende agrarische bedrijven. Beleidsmaatregelen die op verhoging van landbouwproductie in de regio zijn gericht, geven een prikkel aan agrariërs om in hun dorp te blijven en migratie voor seizoensarbeid te reduceren. Dit verhoogt het aanbod van arbeid voor de productie van gom

Het theoretische kader dat is ontwikkeld met behulp van de real options methode had als doel economische prikkels voor entry (het planten van gom-bomen) en exit (het afstoten van gom-plantages) in de Arabisce gom agroforestry te analyseren. Monte Carlo simulatie laat zien dat agrarische productie hogere economische baten geeft dan gom-productie. De resultaten suggereren ook dat een toename van negen tot tien keer de gemiddelde alternatieve kosten van arbeid nodig is voordat agrariërs de gom-productie verlaten en gom-plantages verwaarlozen.

Voor de uitbreiding van gom-plantages hebben we twee mogelijkheden geanalyseerd: het omzetten van braak land in gom-plantages en het omzetten van landbouwgrond in gom-plantages. De resultaten tonen aan dat de additionele gemiddelde jaarlijkse baten van gom agroforestry of forestry boven de kritieke waarden voor het omzetten van braak land naar gom-plantages liggen. Dit suggereert dat agrariërs hun gom-plantages kunnen uitbreiden. Dit is echter niet de praktijk; we geven twee interpretaties die dit ontbreken van het omzetten van braak land naar gom-plantages verklaren: schaarste van arbeid en onzekere eigendomsrechten veroorzaakt door politieke instabiliteit in Soedan, waardoor lange termijn-investeringen worden ontmoedigd.

Bovendien zijn de huidige additionele gemiddelde jaarlijkse baten voor het omzetten van landbouwgrond in gom agroforestry (forestry) systemen onder het berekende benodigde niveau voor investeringen. De resultaten suggereren dat een toename van de prijs van Arabische gom van respectievelijk 315 en 775 procent nodig is om een verandering in landgebruik van continue agrarische productie naar gom agroforestry of forestry landgebruik te bewerkstelligen.

In het kader van recente veranderingen in de structuur van de gom-markt en in het voorgestelde beleid van donorlanden voor de subsidie van gom-productie in Sub-Sahara Afrika analyseren we de concurrentie in de export van gom tussen de drie grootste gom exporteurs. De analyse is gebaseerd op het von Stackelberg model en onderzoekt het effect van verschillende subsidie-scenario's. Ons resultaat laat zien dat de proportionele toename van Soedan's winst hoger is wanneer de leider (Soedan) een subsidie gebruikt voor het bevorderen van de productie van hoge kwaliteit gom dan wanneer het een subsidie gebruikt voor het bevorderen van de productie van lage kwaliteit gom. Voor de volgers (Tsjaad, Nigeria) echter, hangt de beslissing om de productie van een bepaalde kwaliteit gom te bevorderen af van het niveau van de eigen en de kruiselingse prijselasticiteit. Bovendien suggereren de resultaten dat Soedan, Tsjaad en Nigeria hun export moeten coördineren, waarbij Soedan Tsjaad en Nigeria compenseert voor lagere winsten ten gevolge van een lagere export van hoge kwaliteit gom.

TRAINING AND SUPERVISION PLAN

Description	*Institute*	*Credits*[35]
Mansholt PhD Courses:		
Mansholt Introduction Course	Wageningen University	1
Pathways for Agricultural Intensification	Wageningen University	2
Social Science Research Methods	Wageningen University	1
Writing and Presenting a Scientific paper	Wageningen University	1
Bio-economics Modeling	Wageningen University	1
Agricultural Models	Wageningen University	5
Econometrics 11	Wageningen University	3
Other PhD Courses		
Microeconomic Theory	Tilburg University	4
Macroeconomics Theory	Tilburg University	4
The Economics of Household Behavior	NAKE[36]	2
Environmental Problems and Policy : A theoretical Introduction	NAKE	2
Social Economics – Heterodox Approaches to Economic Theory	NAKE	2
Bayesian Inference	NAKE	2
Welfare Economics	Göteborg University-Sweden	5
Environmental Valuation	Göteborg University-Sweden	5
NAKE Workshops	NAKE	8
Oral Presentations Mansholt Multidisciplinary Seminar 9th North American Agroforestry Conference, 12-15 June, 2005, Rochester, Minnesota, USA		3
International Workshop: Sustainable Poverty Reduction in Less-favored areas, 8-9 December, 2005, Wageningen, The Netherlands		
International Conference: Economics of Poverty, Environment and Natural Resource Use, 17-19 May, 2006, Wageningen, The Netherlands		
3rd World Congress of Environmental and Resource Economists, 3-7 July, 2006, Kyoto, Japan		
26th Conference of the International Association of Agricultural Economists, 12-18 August, 2006, Brisbane, Australia		
Total (min 20 credits)		51

[35] I Credit point represent 40 hours.
[36] NAKE stands for Netherlands Network for Economics.

CURRICULUM VITAE

Afaf Rahim was born on 23 July 1969 in Nuhud, Sudan. She graduated with a master degree in Agricultural and Rural Development from the Faculty of Agricultural Science at Khartoum University in 1995. Soon after graduation she worked with Oxfam Sudan Program at various positions. First as an agricultural officer based in Malakal (South Sudan) and later as a support person for Oxfam program on conflict management based in Khartoum. In 1999 she was awarded the Joint Japan World Bank Graduate Scholarship Program (JJWBGP) to study a master degree in Agricultural Economics and Management at Wageningen University. Upon completion, she was awarded a grant from the Netherlands Foundation for Tropical Research (WOTRO) for Ph.D. study at the Environmental Economics and Natural Resources Group of Wageningen University. She received Storm van der Chijs Prize for her Ph.D. proposal in 2002. She also received a diploma from the Netherlands Network of Economics (NAKE) in 2004 and a certificate from Mansholt Graduate School in 2005. Results of her Ph.D. research have been presented at several international conferences and accepted for publication in a peer-reviewed journal.