

Modelling poverty traps

The prevention of erosion in Eastern-Africa

Tanzania as a case study



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Preface

This thesis is, what I started to call, 'the last mountain I have to climb in order to graduate for my Msc in Wageningen'. Ending a period of 23 years in school was not easy. It took me considerable effort. The following people have helped me to finish.

I want to thank my supervisor Rolf Groeneveld, who kept being calm and understanding during the process. My thesis took more time than we planned, but he kept reachable for comments via email and regular meetings. Gineke Boven, my study advisor and friend, was very important as well. She and her husband have helped me rethink the issues in my thesis and kept me positive about it. I want to thank Hans Peter Weikard for co-reading my thesis. My friends from de Paardengroep have been amazing this last year. They showed me that there was a life next to the thesis. The same held for Jacob en Nienke and their three horses. Furthermore, I want to thank my parents and sister for their continuous support and George and Margriet for offering me an office to work in. Last, but certainly not least, I want to thank David for being very supportive and caring.

At last, I hope this thesis made clear how urgent the need is to focus on land use and soil quality to improve production and consumption in developing countries.

Doutzen

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1. Introduction

Poverty has been the subject of numerous research, and the reduction of poverty is an important policy objective in several countries and international institutions. Substantial poverty does, however, still exist (Sachs 2005, 2009; Sachs and McArthur 2005, Azariadis and Stachurski 2004; UN 2007, 2008; Worldbank 2008a, 2008b, Christiaensen et al. 2010). Estimates of the United Nations state that 75% of the world's 1.2 billion poorest people live in rural areas, where they depend on ecosystem services from privately owned fields and public open space (UN 2007). In Sub Saharan Africa, seven out of ten people live in rural regions and depend for their living on small-scale farming, livestock production, fishing, hunting, mining and logging (IFAD in WRI 2005). Despite this large dependency, in many regions on the globe agricultural yields are on or barely above subsistence levels (Sylwester 2004). Yields in African countries are far below the global average, they are for example one third of that in South-Asia and half of that in South America (FAO 1997 in Barbier 2000). For years, opening new lands for grazing and cultivation has been the solution to declining harvests (Barbier 2000). This agricultural expansion has progressed at the cost of forests and public nature reserves, resulting in substantial land degradation and desertification on a large scale (Rabbinge 2009; Worldbank 2008b). There seems to be a vicious circle in which the poorest people degrade their soils because of their poverty, causing declining yields, which further accentuates their poverty (Chambers 1987 in Makhanya 2004; Sylwester 2004). This vicious circle has been explained as a poverty trap (Barrett 1991; Sylwester 2004; Sachs 2005). As millions of people live in poverty, strongly depending on natural resources, it is important to identify the mechanisms behind and possible ways out of such vicious circles or poverty traps. Also from a global perspective in which climate change and food availability are important topics, solving serious soil degradation in the world's poor regions should be a priority (Rabbinge 2009).

Christiaensen et al.(2010) warn that it is too easy to make the conclusion that because the poor are dependent on agriculture, large investments in agriculture should take place. However, he finds that when it comes to the poorest of the poor (-\$1 day per day) agriculture is up to 3.2 times better at reducing poverty than non-agriculture. As economic growth in the cities has little effect on the poorest of the poor, solving severe poverty in rural areas starts in agriculture. Agriculture is also labor intensive in those poorest areas, investment in this sector has therefore a poverty reducing effect (Christiaensen et al. 2010). There seems to be consensus that improved land management and agricultural intensification are important for the poorest to improve their quality of life (Semgalawe 1998; Barbier 2000; Rabbinge 2009, Christiaensen et al. 2010). The adoption of soil preservation technologies is essential to secure livelihoods for the poorest and at the same time improve land use efficiency to fulfill world demand for food, feed and fuel. Therefore the Worldbank emphasizes the importance of sustainable land management, which is defined as: a knowledge based procedure that helps to integrate land, water, biodiversity and environmental management to meet rising food and fiber demands while sustaining ecosystems and livelihoods (Worldbank 2008b). Although several soil fertility management technologies have been developed, these technologies have not generated the desired impacts due to a low level of adoption (Semgalawe 1998; Odeno et al. 2006). The non-adoption of such technologies is often assigned to a shopping list of factors such as credit

constraints, disease and malnutrition, lumpiness in technologies, insecurity, short time horizons etcetera. In this thesis the poverty trap mechanism will be used to bring structure in the shopping list of causes.

1.1 Problem description

Land degradation is a widespread problem in Africa, especially in the highlands that are more sensitive to erosion (Semgalawe 1998; Barbier 2000; Sylwester 2004; Muchena et al. 2005; IFAD 2010). Mountain areas capture rainfall, usually have better soils and are characterized by a shorter dry season in summer, which makes those areas suitable for agriculture, herding and water catchments (Ndufa et al. 2007). Mountain areas protect to some extent for diseases and insects (Brain 1980 in Jones 2000). However, high soil erosion rates have been reported in various parts of Africa's mountains (FAO 2002). Erratic rains have, together with unsustainable farmer practices, resulted in the existence of large areas of degraded land (Oldeman et al. 1991; Barbier 2000 in Cocchi et al. 2004; FAO 2002). This degraded land is often still in production by subsistence farmers, which leads to more degradation and lower crop yields. Although technologies are available to improve soil quality like the use of fertilizer, planting grass strips or creating terraces, the implementation of such technologies is till today very little. Research by Semgalawe (1998) and Jones (2002), indicate that the majority of farmers in East-Tanzania perceive the problem of soil degradation and most of them take measures like planting grass strips. There is however a category that doesn't invest in such techniques although they acknowledge degradation as a threat (Semgalawe 1998). Why have those farmers not invested in their soil quality? Some suggest that there is a relation between poverty and soil degradation, which manifests as a vicious circle into a low level equilibrium from which farmers can hardly escape (Perrings 1989; Dasgupta 1997; Barbier 2000; Sylwester 2004; Sachs 2005; Ndufa et al. 2007). Which mechanisms cause such poverty traps related to erosion and how can poverty trap theory be used to demonstrate why some subsistence farmers have not invested in soil quality?

1.2 Research objective

The goal of this thesis is to give insight in poverty trap mechanisms that prevent subsistence farmers from improving their soil quality. The findings from earlier research are combined with modelling exercises, to demonstrate when a poverty trap appears and which mechanisms make it difficult for the farmers to step out of such traps. Furthermore, existing literature on poverty traps will be structured. At last, recommendations will be given to policy makers and development workers about how to implement suitable policies that prevent people from falling in poverty traps.

1.3 Research questions

The main research question is:

Which are the main poverty trap mechanisms that prevent subsistence farmers in the highlands of developing countries to invest in technologies that improve their soil quality?

1. What is a poverty trap and what are the economic and institutional causes for poverty traps related to soil quality at the household level?
2. Which economic models have been applied to study poverty trap mechanisms in rural areas with respect to the management of soil quality?
3. How can small simulation models show us how different factors that influence the decision making of subsistence farmers, relate to each other?
4. How can the concepts from poverty trap theory and the findings from literature and modelling, be used by policy makers or development workers?

1.4 Methods

The research follows on the work of Sengalawe (1998) and runs parallel to a larger research program on erosion and the scaling up of sustainable land management practices conducted in Tanzania and Kenya funded by the WOTRO. The research builds on articles about poverty traps by Perrings (1989), Dasgupta (1997), Sylwester (2004) and Barrett (1991, 2008), Barrett and Carter(2006) and Bowles et al (2005). The research questions will be answered via a literature review, expert interviews and modelling exercises. In the following sections it is explained how each research question will relate to the overall question and objective.

1.4.1 Literature review

Research question 1 will be answered by the use of economic theory on poverty traps, institutional economics and soil sciences. Poverty traps occur when the mathematical conditions for the main functions do not hold as predicted in economic theory. Institutional economics is therefore a logical tool in describing and analyzing poverty traps. In order to understand the applicability and relevance of the findings from general theory, the concepts from theory will be linked to the specific empirical literature on subsistence farming in mountain rich areas. The large collection of PhD theses written about erosion and soil management in Eastern Africa will serve as an important source of information. The answer of the first research question will be the second chapter of the thesis.

Research question 2 will be answered by examining existing models in which an attempt has been made to model poverty traps. As it would be too broad to include all types of poverty traps, the focus will be on local poverty traps related to soil degradation. Analyzing the underlying mechanisms for such a trap to occur will help increase the understanding of the mechanisms behind poverty traps and provide steering for the modelling exercises.

1.4.2 Modelling

The literature review provided insight in what poverty traps are, how they come to being and which institutional characteristics prevent or preserve them. The mechanisms that cause the traps are discussed but not yet demonstrated. Therefore a modeling approach will be applied to give an insight in the mechanisms and their interaction. As poverty traps are dynamic phenomena, analyzing them empirically requires a large dataset with longitudinal data. For reasons of availability, time and economy, it is not possible to work with such datasets. Therefore simulation modelling is chosen to unravel the mechanism behind poverty traps without strict data needs. Two small simulation models will be created, using the program GAMS. The main goal of the models is to show the possible mechanisms that trap people in poverty. The models are used to explain and to show graphically why certain people are trapped in poverty.

1.4.3 Case study

The thesis is theoretical in nature and investigates the mechanisms behind poverty traps. However, it is important to make the link to practice. What can the finding from theory do for the policy makers and development workers that deal with poverty and erosion? This is discussed in chapter 6 in which research question 4 is answered. In a case study about Tanzania the main elements from the first chapters are combined with the experience from three experts and publications about Tanzania. The experts are Kor Voorzee, who has been the program director for Tanzania for Cordaid in the past 6 years. Gert Boven, who works for TEAR and has expertise in Kenya. Izaak van Melle, who used to work for the organization Heifer in Tanzania. The structure of the interview is a semi-structured interview. The focus of the case study is on the highlands of Tanzania. The country is politically and demographically relatively peaceful. Analyzing poverty traps related to soil degradation in one of the other countries is extra difficult due to civil unrest, war and conflict. When people are aware that they might have to leave their land to flight from terror, they are probably less likely to take care of their soils and invest in soil conservation. Assuming that those fears are less in Tanzania, the mechanisms behind the poverty trap focused on in this thesis, might be easier to distinguish. The second reason is the fact that Tanzania is mentioned as a macro-economic success story in the region. Which makes it interesting to analyse whether on a micro-scale, farmers are able to step out of poverty or not. At last, the large amount of previous research on Tanzania makes it easier to analyse that country.

1.5 Structure of the report

The thesis proceeds as followed. The literature part includes chapter 2 till 4. Chapter 2 explains the main concepts from poverty trap theory. Chapter 3 briefly discusses the main issues in soil erosion and the economics of investing soil conservation technologies. Chapter 4 discusses the models about poverty traps made by others. Chapter 5 is the analysis of two trapping mechanisms relevant for subsistence farmers in an environment where degradation takes place. Chapter 6 combines the findings from literature with the ones from the models and the expert interviews, resulting in a chapter about poverty traps in Tanzania. Chapter 7 summarizes the main findings from the thesis and in chapter 8 points for discussion and recommendations for further research are given.

2. Poverty trap theory

Until today severe differences in wealth exist between regions, villages or families. The poorest fifty percent of the world population receives, for example, less than ten percent of the world's income (Bowles et al. 2006). Sub-Saharan Africa continues to be the poorest region in the world. Many rural poor in Africa depend for their living on the natural resources in their surroundings (Christiaensen et al. 2010). Especially in the mountains of East Africa erosion and poverty are substantial, while those areas are potentially fertile and suitable for agricultural production (FAO 2002). Despite efforts of NGO's and governments to help the poor improve their standard of living, poverty and degradation continue (Semgalawe 1998). According to some, the poor are trapped in a situation of poverty and degradation, making them unable to deal with, adapt to or undo the changes in their environment. This idea of a trap is reflected in poverty trap theory. A poverty trap is any self-reinforcing mechanism which causes poverty to persist (Azariadis and Stachurski 2004; Matsuyama 2005; Barrett 2008). As many poor are involved in subsistence activities which are a part of the informal rather than formal economy (Sjaastad et al. 2005; Vedeld et al. 2004 and Cavendish 2000 in Worldbank 2008b), poverty is in this thesis defined as a lack of assets to accumulate income above a certain poverty line. More traditional measures of poverty are often based on daily income. An important aspect of a poverty trap is the existence of critical wealth thresholds. Below such thresholds, the necessary investments towards an optimal growth path cannot be made. In the rest of this chapter the main notions of poverty trap will be explained. Before analyzing the main concepts one remark has to be made. For some, poverty trap theory has a negative connotation as it has been used in the past to justify a rigorous stepwise approach towards development based on state guided or central led planning (Easterly 2005; Moyo 2009). Although poverty trap theory is the focus of this thesis, the focus will be on local micro-poverty traps rather than on macro-economic traps. I will thus try to avoid the sensitive aid versus non-aid debates related to poverty trap theory at the macro-level.

The branch of poverty trap literature discussed in this thesis relates to a general stream of scientific literature on multiple equilibria, feedback effects, stable states and critical thresholds (Hoff and Stiglitz 2000; Azariadis and Stachurski 2004; Barrett 2008; Scheffer 2009). Thinking about equilibria in complex systems is especially done in ecology with as the main example the equilibria of shallow lakes (Scheffer 2009). Economists have used those concepts to analyze why some people, communities or even nations remain poor whilst others have enjoyed rapid improvements in standards of living or economic development (Hoff and Stiglitz 2000; Azariadis and Stachurski 2004; Barrett 2008; Scheffer 2009). Several authors start their analysis of the reinforcing mechanisms that can lead to situations with several equilibria, with the basic neoclassical economic model and look for assumptions that might not hold in the context of developing countries. There is a tendency in development economics to take a more 'ecological' approach than traditional economists have done so far (Hoff and Stiglitz 2000; Azariadis and Stachurski 2005; Bowles et al. 2006). Modern development economics tends to be influenced more by biological than physical models (Hoff and Stiglitz 2000, p. 396). This way of analyzing economic systems focuses less on

unique equilibria and more on evolutionary processes, complex systems, and events that cause systems to diverge (Hoff and Stiglitz 2000) rather than converge.

Poverty trap theory aims at describing and investigating this complexity and these dynamics. According to poverty trap theory, economic systems can contain multiple equilibria if investments are lumpy or have economies of scale, spillover effects exist, access to product, credit and labor markets is limited, institutions are dysfunctional, neighborhood effects occur and biophysical relations have particular nonlinear properties (Barrett and Swallow 2006; Bowles et al. 2006; Barrett 2008). The poverty trap argument has been made on different scales and might apply in developing and developed countries (Bowles et al. 2006). An example of a poverty trap in developed countries is the trap in which the poorest people in society, who receive financial assistance, accompanying subsidies and other income dependent services, have little incentive to look for a job. The income they will earn in the job is likely not to outweigh the extra financial services they currently receive in their unemployed situation. This reverse incentive to improve their situation is demotivating them to improve their situation (CPB 2008). In this chapter various examples of poverty traps in developing settings are discussed.

2.1 An introduction in poverty trap theory

Already in 1953 professor Ragnar Nurkse wrote in his book *Problems of Capital-Formation in Underdeveloped Countries* that the idea of 'the vicious circle of poverty' which he saw coming back in many publications in development economics, seemed to be treated as something obvious, too obvious even to be worth examining. He decided to study why it was such a logical assumption and what was behind this cycle (Nurkse 1953 in Azariadis and Stachurski 2004). The theoretical explanation of poverty traps starts on the macro-level and begins with the neoclassical model, market failure and multiple equilibria.

2.1.1 The neoclassical economic assumptions

It makes sense to start the analysis of poverty traps at the simple benchmark neoclassical economic model. The term 'neoclassical models' is used for 'models with maximizing agents who interact through a complete set of perfectly competitive markets' (Hoff and Stiglitz 2000, p.444). The three core aspects in these models are: preferences; technology; and resources. According to Hoff and Stiglitz (2000) 'there are good reasons to start with this benchmark as it has relevance in practice as the profit motive is a powerful force'. In development economics it is sometimes suggested that the neoclassical fundamentals provide little or no explanation to what happens in developing countries. 'Although neoclassical economics has failed to provide us with a theoretical framework for thinking about the problems of developing countries, it has played a critical role in the evolution of development theory (Hoff and Stiglitz 2000)'. The neoclassical theory does, however, provide a strong fundament in economics. Starting with the well-tested benchmark model, relaxations can be made to make the model more realistic or suitable to the situations of developing countries.

Multiple equilibria should not appear according to the standard neoclassical economic theory, neither should poverty traps. Economic textbooks often show graphs that follow all mathematic criteria for unique and stable equilibria (Mankiw 2006, Krugman and Obstfeld 2006). The benchmark situation in competitive, neoclassical economies is based on assumptions of complete markets, free entry and exit, negligible transaction costs and convex technology, like in the Solow-Swan model (1956) and the work of Cass (1965) and Koopmans (1965). First the main assumptions of neoclassical economics are given, in order to start understanding poverty traps. The main assumptions in neoclassical models are the following (Slangen et al. 2008, p.65):

1- Rationality: utility maximization by households and profit maximization by firms

The neoclassical model with diminishing returns (Solow 1956) begins with an aggregate production function in which the output of a certain product is on the left hand side of the equation. The right hand side of the equation represents a function of capital and labor, describing the set of inputs that produce the maximum output. A producer wishes to maximize profits; given the production factors he has available for production. When opportunities to earn profit exist in a certain market, other firms will enter and the profit will converge to zero (Varian 2006). An individual consumer maximizes his well-being, by making rational choices based on perfect information about his preferences, different options to satisfy those preferences and his time and income constraints. The utility function describes how preferences relate to certain consumption decisions. The farmers in this thesis are consumer and producer at the same time. In this case they maximize well being, represented by a utility function that links consumption to their own production decisions.

2- The availability of complete and perfect information

'Complete and perfect information' refers to the assumption that all information is available to each individual and all information about a good is captured in the price. Perfect information is however rare in reality. The price can often not capture all dimensions of a good. Externalities can appear and in some cases a market price is absent. Information can be available, but not equally to all parties and at last information can be costly (Slangen et al. 2008, p.123).

3- Completely defined and enforceable property rights

In the standard neoclassical model it is assumed that all resources have a single owner who has the right to use, sell or exploit the resource. In other words, the person has the property right over the asset. A property right should be perfectly defined, completely private, enforceable and can be sold or bought without extra costs (Slangen et al. 2008, p. 70). In reality, property rights are often not defined or poorly protected. Speaking about property rights asks for a sharp definition. Each discipline has its own use of the word ownership, and even within economics ownership and property rights are not always clear concepts.

4- Unlimited and free market transactions

When there are unlimited market transactions and the market mechanism does not include any costs, such as the costs to find a supplier, there are no transaction costs. When there are many buyers and many suppliers of homogenous, anonymous goods, there is a market of perfect competition in which no market power exists.

5- Completely divisible inputs and outputs

The assumption of completely divisible inputs and outputs suggests that when it would be beneficial to use a fraction of a unit extra labor, capital or another variable input to produce one more unit output, this is possible. The opposite, indivisibility or lumpiness means that for providing some goods a certain scale is required.

6- Free entry and exit in complete markets

In the market situation described in traditional economics, demand and supply are balanced, there is a price high enough to cover costs and low enough to prevent rivals from increasing their market share by decreasing prices. Free entry and exit means that the costs curves of new entrants are similar to those that already operate in the industry and that it is possible to leave the industry without incurring losses (Slangen et al. 2008 p.51). This can only be reached when there are no sunk costs and new entrants are not disadvantaged in comparison to established firms concerning product quality and technology. In reality sunk costs, asset specificity, exit barriers, market power and the institutional environment make that those assumptions are seldom met in reality.

7- Diminishing returns to technology

Several books have been written about technology and economic growth. Some suggest that technological progress is exogenously determined; others predict it to be endogenously dependent on human capital and resources invested in Research and Development. In the neoclassical model it is often assumed that “most basic proposition of growth theory is that in order to sustain a positive growth rate of output per capita in the long run, there must be continual advances in technological knowledge” (Aghion and Howitt 1997, p. 11 in Mokyr 2005). Technological progress makes it possible that less people produce the same amount of goods. Because of diminishing returns to capital, economies will eventually reach a point at which no new increase in capital will create economic growth. An accompanying assumption is that poor countries with less capital per person will grow faster because each investment in capital will produce a higher return than rich countries with ample capital. Neoclassical economics implicitly assumes no significant indivisibilities or non-convexities (Azariadis and Stachurski 2004, p.16). This means that the best technologies will be used, and used efficiently.

To summarize: In the benchmark situation holds that markets are complete, entry and exit is free, transaction costs are negligible, and technology is convex at an efficient scale relative to the size of the market. A complete set of virtual prices ensures that all projects with positive net social benefits are undertaken (Azariadis and Stachurski 2004, p.4).

2.1.2 Multiple equilibria

The study of equilibria, stable states and thresholds appears in different disciplines. Ecologists are concerned with critical thresholds in ecosystems, for instance in oceans or forests. Identifying the presence of such thresholds can help preventing catastrophic collapses in such ecosystems. In economics the analysis of stable states and equilibria can especially be linked to the study of international wealth accumulation (Azariadis and Stachurski 2004; Barrett 2008). Economists have had a difficult time to explain the divergence between rich and poor countries using the classical economic assumptions (Barrett 2008). The poor countries should in theory quickly catch up with the richer ones and wealth should converge to a certain level (Ravallion 2009). This should be the case because the marginal benefits of using a new technology are larger in poor countries than in already richer countries. When the neoclassical assumptions hold, converge rather than divergence should happen. Also at the micro-economic scale, vast differences in wealth are hard to explain. When there is a convex set of production possibilities, preferences are consistent with economic theory and credit is available, a unique equilibrium will exist rather than multiple equilibria.

The poverty trap thesis says that there is a basin of attraction towards a lower level equilibrium. The definition often used is the one of Azariadis and Stachurski (2004): a poverty trap is any reinforcing mechanism which causes poverty to persist. This can be a unique equilibrium that is located at a low level of well-being. But situations in which multiple equilibria are present are the ones especially interesting (Barrett 2008). The concept of equilibrium comes back often in economics. A well-known example is the equilibrium in the market system where demand and supply for a certain product are equal, achieved through the price mechanism in a free market. An equilibrium is a situation in which the processes that affect the state of a system precisely balance out so that the system does not change (Scheffer 2009). In classical economic theory, equilibria are unique and stable (Hoff and Stiglitz 2000). Prices, interest rates, factor rewards, and the exchange rate bring equilibrium in the demand and supply for money, (international) goods and services, labor and other production factors (Mankiw 2006, p.65). An example of an equilibrium at the micro-scale is the herd size of a pastoralist. A pastoralist might experience that a herd size of 35 animals is optimal for him. The diseased and born animals balance out each other and when a shock appears the animal stock is able to restore itself to 35 animals again (example taken from Lybbert et al.2004). At the same time the pastoralist can oversee his herd when it is around 35 animals and there is sufficient food for all animals. In order for a system to be trapped in a low level equilibrium, a system needs to have at least two equilibria. That means that there are alternative stable states to which a system can converge. Alternative stable states are contrasting states to which a system may converge under the same external conditions (Scheffer 2009). In ecology an example of two alternative equilibria can be a bright lake with several fishes and plant varieties and a lake with trouble water dominated by just a few species.

An equilibrium, a stable point for a system to converge to, is also called an attractor (Scheffer 2009). A system will converge towards one of the attractors but needs sufficient time to do so. Normally the equilibrium in a dynamic system moves smoothly in response to changes in the environment, but there are also systems where alternative stable states exist with an unstable equilibrium that marks the border between the two stable attractors (Scheffer 2009). When there are two stable attractors divided by an unstable equilibrium, it is difficult to move from one equilibrium to the other. There is then a large shock needed to prevent the system to converge back to the low-level and stable equilibrium (Scheffer 2009). When small steps are made towards a higher equilibrium the system will behave like a vicious cycle back towards the low level equilibrium. Economic systems can contain multiple equilibria if, for instance, investments are lumpy or have economies of scale, access to product, credit and labor markets is limited, and biophysical relations have particular nonlinear properties (Barrett and Swallow 2006; Bowles et al. 2006; Barrett 2008). The bimodal pattern of wealth is apparent not only for countries; it appears on various scales (Scheffer 2009).

2.1.3 Market failure and institutions

The step from perfect functioning markets towards multiple equilibria can be made by critically examining the assumptions of the neoclassical model, especially in the light of the situation in developing countries. Markets for capital, insurance, labor or products might not be complete, information is often not perfect, technological options might not be known or accessible, there are public goods and technologies can have non-convexities (Stiglitz 1985). Bounded rationality, market power, non-convex technologies, imperfect information, and costly transactions make that the economic behavior as predicted in the neoclassical models might not always occur in reality (Slangen et al. 2008, p.400). These factors make that institutions and other 'rules of the game' become critical to economic performance (Azariadis and Stachurski 2004, P.4).

Economies of scale, spill over and positive feedbacks

In real life the best technologies are not always adopted (Azariadis and Stachurski 2004, p.2). In many poor countries, regions or families the technologies used have barely changed over time. The adoption of technologies from the wealthy to the poor doesn't go as expected. Technology might not be convex. There can be scale economies, spillover effects and positive feedback effects. Modern techniques can involve large fixed costs or demand a greater specialization of the production process. For the provision of certain goods a minimum scale is needed. This scale is needed because of lumpiness, or imperfect divisibility. Lumpiness results in high fixed costs and relatively small variable costs. For electricity, roads, gas, water and other networks and infrastructure services, large fixed costs have to be paid initially. It is too costly and inefficient to invest in such goods when the scale is not sufficiently large (Slangen et al. 2008, p.198). But also for goods that are in principle perfectly divisible, like fertilizer, indivisibilities can appear. According to a study of the Worldbank, fertilizer is in Ethiopia especially available in bags with 25 kilograms (Worldbank 2006, in Dercon and Christiaensen 2007).

When the demand for a good or service is low, investment in an increasing returns technology might be small, which reduces productivity and reinforces high prices and low demand. High fixed costs are a larger problem in poor countries where markets are relatively small. If markets are small, then the neoclassical assumption that technologies are convex at an efficient scale, may not hold (Azariadis and Stachurski 2004, p.5). Increasing the market size in order to overcome this problem can be complicated in countries far from oceans, land locked, or in areas where infrastructure is poorly developed (Sachs 2005). When returns to an investment are increasing, a rise in output lowers unit costs. This sets in motion a chain of positive self reinforcement. Lower unit costs encourage production, lowering unit costs and so on. Such feedbacks can strongly reinforce development (Azariadis and Stachurski 2004, p.5).

Imperfect or absent markets

The assumptions that companies can easily enter and leave a market and that production factors can move easily towards their most efficient use, often do not hold. Markets for labor can be absent, which is the case in many subsistence regions. Credit and insurance markets might face problems due to asymmetrical and imperfect information, leading to a large risk for the lender and incentives to cheat for the borrower. 'It is well documented that some markets are 'missing' to certain households in developing countries' (Bulte and van Soest 1999). The underdevelopment or malfunctioning of markets, especially for labor and food, is also acknowledged by the World Bank for the case of Africa (Worldbank 1990 in Bulte and van Soest 1999).

Production factors

Labor, capital and land are, together with entrepreneurship, often mentioned as the main factors for production. Capital and entrepreneurship (the latter referring to taking risk, and trying something new with uncertain success) are discussed in separate parts below. Markets for labor and land are often not as perfect as assumed in neoclassical theory. Land is the most important possession of the rural poor. In many countries it is difficult to buy land, prices are simply too high, there is no access to loans, or land rights are difficult to require due to governmental bureaucracy. Around 100 million households depend for their living on farming land they do not own (UN in Smith 2005). When farmers have insecure land tenure rights there is a tendency to treat it as a short-term resource (Smith 2005, p.37). However, even with enough land to produce beyond subsistence levels, there has to be a market for the produced goods. In poor regions, lacking electricity or roads, there are little alternatives for the labor force to earn an income. In order to start a healthy business, there needs to be the possibility to sell the produce. In poor regions it is questionable whether there is this possibility. Together with the notion that transportation is difficult and costly, because of bad roads, it is difficult to start new businesses. This leads in several countries to situations in which the number of jobs is very small in relation to the large offer of labor (Smith 2005, p.96). 'The poor say the most important thing, to them is finding a job with a steady income' (Smith 2005, p.103).

Credit

In poor countries, the risk to lend out money to the poorest is large, as valuable collateral is often absent. The poorest therefore often lack access to credit markets, which preserves their poverty as they cannot make the initial investments to run a successful business. Funds are needed to take advantages of the economic opportunities, especially those involving fixed costs (Azariadis and Stachurski 2004, p.6). Micro-credit institutions try to overcome the problem of little to no collateral by using trust or the social relatedness in a community as collateral (Moyo 2009). For poor rural farmers, access to credit can provide the chance to purchase tools, fertilizers, a draft animal, a small tractor or irrigation. In such a way productivity can increase steeply, providing possibilities for commercial farming. However, when micro-credit is used for consumption or for the perseveration of so called Ponzi-schemes it is likely to worsen rather than improve the situation (Moyo 2009).

Insurance

Closely related to the market for credit is the market for insurance. Together, those financial markets permit people to insure against shocks ex-ante or to borrow ex-post (Barrett et al. 2006). When someone insures himself against the happening of a certain event, for instance theft or fire, he pays the insurer a monthly or annual premium in return for a fixed amount of money when the event happens. The insurer has such contracts with many clients and insures especially the risk for which it is unlikely that all clients suffer damage at the same time. However, credit and insurance are routinely undersupplied in low-income rural areas, especially to poor people. Formal insurance schemes are mostly absent and informal risk-sharing arrangements and savings offer only partial consumption smoothing (Morduch 1995; Dercon 1998). Why are such markets malfunctioning? The standard economic problems associated with insurance: asymmetric information and moral hazard play an important role. The specific situation of the rural poor is also important. It is often difficult for an insurer to offer insurance against droughts or natural disasters, which are exactly the risks to which the poorest are often exposed. "Spatially-correlated catastrophic losses can exceed the reserves of an insurer or lender, leaving unsuspecting policyholders or depositors unprotected" (Barrett et al. 2007). The transaction costs of offering financial services in rural areas are much higher than in urban areas because of limited transportation, communication, and legal infrastructure (Binswanger and Rosenzweig 1986), and higher for smaller contracts than for large (Barrett et al. 2006). Not being able to take out insurance can distort almost everything a person does (Smith 2005). Which is made very clear in a quote from the Washington Post (Wax 2010) "Farmers who find themselves with a little disposable income are turning to insurance, plan with confidence and have hope in the future" .

Bounded rationality and information

People do not have perfect information and are not perfectly rational (Herbert 1957; Rubinstein 1998; Kahneman 2003; Slangen et al. 2009). Institutional and behavioral economists have introduced the term bounded rationality (Herbert 1957; Rubinstein 1998; Kahneman and Smith 2002). With which they summarize the "limitations on human mental abilities that prevent people from foreseeing all possible contingencies and calculating their optimal behavior"(Slangen et al. 2008, p.389). In other words, people cannot know

everything and cannot take all relevant information into account when making a decision. Even when markets would work perfectly, it can happen that an inefficient technology keeps being used. Although productivity in agriculture can increase by technical progress like high quality seeds, improved fertilizers, and improved farming practices. Small farmers might not be able to acquire and disseminate this information. There can be fixed cost associated with getting information (Stiglitz 1985). If the farmers do not know about a new technology, they might all choose an inefficient one, which is reinforced by herd effects. This herd effects refers to an effect where people follow each other in certain choices (Hof 2000 in Azariadis and Stachurski 2004, p.8). The risk to use a technology that is already successfully used by others is smaller than the risk to use of a new, unknown technology.

Transaction costs

The market mechanism is not costless. There are certain costs involved in using the market, like looking for information, finding a transaction partner, negotiating about terms and conditions, developing a contract and using institutional arrangements to obtain and secure ownership (Slangen et al. 2008). Transaction cost economics is a branch in economics that describes transaction costs. Transaction costs are defined as: 'the costs of carrying out a transaction, or the opportunity costs incurred when an efficiency-enhancing transaction is not realized' (Slangen et al. 2008).

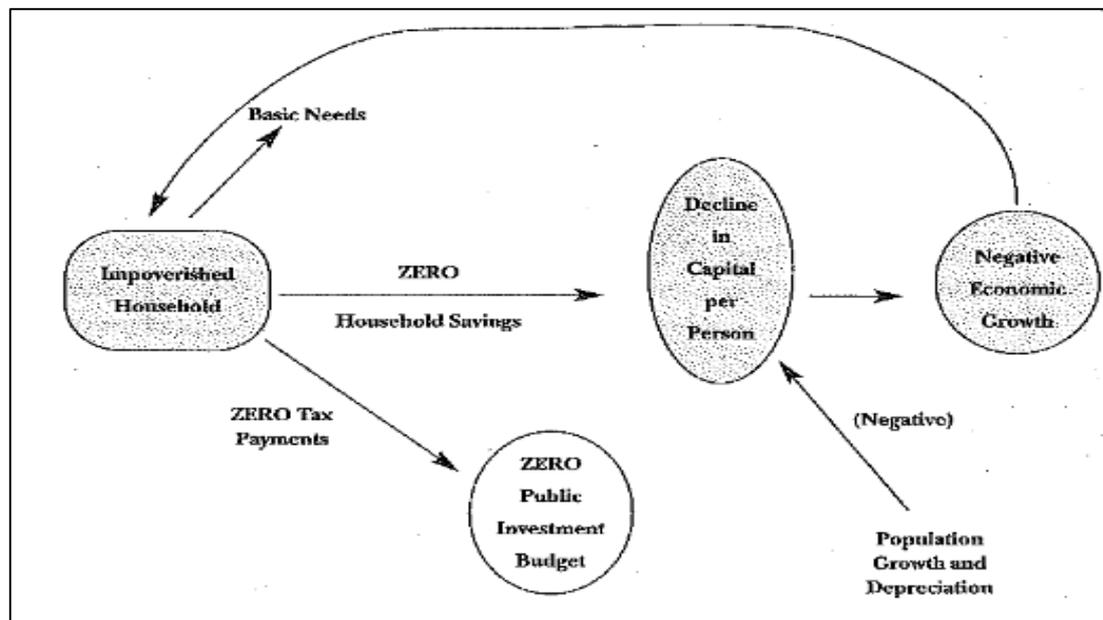
Institutional structure

When information is incomplete and agents are boundedly rational, outcomes are likely to be driven by institutions. Institutions are the rules of the game in society, they are the humanly devised constraints that structure human interaction. They are composed by formal rules, informal constraints and the enforcement characteristics of both (Slangen et al. 2008, p.25). The term institution describes the formal rules of the institutional environment and the institutional arrangements themselves (Slangen et al. 2008). The institutions in a society, for instance the social relations, norms and values, have developed over time and are in such a way path dependent. This means that history has channeled social norms, habits and institutions. In India it can for instance be observed that, although women do the majority of the work in the country, they are excluded for services and discriminated against in several daily situations (Smith 2005). The institutional framework that corrects market failure is an endogenous factor in the economy. When institutions are corrupt, they might send out incentives to preserve this corruption (Azariadis and Stachurski 2004, p.4). North (1993) states that 'institutions are not necessarily created to be socially efficient, they are created to serve the interests of those with the bargaining power to create new rules' (North 1993, p.3 in Azariadis and Stachurski 2004, p.7).

2.3 Examples of different trap mechanisms

The mechanisms that reinforce poverty may occur at any scale of social and spatial aggregation. Traps can arise not just across geographical locations such as nation boundaries, but also within collections of individuals affiliated by ethnicity or religious belief (Azariadis and Stachurski 2004). The main poverty trap seems to be caused by poverty itself (Sachs 2005). In a situation in which poor rural villages lack trucks, paved roads, electricity generators and irrigation structures, there is little hope that sustainable land management

practices are adopted. In such areas human capital is low as education fees might be too high or schools or teachers are absent. Hunger and diseases are daily phenomena. Natural capital declines and soils are depleted. The poor are too poor to save for the future and thereby accumulate the physical, human and natural capital that can improve their situation (Sachs 2005). This cycle is depicted in figure 2.1.



Source: Sachs 2005

Figure 2.1: Zero saving poverty trap

Bowles et al. (2006, p.2-3) group the variety of causes of persistent poverty in three larger causes: critical thresholds in overall wealth and human capital, dysfunctional institutions and neighborhood effects. The latter refers to group and herd effects in economic society where ones membership of various groups is fixed or depends on the economy (Bowles et al. 2006, p.3). Barrett (2008) groups the variety of causes into three different categories: 1. market imperfections, 2. imperfect learning and bounded rationality, and 3. spillovers, coordination failures and economically dysfunctional institutions (Barrett 2008). Smith (2005) mentions 20 examples of poverty traps in developing countries. Below the most important traps and accompanying causes are given.

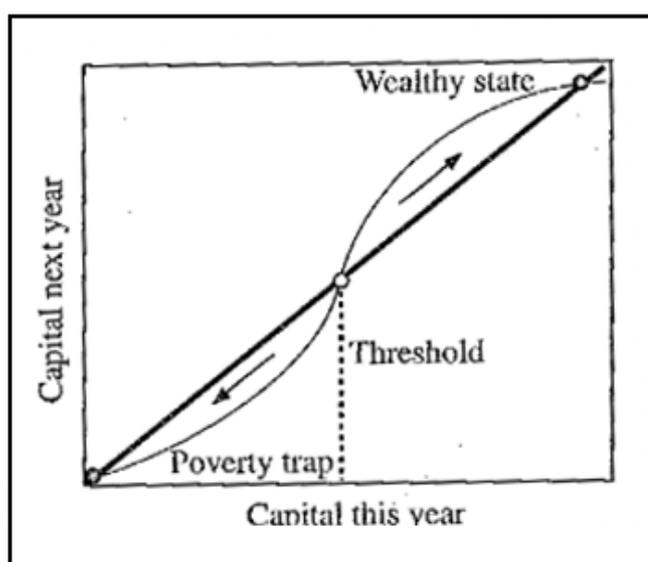
Family-child labor and illiteracy traps

If parents are too unhealthy and unskilled to produce enough for the survival of the family, children might have to work (Basu and Van 1998 in Barrett 2008). When they work they aren't going to school, causing a new generation of uneducated people (Loury 1981 in Barrett 2008). In such a way, poverty is transmitted across generations (Smith 2005). Also when children don't have to work, they might not necessarily be able to go to school. When the school is too far away, uniforms are expensive or attendance fees are too high, the same problem arises as with child labor. It can also be the case that schools have no qualified teachers or that it is too costly to start up a school. In the latter case the lumpiness of the investment in a school prevents the school from being built.

Capital traps

The neoclassical model emphasizes the importance of technology in economic development. Investment in technology is closely related to the ability to save and borrow money. In the neoclassical model, saving is a fraction of national income that is rewarded with an interest rate. Put very simply, the saved money is available for companies to use for investment (Mankiw 2006). Formal and informal banks are the institutions that make saving and borrowing possible and in such a way create investment possibilities. In developing countries the financial services to store or borrow money are till today poorly developed, especially in rural areas (Besley 1995 in Barrett 2008). The absence of such institutions may also be a consequence of the fact that the farmers, oriented to reduce risk, prefer to save in real assets. 'Saving in real assets, like cows or goat, provides both a means of direct consumption in the case of drought, insurance against direct entitlement failure, and a degree of protection against the volatility of product prices' (Perrings 1989).

A lack of borrowing and lending facilities is one of the necessary conditions for a poverty trap manifest. When farmers could freely borrow to invest at an interest rate that is lower than the improvement in the expected terms of trade that result from access accumulation, they would be able to repay the loan (Barrett 2008). However, access to capital is limited and most small farmers own little capital, or productive assets. The capital trap is represented in figure 2.2. The 45 degrees line represents a situation in which the amount of capital in this year (x-axis) equals the amount of capital next year (y-axis). The dot in the middle is the threshold value. This is a point where the system is very sensitive to changing conditions. Policy incentives to lift people out of the poverty trap have to lift them over the threshold. From the threshold value downwards the amount of capital decreases over year towards the 0 point and from the threshold upwards the amount of capital increases towards a growth path (Wilson 2007, p. 98; Khandke 2003; Yunus and Jolis 1998 in Gehlich-Shillabeer 2008).



Source: Scheffer 2009

Figure 2.2: Graphical illustration of a poverty trap due to a threshold level in capital stock

Micro credit might be a solution to this trap (Yunus and Yolis 1998, Wilson 2007, in Gehlich-Shillabeer 2008). Then the money should be used in a productive manner, for instance improving soil quality, buying productive assets like goats or improved plant varieties and so on. Rahman(2007) concluded that only fifty of loans distributed in Bangladesh were used in a productive manner. Gehlich-Shillabeer concludes in a case study about micro credit in Bangladesh that 87 per cent of the loans were used to finance consumption (Gehlich-Shillabeer 2008).

Mal functioning credit systems can also work as a poverty trap. In developing settings, it is not uncommon that the interest rate is so high that the earnings derived from the money are insufficient to cover the interest costs, let alone to pay back the borrowed sum. The poor can have debts with a middle man, which they repay with the money from micro-credit, and when it is time to pay the micro-credit organization they borrow from the middle man again. This borrowing from one lender to pay off another is known as a Ponzi scheme (Moyo 2009, p. 130). There are cases where the borrowers have to work for the lender in order to repay the bond, leading to slavery-like situations (Smith 2005, p.12). The other side of providing small amounts of money to the poor is giving them a place to store the money in a safe way. When smallholders are able to save some money they are forced to store the earned money in their houses with the risk of theft. It is more likely that they will buy cattle to prevent their money from being stolen, than that they save money to invest in better seeds, tools to work on the land or fertilizer. A trustable and accessible financing system in which money can be borrowed and saved can be the first 'push' out of the cycle of poverty.

Information traps

There is a broad discipline in economics that analyses situations of imperfect or asymmetric information. In a complex environment with nonlinear dynamics it is optimistic to assume that individuals can predict the consequences of behavioral change. Changing in for instance land quality are difficult to observe until large changes appear. There can be important lags in information availability. Soil loss is one example. Individuals might come aware of new technologies or marketing channels with different time lags, where the slower ones face reduced returns to adoption (Barrett 2008). Information is not always accessible to everyone. Many workers lack information about other job possibilities or wage rates in different companies or sectors, or don't have the energy or time to investigate those opportunities (Smith 2005, p.14). According to Barrett (2008), the differentiated nature of the social networks through which information flows can cause lags or barriers to learning about this information (Barrett 2008). Information can also be costly. It can be the case that information about market prices is not accessible without a mobile phone. Whilst having access to up to date market information would help farmers to make right production decisions, the costs associated with getting the information can be too high.

Risk traps

The risk attitude of people can lead to poverty trap situations. Risk means that although the future is unknown, the probability of a certain outcome is known. Uncertainty means that the probability of any outcome is not known. The term shock is used for the adverse realization of a stochastic variable. After a shock, the asset base of production can become

lower than the critical asset threshold which can lead to a poverty trap (Barrett and Carter 2006; Lybbert et al.2004) but this is not related to uncertainty or risk. The poverty trap related to risk is an ex-ante phenomenon. The risk minimizing strategies a farmer can perform bias production and consumption decisions in favor of tried practices and traditional products, and against technological innovation (Perring 1989). This approach to decrease the variation in income goes at the costs of a lower median (Barrett 2008). While specializing in one cash crop might be profitable, a farmer might stay with a broad portfolio of crops. The risk of catastrophic diseases or low prices for all crops at the same time is smaller. However, scale and specialization benefits exist when only one or two crops are produced (Barbier 2000). The poorer the farmer is initially, the more risk averse he will behave. The ones with a higher start capital are better able to self-insure themselves or bare the risk of low prices or a bad harvest (Barrett 2008). This can lead to risk induced poverty traps, whereby those who can insure their consumption against income shocks can take advantage of the more profitable opportunities, whilst others are stuck with low risk but low return activities, trapping them into poverty (Barrett et al. 2006). Micro-insurance can help those starting in a poor situation: "In addition to providing a measure of security, insurance has been an economic catalyst that has allowed farmers to invest more boldly in new livestock or equipment, without the fear that a single storm or accident could wipe them out"(Wax 2010, Washington Post).

Health induced traps

Labor is often the most important production factor in poor households. Although the labor of the family is a free production factor, it needs to be paid with calories. The need for a minimal quantity of food among the poor remains relatively inelastic (Prakash 1997). Malnutrition is the leading health risk among the poor, accounting for 1 in 15 deaths globally (WHO 2002, p.54 in WRI 2005). Of the 1.1 billion people living below the "dollar-a-day" threshold, 780 million suffer from chronic hunger (FAO et al.2002, p.8 in WRI 2005). Undernourished people are weaker and less productive, leading to a lower production and more hunger. 'Chronically hungry people are less productive at whatever labor they are able to obtain, and thus find it harder to accumulate the financial capital they need to take them out of poverty' (FAO et al. 2002, p.10 in WRI 2005). This is one of the worst poverty traps. A similar mechanism can occur when family members are ill (Smith 2005, p.14).

High fertility trap

Poor households chose for very legitimate reasons to have many children. The risk of child mortality and unsupported adult disability is compensated by a high fertility, so that children can work and take care of their parents. But endogenous population growth can also mean a subdivision of other assets, such as land and livestock (Barrett 2008). The small plots of land however might not be able to feed so many mouths. As a generation passes, the parents die and the land is divided and given to the sons, who start their lives on the land with their wives and children (Sachs 2005). The smaller the plot becomes, the more difficult it is to produce enough food in an efficient way. The smaller plot has to provide the same amount of food, which can be problematic given the ancient technologies applied. Certain technologies also require a sufficient scale to be profitable. Semgalawe (1998) observes that average land possession is usually small due to continuous fragmentation among the

household's sons. The average size is 0,4 to 1 hectare (Semgalawe 1998). Rapid population growth puts stress on farm sizes and environmental resources. This experience has been prevalent in rural Africa in the most recent generations (Sachs 2005 p.55). Due to a lack of possibilities in other sectors than agriculture and poor education, the children are often forced in the same livelihood of their parents. The vision that the environment cannot support a large population is a version of the Malthusian models. Thomas Malthus described cycles of population growth and decline depending on the resources available and predicted that the growing population would never have enough to eat. The opposite view is that population growth and environmental degradation are not negatively related to each other and that food production will increase together with population growth. The Boserupian view says that when there are more people available, more effort can and has to go to soil conservation in order to increase productivity (Shiferaw and Holden 1998).

Subsistence trap

When all neighbors are subsistence farmers and the infrastructure to larger markets is poorly developed, a farmer has no incentives to specialize in one crop. He can't sell his produce and cannot buy other products. Transportation costs might also prevent commercial transactions from occurring. This is one of the poverty traps in subsistence areas. Although the step towards market based commercial farming offers possibilities towards growth, the barriers and risks involved keep a farmer from doing so. When the transport costs (gasoline, food for a horse or donkey, calories) of bringing produced goods to the local market outweigh the revenues earned on the only and far distant market, it might not be worthwhile going to the market. When one of the farmers has saved money to buy a strong four wheel drive truck, he can serve as middle man and collect the food of some small producers and bring the produce to a market place. He has to be able to communicate about the quality of his products and establish trade relations. But a middle man needs farmers that produce specialized goods in order to be able to do his business. When all farmers are poor subsistence farmers, no middle men can do the job and without middle men, distant markets stay out of reach for subsistence farmers (Smith 2005, p.15).

Farm erosion traps

There are dynamics and feedbacks between humans and their environmental surroundings, which are especially important for those people that heavily depend on natural resources. Degradation of the environment can have large impacts on the poorest, but the poor can also degrade their environment (Barrett 2008). When the poor are so desperate to produce food in order to stay alive, they might overuse their land even though they know it will lead to a worse productivity in the future. Any small gain in productivity from learning another technique or using more labor will be undermined by a poorer soil quality. Although solutions like fertilizer might exist, the poor might lack the access to money to finance them. Investments might have a threshold values, fertilizers work only when a certain amount is applied or after using it for two or more years. The short term costs are then high and the benefits not visible (Smith 2005, p.16).

Common property mismanagement traps and collective action traps

In several developing countries, the well defined and enforceable property rights of the neoclassical model can't be found. The poor make extensive use of goods collected from lands or waters over which no one individual has exclusive rights (Jodha 1986, p.1169, Ostrom 1990, p.30 in WRI 2005). Common resource management goes well in communities where there is cooperation and a sense of belonging. Unfortunately, community management of common resources has often broken down (Smith 2005, p.16). The common property mismanagement trap refers to the tragedy of the commons, where each individual has the incentive to extract as much as possible instead of choosing a socially optimal level of extraction. Although working together in, for instance, cooperatives would be beneficial to all individuals, it requires initial leadership. Being the leader requires time, resources, knowledge and responsibility. This time and effort cannot be put into working on one's own land. As the benefits of those efforts go to the whole group, rather than to the individual, the reward rarely offsets the risks (Smith 2005, p.16).

Criminality traps

In the capital related trap we've seen that the risk of theft is a barrier for the poorest to save money in their houses. Safe banks are therefore important. When the parents are trapped in poverty and the children have no access to education or jobs, criminality might be the only solution. Criminality can work as a poverty trap for a community in the benefits of one or a few persons. When assets are destroyed, resources are taken away from others for personal benefits and healthy people are even killed, the social and economic conditions are worsened. This will in return drive more people into criminality. An unsafe environment can prevent people from investing in new assets or technologies, leaving development possibilities aside.

Mental health traps and powerlessness traps

Many poor people are deeply ashamed of their situation (Smith 2005). Those deep feelings of shame can lead to serious depressions and a feeling of hopelessness (Gert Boven 2009). This situation can lead to alcohol or drug abuse, placing people in even more severe poverty. The first steps of entrepreneurship or risk taking behavior will therefore not be made, even though economic possibilities might be present.

Institutional traps: Social norms and corruption

Markets can fail and reduce possibilities to step out of poverty, but governments and institutions can do so as well. Institutions at any scale can undermine incentives to invest in asset accumulation or to increase productivity (Barrett and Swallow 2006, Bowles et al. 2006). Corruption, weak property rights and limited supply of public goods can cause reverse incentives to development. In these examples the 'rules of the game' are not constructive for economic development. When institutions are regarded as products of a certain society, it is possible that they are created to preserve rather than to overcome poverty (Hoff and Stiglitz 2000). Institutions can then work as a trap. It can for instance be the case that taxes have to be paid over activities the poor perform to make a living. 'Around Lake Chad in central Africa, fishery fees are levied by three distinct groups: by traditional authorities, by the central government, and by soldiers' (Béné 2003, p 970 in WRI 2005). The literature on

property rights is extensive. When the property of one's assets is insecure, incentives to invest are reduced. If assets degrade due to little conservation effort, competition over productive assets increases. This increases competing claims on such assets and therefore the risk of losing that asset to someone else. De Soto (1989; 2000 in Barrett 2008) claims that weak property right regimes are the fundamental cause of underdevelopment. The poor do own assets but this ownership is not formally registered or acknowledged.

Summary:

In order to arrive in a poverty trap, there need to be multiple equilibria. Multiple equilibria only appear when the conditions of neoclassical economics are relaxed. The main functions will then exhibit non-convexities. Although the examples given above are very diverse, the main poverty trap mechanisms have in common that critical thresholds in wealth and health, risk and institutional failure are the underlying sources of the trap. All the poverty traps mentioned above have in common that the poor are less willing to take risk and have a limited access to the resources that smooth out risk like insurance or credit. Risk aversion is further increased by imperfect information.

3. Economics of soil conservation in developing countries

Soil degradation is a substantial problem especially in developing countries, where the majority of people is directly dependent on subsistence agriculture (El-Swaify et al., 1985 in Eaton 1996, Barbier 1990). Till thus far, the terms land degradation, soil degradation, depletion and erosion have been used interchangeably. In scientific literature they have a distinct meaning. Land degradation is the broadest concept and refers to the degradation of soil, water, climate, fauna and flora. Soil degradation refers to water erosion and wind erosion, as well as chemical, physical, and degradation of the soil (Hurni 1996 in Worldbank 1997). Soil degradation is thus a loss in essential nutrients caused by processes like erosion, leaching and salinity (Semgalawe 1998) and results in a decreased productivity (Semgalawe 1998). Soil erosion refers to a loss in soil productivity due to: physical loss of topsoil, reduction in rooting depth, removal of plant nutrients, and loss of water (Eaton 1996). The level of erosion in a given place is determined by the interaction of a number of factors including climatic erosivity, soil erodibility, land use and land management (Eaton 1996). It has long been suggested that farmers in some of the poorest regions are not aware of erosion and therefore do not take sufficient measures to reduce erosion (Jones 2002, Semgalawe 1998). Recent research shows that many farmers know that erosion affects their soils. Allowing for some erosion can however be economically efficient (Perrings 1989, Deaton 1996). In this chapter the basic intuition of the economics of erosion are given.

3.1 Erosion prevention

Erosion is in this thesis defined as decreased soil productivity as a result of a decreased top soil depth, caused by natural and human induced factors. The Universal Soil Loss Equation (USLE) is often used in models about erosion (Stone 2000). The USLE predicts the long term average annual rate of erosion on a field, based on the slope, rainfall pattern, soil type, topography, crop system and management practices. All of those factors have their own influence on the erosivity of soils. The last two can be influenced by the farmers. Erosion affects the farmers via a declined harvest, but measures can be taken to tackle the erosion problem.

Technologies that relate to soil erosion can be exogenous and endogenous. The later technologies increase the depth of the fertile top soil, where the first keep the yield at an acceptable level given loss in soil nutrients and a decrease in fertile soil. Examples of the first are the application of fertilizers, ploughing or the use of high yield varieties. Examples of the second group are the creation of terraces, planting grass strips, creating trash lines, planting nitrogen fixing trees, intercropping, mulching, zero grazing, ridge cultivation, gully control and rotational grazing (Semgalawe 1998). Some of those technologies require a large time or money investment, they are lumpy (Barrett 2008).

3.2 Investment behavior

Erosion is a complicated process affecting not only the soil properties but also the micro-climate at a certain location (Lal 1987, pp. 313-4 in Eaton 1996). The extent to which erosion affects the harvest depends on the factors mentioned earlier and thus varies per crop, soil type and management system. Lal (1987) estimates an exponential relation between erosion and declining harvests. Initial declines are very high but fall as erosion proceeds (Eaton 1996). While different researchers have found somewhat different relationships between erosion and yields, there is growing evidence that, at least in the tropics, the decline in yields is of an exponential form (Blaikie and Brookfield 1987, p. 17 in Eaton 1996). There are diverse possibilities to tackle the erosion problem. How do farmers decide whether to invest in those technologies or not?

McConnell (1983) is often cited as one of the first to model farm behavior with respect to soil erosion in a dynamic setting. Several authors cited this publication as the first attempt to model the economic rationale for soil conservation (Barbier 2000, Bulte and van Soest 1999). His model shows that it is rational and efficient for farmers to allow for a certain amount of soil erosion. The decision to invest in soil conservation follows the basic economic rule for investment. In the optimal investment point, the marginal costs of preventing erosion should be equal to the marginal benefits of implementing soil conservation. A rational farmer with perfect information would analyse the costs of erosion and the benefits of preventing erosion and take into account opportunity costs. Soil conservation measures like terraces take land out of production. The harvest that he could have obtained from that land is then the opportunity cost of soil conservation. McConnell uses soil depth to describe the state of soil degradation. Soil depth is related to past production levels (McConnell 1983). McConnell (1983) and Barrett (1991) use a transition function of the form $S = q - u$, where q is the rate of soil accumulation describing how the soil is renewed and u is the rate of soil depletion.

When the costs of investments are larger than the benefits, a farmer should not invest. Shiferaw and Holden (1998) conclude that soil conservation is not profitable for smallholders in the research area in Ethiopia. 'The low returns to proposed conservation options were mainly caused by a lower yield because the effective area planted is now smaller, their limited technical efficiency to curb soil erosion, and the high initial labor costs'. As the yields are already low on the poor soils with only a shallow layer of fertile organic matter, production might become unprofitable. When the yields are too low, not enough money might be left to pay back the investment costs. Therefore the authors conclude that it is rational and efficient for the farmers not to invest in soil conservation. Antle, Stoorvogel and Valvida (2006) have a different reason why farmers might not invest. In a recent publication they demonstrate how soil conservation techniques may induce agricultural systems to induce equilibria characterized by low and high levels of soil degradations. The equilibria are separated by a threshold level of soil degradation beyond which investments in soil conservation will not yield positive returns. In such cases it doesn't make sense to invest in soil conservation. It will either not have an effect or be too expensive. Duflo et al.(2009) have a different view on underinvestment in soil conservation. Rather than resource constraints, procrastination of applying fertilizer was found to be an important factor in Kenyan agricultural.

4. Modeling poverty traps

This chapter will shortly summarize the modelling approaches undertaken by others to demonstrate poverty trap mechanisms at a micro level and report the most important findings. Theoretical models have been used to give the intuition behind trap mechanisms and empirical research has tried to prove the existence of such traps in real life. Different mechanisms that cause trap situations have been distinguished in earlier research. Examples are minimal nutritional requirements (Dasgupta 1997, 1998; Sylwester 2004, Barrett 2008), little asset holding (Carter and Barrett 2004; Shively 2001; Barrett 2008; Hanjra 2009), the seasonal character of agriculture (Dercon and Krishnan 2002 in Orr et al. 2009; Orr et al. 2009), poorly defined property rights (Perrings 1989, Carter and Barrett 2004, Bromley 2007), illness and diseases (Sachs 2005), large fixed investment costs (Dercon and Christiaensen 2007), natural disasters and droughts (Carter and Barrett 2004, Carter et al. 2007), high perceived risks of land conservation technologies (Pereira et al. 1994, Dercon 1996, Dercon and Christiaensen 2007) and limited access to credit and insurance systems (Dercon 1996, Barrett 2008, Dutta and Mishra 2009) have been studied. In the following part only the ones that give an insight in the trap mechanisms and relate to farmers conservation decisions are taken into account.

4.1 Modeling poverty traps

The poverty trap discussed in this thesis is a rural phenomenon of farmers caught in a spiral of declining soil quality and a constant or falling food production per head (Sachs 2005, p.70). A growing literature emphasizes the possibility of non-stationary income processes that may yield multiple dynamic equilibria, with one or more stable equilibria below the poverty line. Land degradation has been identified as a source of poverty traps in many developing regions (Dasgupta and Maler 1991; Barbier and Lopez 1999 in Shively 2001). In many parts of the world the well being of the rural poor depends on good agricultural performance, conditioned by rainfall patterns. Frequent droughts, limited input use and a poor infrastructure make it difficult for those poor to improve their well being (Hanjra et al. 2009). Sylwester(2004) remarks that poverty and land degradation are not necessarily correlated. There are subsistence farmers who do not suffer from increasing degradation. It depends on the activities farmers who produce under subsistence characteristics have to undertake to obtain a subsistence level of income whether a vicious circle of poverty and degradation appears or not (Sylwester 2004). According to poverty trap theory, somebody who is trapped in poverty will not be able to grow out of poverty. Time is thus not a remedy (Carter et al. 2007). Barrett (2008) explains how, when financial market imperfections exist, initial endowments matter in such trap situations: "Given the pervasiveness of financial market imperfection in the developing world, livelihood choices typically are constrained by agents' asset endowments" (Barrett 2008, p.3). The idea that initial conditions matter contradict the worldview in which hard work can make anyone wealthy. Antman and McKenzie (2005), mention that 'the empirical literature has found it hard to adjudicate between these two worldviews'. It is, in other words, extremely difficult to empirically demonstrate the existence of poverty traps.

One of the largest problems to overcome is the data required for an analysis of poverty traps. Since poverty traps are dynamic phenomena, analyzing them empirically requires a large dataset of longitudinal panel data on household standards of living and asset holdings (Carter and Barrett 2004, Carter et al. 2007). Such long term data are required in order to distinguish between a poverty trap and temporal poverty. “When several years after a shock or a prolonged event poor households are more affected than wealthier households, it may mean that the poor fell in a permanent poverty trap, but it can also imply that they recover more slowly and will eventually converge to their pre shock equilibrium destination”(Carter et al. 2007). Panel data that cover a period long enough to make statements about poverty traps are scarce. In existing panel data, attrition and measurement error are common problems (Antman and McKenzie 2005). Antman and McKenzie (2005) therefore use pseudo-panels to investigate poverty traps in Mexico City. Due to the strict data requirements necessary in a poverty trap analysis, evidence that wealth dynamics may exhibit nonlinearities and multiple equilibria, is difficult to find. However, in research after wealth dynamics in a pastoralist community in Ethiopia nonlinear wealth dynamics characterized by poverty traps has been reasonably well established (Lybbert et al. 2004, Santos and Barrett 2006a in Santos and Barrett 2006).

Theoretical simulation models and econometric analyses are more often used to demonstrate and analyze poverty traps. With econometrics, flexible non-parametric methods can be used to explore asset dynamics (Lybbert et al. 2004, Adato et al. 2006, Barrett et al. 2006) or to identify the critical bifurcation point using Hansen’s threshold estimator (Hansen 2000 in Carter et al. 2007). Caveat of Hansen’s threshold estimator is that the threshold line is the same for all units, while several authors suggest that the threshold level should rather be a function of individual characteristics like skills, entrepreneurial qualities etcetera (Antman and McKenzie 2005, Barrett and Carter 2006). The same plot of land can for instance produce different amounts of crops, depending on the skills of the farmer to chose the crops, planting and harvesting times, input use etcetera.

4.2 Earlier research

Barrett and Carter (2006) suggest that there are three factors that cause poverty traps: less wealthy households tradeoff expected gains against lower risk, the production technology may exhibit increasing returns to scale and some high return production process may require a minimum project size such that only wealthier can afford the switch. Those three are the starting points for the models in chapter five. In the next section, current models are grouped together under the headings risk and critical asset levels. The last one incorporates increasing returns to scale and lumpiness.

4.2.1 Risk as a poverty trap

The large dependence on natural systems makes agriculture a risky business. Farm performance depends not only on the skills and effort of the farmer but also on rainfall, sun hours and the presence or absence of disease and plague outbreaks. Natural disasters can destroy not only the harvest but also the asset base for production, and have long term consequences. In a developing setting the access to formal insurance is limited, especially for the poorest. Economic theories of risk sharing, rooted in the work of Arrow (1964), Diamond (1967) and Wilson (1968) tell that individuals will use a variety of instruments to smooth consumption over time in order to protect themselves from the large variation in income that is common in a developing setting (in Santos and Barrett 2006). Informal insurance based on interhousehold transfers in social networks or kinships is an example of such an instrument. However, research suggest that the poorest are often excluded from such informal insurance networks. As they have little possessions, sanctions are less worrisome to them. Santos and Barrett (2006) therefore examine how a poverty trap situation affects the way informal insurance works and affects the people already trapped in a poverty trap, or close to the critical threshold level.

Another branch in literature emphasizes how uninsured risk can cause a poverty trap. The majority of authors emphasize the role of ex ante choices and the intend to diminish the impact of shocks (Binswanger and Rosenzweig 1993, Bardhan, Bowles and Gintis 2000, Carter and Barrett 2004, Dercon 2004 in Santos and Barrett 2006). Risk is an important factor contributing to poverty traps. Risk of losing your land because of tenure insecurity, risk of a serious period of drought, the risk of hunger, the risk of theft, there are many risks that might affect ex-ante decisions on soil conservation. Conservation structures can be costly to construct, might take cultivable land out of production, or shade food crops. There are opportunity costs for the area occupied by conservation structures, and those costs are implicitly higher when there is a minimum consumption target (Shively 2001). Investments can be risky, because using resources to invest can in the near-term have consequences for consumption. Given the fact that borrowing money is not always possible, this would imply that decisions about soil conservation are a tradeoff between short term liquidity risk and long term yield risk (Shively 2001). Shively (2001) investigates whether the risk of a bad harvest and accompanying low revenues, can lead to the decision not to invest in soil conservation. In his dynamic model, optimal investments are calculated given farm size, soil degradation and subsistence constraints. A Bellman equation is used for this optimization problem in which a random shock affects the outcome. The factor for soil degradation includes a stochastic factor, describing the chance of catastrophic soil loss. In such a way consumption risk and yield insecurity are made explicit in the model. The model shows that marginally food-sufficient households avoid soil conservation because adoption pushes them into regions of insufficiency. An empirical investigation of the model with data from the Philippines shows that adoption rates of soil conservation among the poor are higher than the model predicts. The difference can be caused by the ability of farmers to save some crops rather than money, to smooth consumption or the possibility to invest in certain plots and not invest in other plots.

Dercon and Christiaensen (2007) investigate basically the same. They focus on the differential ability of households to adopt risky technologies in fear of welfare consequences if harvests are poor. The risky investment the authors investigate in this paper is the use of fertilizer. Applying fertilizer generally results in higher yields and higher revenues. However, when due to other circumstances like poor weather conditions the harvest is small, revenues tend to be only moderately higher than when no fertilizers were used. As fertilizers are sunk costs that have to be paid and revenues are lower due to the other circumstances, it is risky to use fertilizers. When farmer take into account the risk of having a poor harvest despite fertilizer use, they might choose not to do so. The difference between the income when more risky crops would have been planted and the safe crops can be seen as a risk premium. In an earlier paper, Dercon(1996) finds that farmers in western Tanzania grow lower return but safer crops. Fertilizer application rates applied in Ethiopia are also significantly lower due to downside risk in consumption. Measures to insure people against downside consumption risks might have beneficial effects (Dercon and Christiaensen 2007).

4.2.2 Critical levels in asset holdings

Another branch of poverty trap models investigate critical thresholds in asset holdings. The main idea of this approach is that there can be asset levels at which investment behavior naturally bifurcates, with decumulation occurring below the threshold, and accumulation above it (Lybbert and Barrett 2007). Examples are the lumpiness of a technology, the fixed costs attached to investments and biological cycles of regeneration. Antle et al.(2006) demonstrate that soil conservation technologies may induce agricultural systems to exhibit equilibria characterized by low and high levels of soil degradation. There is a threshold level in soil degradation that divides those equilibria. Below this threshold, conservation investment will not yield positive results (Antle et al. 2006).

Perrings (1989) creates a dynamic model of an open agrarian subsistence economy in which the poverty trap is present. Although he doesn't use the term poverty trap, the "optimal paths towards extinction" in systems with multiple equilibria are similar to poverty traps. The mechanisms behind the poverty trap are the need for subsistence consumption in each period, risk avoidance resulting in the use of ancient technologies, a parabolic, symmetrical resource use function, limited saving and a high discount rate.

Carter and Barrett (2004) create a model with a poverty trap and focus strongly on the asset base of production. They argue that only a focus on asset dynamics can identify the structurally poor. Their approach starts with the idea that a positive return on assets exists at a certain level of wealth. This is similar to the notion of non-convexities in technology use. The authors use a simulation model to estimate the minimum asset threshold associated with the low level equilibrium of a poverty trap. In their model a dynamic critical asset level is identified. The authors mention that poverty traps do not have to appear when the poorest are forward-looking and make the strategic decision to borrow sufficient funds to arrive at a higher returns asset level. But then borrowing should be possible or the family should be able to sacrifice short term consumption for a while. They conclude that "if the poor wish not to or cannot undertake extraordinary savings, then they settle into a poverty trap".

Sylwester (2004), builds a dynamic model and finds theoretical prove for poverty traps. In his model, land quality is an input and agents choose how intensively to use the land. Soil quality is not only determined by soil depth but is described in two parameters S and u. A high value for S can mean that the farmer has a large area of land or that a smaller plot provides high yields. A large u means that a smaller fraction of land is left unused or that more intensive techniques are used. For each period a minimal consumption level is set. Discounted utility over time is maximized. The model demonstrates the existence of two long run outcomes dependent upon initial conditions. Farmers reach a steady state in which they produce above subsistence or they remain in a poverty trap where natural resources continue to degrade (Sylwester 2004).

Carter et al.(2007) explore the long run economic impacts of environmental shocks using an econometric approach and test their estimated model for Honduras after hurricane Mitch and in Ethiopia after a serious drought. They wonder if there is a critical asset level below which people will become mired in a low level equilibrium trap. This focus on a critical asset minimum is adopted from Carter and Barrett (2004), who call the threshold level the Micawber threshold. As a result of critical thresholds, bifurcated growth patterns will emerge. The authors test this assumption by studying the asset accumulation patterns pre and post shock and try to find consumption smoothing and assets smoothing. Asset smoothing means that the asset stocks in kept constant over time. Asset smoothing might include that consumption reaches unsustainably low levels (Set 1989 in Carter et al. 2007). Consumption smoothing takes place when some assets are sold in order to protect a constant level of consumption. The ones that are able to do consumption smoothing, might be expected to rebuild their asset stocks after a while. For Honduras the authors conclude that “although further methodological improvements are needed to fully explore poverty traps, the hurricane Mitch quasi-experiment does unambiguously indicate that asset shocks have long lived, unequalizing effects” (Carter et al. 2007). The second case described, a period of severe droughts in Ethiopia, is similar to the situation in Tanzania. In several East African countries rainfall is erratic and droughts have destructive effects. It is likely that the severe droughts have comparable effects on farmers and pastoralists in Tanzania. In the drought situation, assets are not destroyed by a disaster but farmers decide to keep them or to sell them in order to survive the circumstances of their environment. The data on Ethiopia do signal the existence of two distinctive equilibria. Although the poorest are able to quickly rebuild their livestock, there is a low level equilibrium point at which the farm size stops growing.

5. Poverty traps in models with soil conservation

This chapter is about a smallholder's decision to invest in soil conservation in a developing country setting. The latter implies that land holdings are small, on-farm production is at least partly used for household consumption, land degradation threatens production and consumption, access to financial and insurance services is limited and land tenure can be uncertain. Rather than modeling the unique investment path for a unique household, using adequate farm-household data, the purpose of this chapter is to illustrate and give insight into the mechanisms that can trap farmers in poverty. Carter and Barrett (2004) explain that there are three mechanisms that can lead to a positive relationship between wealth and the returns to assets:

Case 1: The underlying production or income generation technology may itself directly exhibit increasing returns to scale

Case 2: Some high return production processes may require a minimum project size such that only wealthier households can afford to switch to and adopt the high return process

Case 3: Risk and financial market considerations may cause some lower wealth households to allocate their assets so as to reduce risk exposure, trading off expected gains for lower risk, thereby making expected marginal returns to wealth lower for lower wealth households

Each of these three conditions will not cause a poverty trap when financial markets function properly. Carter and Barrett (2004) do mention that given the perspective of higher returns in the future after a certain level of assets, forward looking households would borrow sufficient funds to make the minimum required investment in order to reach the level of assets that corresponds with high revenues. However, when access to credit is not available or certain groups are excluded from financial services, this initial (lumpy) investment cannot be made. The only option left for the poor to accumulate enough assets is then to save. In order to save, consumption is set aside. This way of saving goes at the cost of the health of family members and their ability to work or go to school (Dasgupta 1998), and is therefore often impossible (Carter and Barrett 2004). It is therefore that a level of minimum consumption is another prerequisite for a poverty trap.

In the following part the first two cases mentioned above will be examined using GAMS modelling language. Modelling risk, for instance the risk of losing land or having a bad harvest despite investments, is proven to be inconvenient in GAMS. In the modeling that has been done in this area, for instance by Dercon and Christiaensen (2006) and Shively et al. (2001), a Bellman equation was used. This is a different branch of modelling, therefore it has been chosen to focus on increasing returns and lumpiness which can be modeled using simulation modelling.

5.1 Increasing returns to investment

In chapter 2 the situation of multiple equilibria has been discussed. In order to arrive in a low level equilibrium, a system needs to have at least two equilibria. A solution landscape with multiple optima can appear when there are non-convexities in the production possibilities set. The convexity of a set implies that when drawing a line between two points in the set, all points on the line are also part of the set. In figure 5.1 two examples of non-convexity are given. In the poverty trap example with increasing returns, the production possibility set is non-convex.

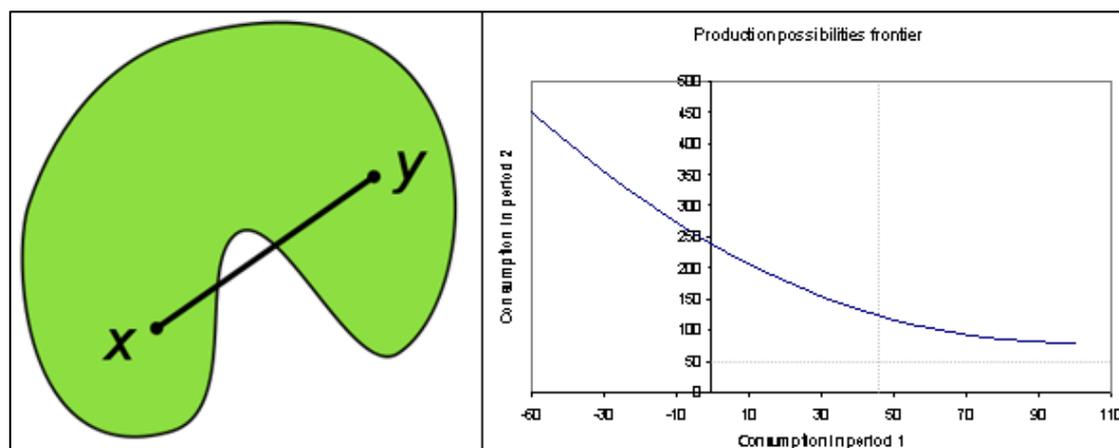


Figure 5.1: Two examples of non-convexity

The non-convexity in the first poverty trap model arises from the fact that there are increasing returns to investment. When the farmer decides to forgo some consumption today, the fraction that is used for investment will be rewarded more than proportionally. This assumption makes that the production possibility frontier is a convex function, and therefore the solution space is non-convex. This in contrast to the standard form of the production possibilities frontier, in which the production possibilities frontier is concave, and the feasible set is convex.

5.1.1 The model

In this model, a farmer maximizes his consumption over time. His consumption depends on the crop production he can get from his land. The production solely depends linearly on the quality of his land. The land quality can in this model be seen as a stock of potential production. It is modeled as a parameter. Soil quality declines over time with factor δ . This factor includes natural soil degradation and soil degradation related to production. In the model, a lower soil quality directly results in a lower production. The factor for soil degradation is constant. Soil loss is then initially higher in absolute terms. The production the farmer obtains is used to feed his family. The crop produced can be interpreted as a subsistence portfolio. Consumption is a linear function of soil quality. The farmer can decide in each period to consume less and invest in improving the soil quality. Investment is paid in terms of crops. Investment will have a positive impact on the soil quality in the next period. Investment can be interpreted as hiring others to cultivate the land with the land hoe. In a dynamic setting the choice the farmer has to make is how much consumption to forgo in

order to invest in soil quality, so that he can maximize long term consumption. This leads to the following equations:

$$\text{Max } \sum_t (C_t / (1+r)^t), \quad (1)$$

$$C_t = Q_t - I_t, \quad (2)$$

$$Q_{t+1} = (1-\delta)Q_t + I_t^\beta, \quad (3)$$

$$0 < Q_t < Q_{\max}, \quad (4)$$

$$I_t \leq Q_t, \quad (5)$$

C_t = Consumption, Q_t = Land quality and I_t = investment

Coefficient β represents how investments influences soil quality. When β is larger than one, there are increasing returns to investment. In the first models discussed, there is no discounting and the discount rate r is zero. Earlier researchers suggest that the relationship between erosion and yields is of an exponential form (Blaikie and Brookfield 1987, p 17 in Eaton 1996). This implies that initial decline is very high but falls when erosion proceeds. The soil quality in this model declines each year with factor δ . The value of δ lays between 0 and 1. Coefficient δ gives the soil degradation as a percentage of soil quality. In such a way absolute soil loss decreases. Equation (1) is the objective function, maximizing consumption over time. Equation (2) describes how consumption depends on soil quality and investment. Soil quality is negatively affected by degradation and positively by investment (Equation (3)). It is assumed that consumption cannot become negative, which leads together with equation (2), to equation (5). Investment is limited by the amount of production as there are no financial markets where funds can be borrowed. There is a maximum level of soil quality for which holds that extra investments will not offer benefits in terms of higher consumption (Equation (4)) and soil quality cannot become negative.

5.1.2 Analysis

In order to understand the implications of non-convexity for the model, the problem is first analyzed in a two-period setting. The consumption in period 2 depends on the investment made in period 1. Since there is no third period, there will be no investment in the second period. The farmer can decide between all combinations of consumption in period 1 and period 2, but is restricted by the soil's productive capacity. The soil's productive capacity is a function of initial land quality, degradation and investment. Hence, consuming a lot in period 2 has the opportunity cost of foregone consumption in period 1. Initial land quality (Q_t), returns on investment (β), and soil degradation (δ) are exogenous. Coefficient β should be larger than one in order to obtain increasing returns. Consumption and investment are endogenous, and therefore so is soil quality in period 2. In order to solve the model in a two period setting, the equations are rewritten so that an indifference function and a production possibility frontier can be modeled.

$$\text{Max } \sum_{t=1} U(C_t) = C_1 + C_2 / (1+r) \quad (6)$$

$$C_1 = Y_1 - I_1 \text{ Thus } I_1 = Y_1 - C_1 \quad (7)$$

$$C_2(C_1) = (1 - \delta)Q_1 + (Y_1 - C_1)^\beta \quad (8)$$

$$C_2(U) = (U - C_1) * (1+r) \quad (9)$$

$$C_t \geq C \text{ min for all } t \geq 0 \text{ with } Y \geq 0 \quad (10)$$

The production possibilities frontier (Equation (8)) gives all possible combinations of consumption in period 1 and 2, but does not tell which combination is preferred. Equation (9) is an equation for the indifference curve based on the utility function from equation (5). The decision to consume a lot in year one or in year two depends on the farmer's time preference. Poor people are often believed to have a short time horizon and make decisions to survive today rather than planning decisions for the future. Their discount rate is therefore high. Equation(10) states that consumption can never be lower than a minimum level. Although this level can vary for instance in relation to past consumption, age and daily activities, this will not be a part of the analysis in this model. In the first models the minimum consumption will be zero, consumption cannot become negative. In Figures 5.1 and 5.2 the discount factor is set on 1.05. The optimal combination of consumption in period 1 and 2 can be found at the point where the indifference curve touches the production possibilities frontier. The possibilities frontier itself is a combination of all optimal points. Any point below the line would leave consumption unused. Therefore the optimal solution is on the curve. The two optimal points in this analysis are the corners of the function, invest everything or nothing.

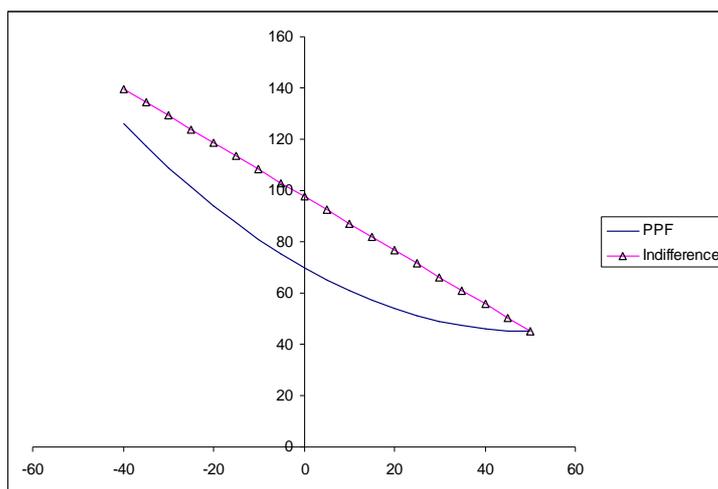


Figure 5.2: Optimal consumption with a low soil quality: The optimal point is located there where no consumption is foregone for investment, which leads to a lower consumption in period 2. When the model is applied to a longer period of time, soil quality will continue to decline.

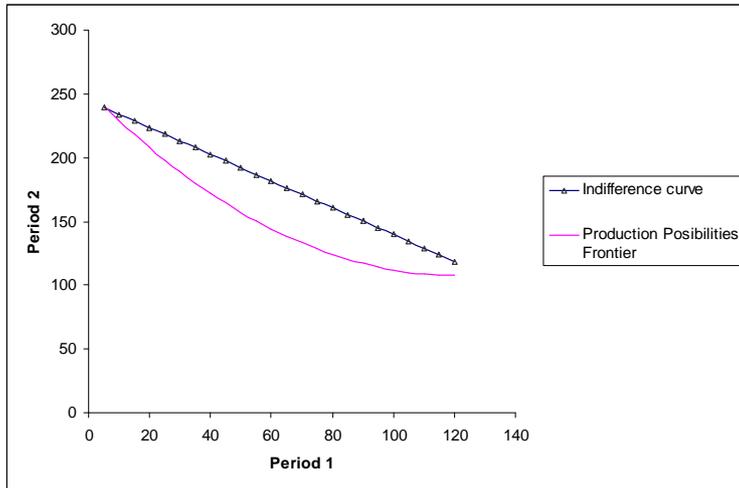


Figure 5.3: Optimal consumption with a high soil quality: The indifference curve touches the production possibilities curve in the point where initial consumption is very small but consumption in the second year is substantially larger. In this point the farmer can benefit optimally from the increasing returns to investment.

In figure 5.2 the optimal point is the point where the farmer consumes everything in period 1 and chooses not to invest in soil quality in period 2. In figure 5.3 the optimal point lies at the point where the farmer consumes nothing in the first period and invests everything for the future. The difference between the two graphs is the initial soil quality, which can be interpreted as the initial wealth of the farmer. This analysis shows that corner solutions rather than interior solutions will be the outcome of optimization calculations when there are increasing returns to scale. A farmer invests all his consumption in the first period, or doesn't invest at all. The option to invest everything is only possible for those farmers that started with an initial higher land quality. This idea that initial conditions matter is characteristic for poverty trap theory.

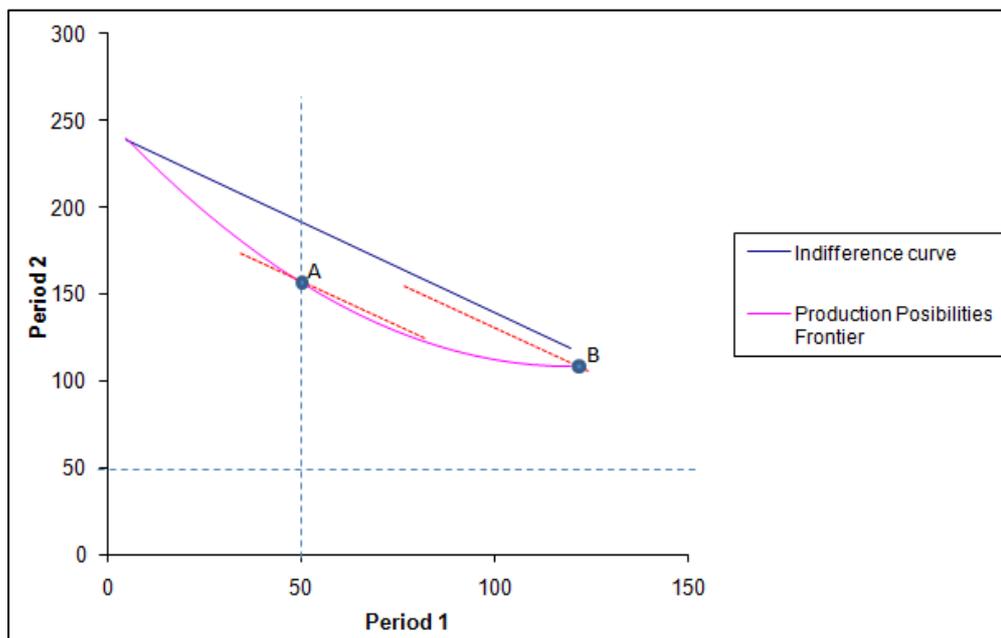


Figure 5.4: Optimal consumption given subsistence requirements

In figure 5.4 the idea of minimum consumption is depicted (Equation (10)). In the previous two graphs there was a minimum consumption of zero. In this part of the analysis the requirements become more strict. In a real life situation people cannot deal with periods of too little consumption. When consumption becomes very small it will cause striking problems and lead eventually to starvation. People need nutrition to survive and to participate in productive activities. The call for the inclusion of food requirements in economic modeling is especially made by Dasgupta (1985, 1986 in Dasgupta 1997). However, few examples exist in which such constraints are modeled. The model of Sylwester (2004) is an exception. In figure 5.3 a minimum consumption of 50 units is added for both years. This makes the feasible area smaller and causes the optimal point from the previous analysis to fall out of the feasible area. The indifference curves (red dashed lines) show point B to be the new optimum. The added requirement for minimum consumption has changed the outcome of the model.

2.1.2.1 Applications in GAMS

The model described above has been modeled in GAMS. That model maximizes consumption over time. The goal of this model is to investigate how the model behaves in GAMS, and whether results of the two-year setting also apply to a multi-year setting. The household's consumption depends again linearly on soil quality. The first two figures (5.5 and 5.6) depict model assumptions where the other figures show the model outcomes. Figure 5.5 depicts the form of the soil quality function. Initial loss is larger than the loss in later periods. The model includes soil quality as a stock of potential production. Consumption depends linearly on production. The graph below can therefore also be seen as maximum possible consumption over time. The farmer can choose to consume less than the possible yield in the first years and invest in order to have something to eat in the future. In this way consumption would be smoothed over time.

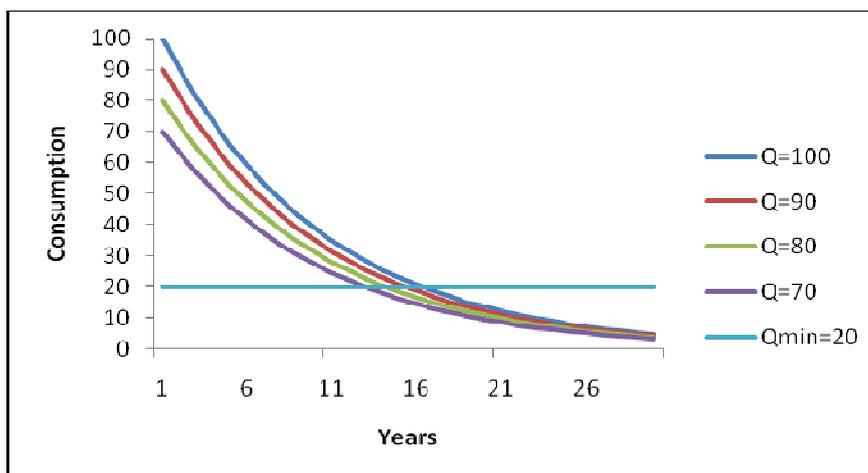


Figure 5.5: Declining consumption with initial soil quality: each year a fraction of initial soil quality disappears via erosion processes. Initial losses are substantially larger than later loss. Over time the soil quality is too small to supply the farmers enough food. In which year minimal consumption is reached, depends on initial soil quality.

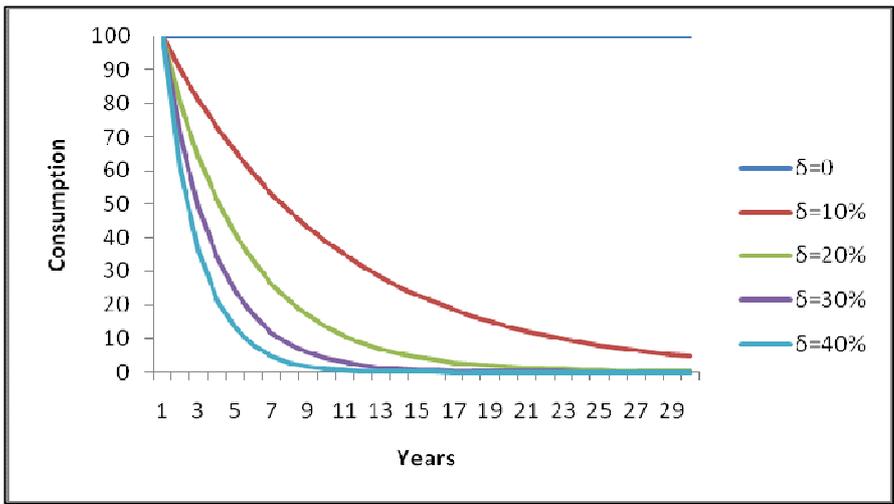


Figure 5.6: Declining consumption as a function of the rate of soil degradation

Figure 5.6 shows how soil quality develops over time with different degradation rates (δ). Initial soil quality and maximum soil quality are set to 100, this means that at the beginning of the modeling exercise the soil is in optimal condition. Especially in the first years the soil quality shows a sharp decline. This is mainly because of the function chosen. It can be observed that the higher the value of δ , which is the percentage of soil quality that is lost, the faster consumption will reach low levels. In real life the rate at which soils decline depends on a multitude of factors.

In figure 5.7 the model was run with different values for β . The two-period analysis suggested that the value of β can cause non-convexity (when $\beta > 1$). How does this come back in the model? Figure 5.7 gives an idea. The patterns are hard to explain. The model determines how much to consume and how much to invest each year. Intuitively it can be predicted that when β is larger and investment is thus rewarded more than proportionally, a farmer will invest more.

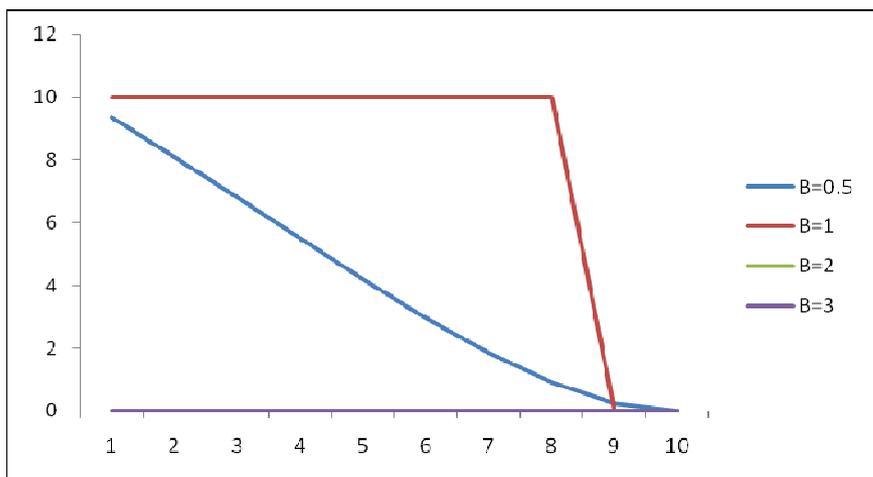


Figure 5.7: Investment dependent on returns to investment, investment is modeled as a function of the returns to investment. The start soil quality has been optimal, soil degradation was 10% and maximum investment was set to 100.

In figure 5.7, the scenario's with increasing returns to investment ($\beta=2$ and $\beta=3$) show a lower total consumption (651 and 691) than the scenario with proportional returns to investment ($\beta=1$ gives a total consumption of 910). There is no investment in the scenarios where investment has the strongest increasing returns to scale, which is unlikely to be correct. What can be observed is that investment stops one year before the last year. This is a common problem in simulation modelling in which a finite time horizon is modeled. Figure 5.7 asks for a careful analysis of the behavior of the model. It could be that the model outcome depends on the starting values. Therefore the model is tested with different starting values (Table 5.1). In table 5.1, the different starting values are depicted. I use the word scenario for each of the eight runs, although I realize that this word can be confusing as there are effectively no differences in the model or the parameters. The first scenario shows the starting values GAMS uses when the modeller doesn't provide start values. The aim of the scenarios is to find out how initial startvalues, the size of those startvalues and the time frame in which the startvalues are given, influence the model outcomes.

Table 5.1: 8 scenarios with different starting values in GAMS

Year	Solve 1	Solve 2	Solve 3	Solve 4	Solve 5	Solve 6	Solve 7	Solve 8
1	0	5	10	0	0	5	10	100
2	0	5	10	0	0	5	10	0
3	0	5	10	0	0	5	10	0
4	0	5	10	5	10	0	0	0
5	0	5	10	5	10	0	0	0
6	0	5	10	5	10	0	0	0
7	0	5	10	5	10	0	0	0

In a model with a single optimum, the 8 different scenarios should give the exact same outcome. The only thing that is done is telling GAMS where to start the calculations for the optimal investment path. Without an explicitly modeled start value GAMS uses the start value 0. Figure 5.8 shows that the model outcomes are very sensitive to the starting values, even though the model structure is quite simple. Depending on the starting values, the optimum can vary by a factor 1,3. When the degradation rate is higher, the differences become even bigger. The solution landscape can therefore be understood as an area with multiple optima, depending where GAMS starts the iterations another optimal point is found. This is on the one hand what we expected and aimed for: multiple equilibria. On the other hand, it is very complicated to analyse the outcomes.

The total consumption is highest in those scenarios where the model started the calculations in the first period at non-zero. In the solutions where the starting value in the first period was zero the total consumption ended lower. In the two scenarios where for each year a non-zero suggested value for investment was given, total consumption is highest. Solve 6 and 7 show the total consumption when there were only non-zero starting values for the first three periods. The size of the start value seems to be of minor importance but the number of periods for which the start values are defined is important. In none of the scenarios investment in the last period takes place. In table 5.2 the investment paths are depicted. The numbers themselves are of little importance but the table shows how starting values and the decision to invest or not are connected.

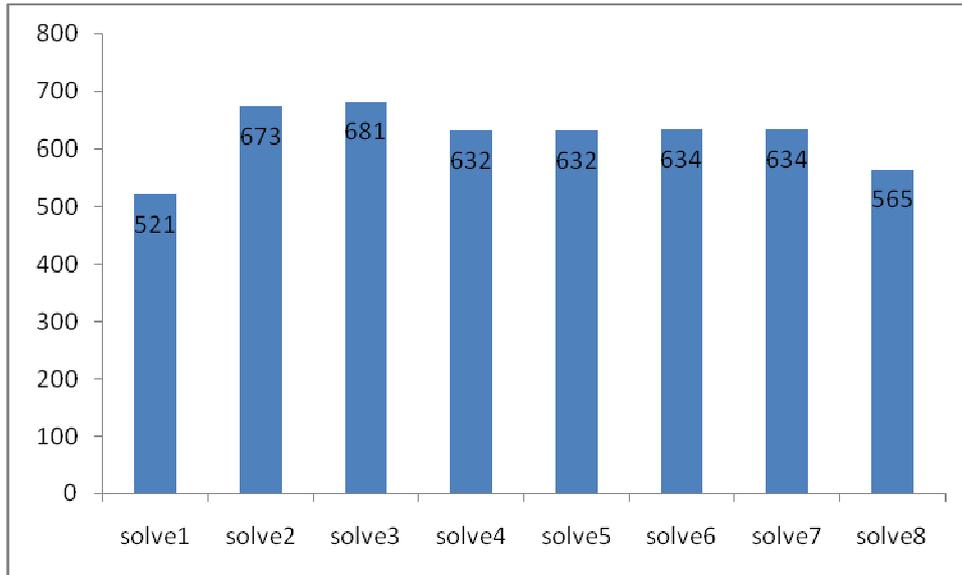


Figure 5.8: Total consumption depending on starting values. The model runs are depicted in table 5.1. The scenarios are different in such a way that GAMS starts its calculation at different points. The β is set to 2 in order to have increasing returns. Initial soil quality is 100 and the degradation is 20% of soil quality.

Table 5.2: Investment depending on starting values

Year	Solve1	Solve2	Solve3	Solve4	Solve5	Solve6	Solve7	Solve8
1	0	3,162	3,162	0	0	3,162	3,162	3,162
2	0	3,162	3,162	0	0	3,162	3,162	0
3	0	0	0	0	0	3,162	3,162	0
4	0	4,359	4,359	5,864	5,864	0	0	0
5	0	3,162	3,162	3,162	3,162	0	0	0
6	0	3,162	3,162	3,162	3,162	0	0	0
7	0	0	0	0	0	0	0	0

In figure 5.9 the value of β is changed to see if for a β of 1 the model behaves correctly. When β is one there are no increasing returns and no non-convexities therefore all scenarios should give the same outcome. This happens. For β is 3 the non-convexities are comparable with those of β is 2.

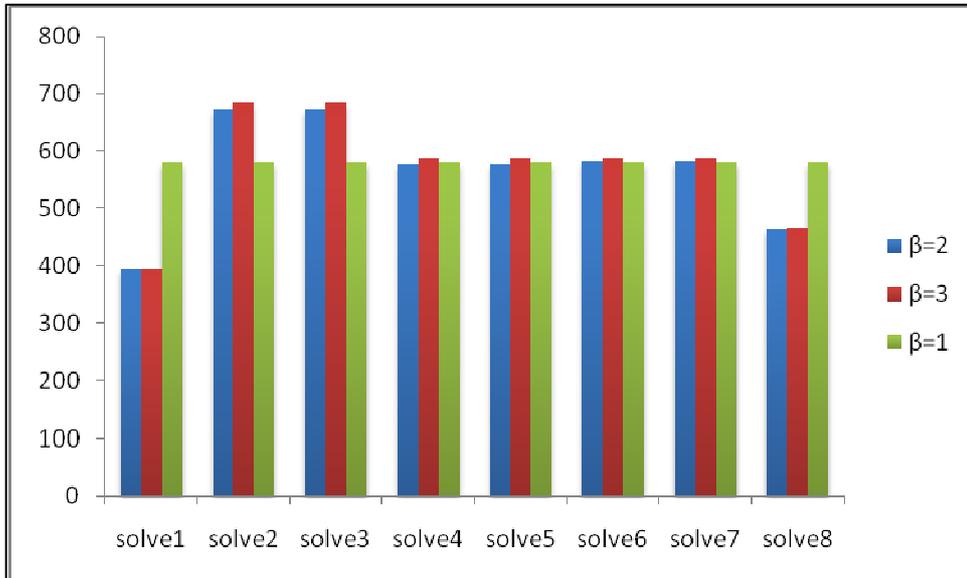


Figure 5.9: Total consumption depending on starting values for three different β 's: the model runs from table 5.1 are modelled with three different values for β . The initial value for soil quality is 100, degradation is 20%.

Previous findings make clear that the model is not suitable for a careful analysis of the poverty trap mechanism. Nevertheless, the role of minimal consumption and discounting are quickly examined. The model from figure 5.8 and 5.9 is run again now including a minimum consumption of 20, rather than zero. In the two-period analysis the minimum consumption restricted the feasible area and led to another outcome. Therefore it could be interesting to add the same constraint to the dynamic model. The extra restriction caused 6 out of 8 runs to become infeasible. Only in the second and third scenario the requirement of minimum consumption was satisfied for all years. The discount rate influenced the outcomes like is expected. The value of total consumption becomes lower when corrected for time preference. The pattern of outcomes is not altered.

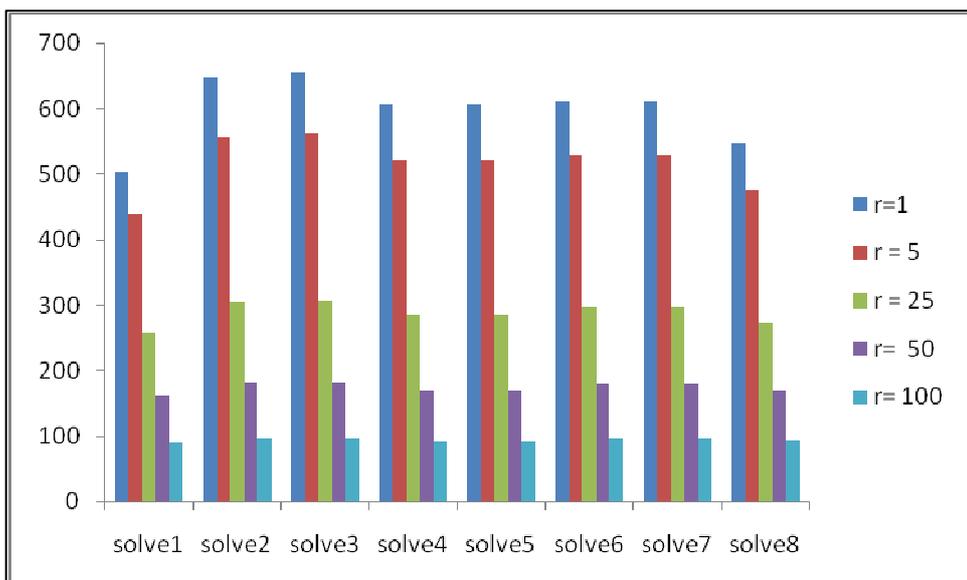


Figure 5.10: Total consumption depending on starting values for 4 discount rates. The discount rate doesn't influence the solution pattern but affects the value of present consumption expressed in today terms.

5.1.3 Model assumptions and relevance

Modeling means making choices about which aspects of reality to study and which to leave out of the analysis. In the previous model several aspects of a farmer's reality are not studied. As the purpose of the models is demonstrating the mechanisms that can lead to a poverty trap, details irrelevant to this topic were ignored. In this section the assumptions of this first model are discussed together with the implications when the assumptions would be relaxed.

1. Consumption is linear in production

In this model consumption is a linear function of production. In reality, a farmer is likely to prefer a stable level of consumption over time. At least a minimum level of basic nutrition should be satisfied each year. The income elasticity of demand for each individual good should then determine how consumption will increase or decrease when income changes. However, as the farmer in the model produces under subsistence circumstances and the level of minimum consumption is already difficult to reach in each period, it is likely that this assumption will not change the trap mechanism.

2. Consumption is maximized over time

In the model, consumption is maximized over time. It is common in economic models to work with utility maximization. The functional form that transforms consumption into well-being can then be chosen in order to fit reality best. Utility can be derived from the consumption of a variety of food crops but also from consuming other goods and services or having leisure time. This model assumed that many subsistence farmers are in the same situation and off-farm work is scarce.

3. Investment is used instead of savings

Saving is not modeled explicitly in the model. But investment in the model has the same function, namely that consumption is postponed to secure future income. In many developing countries saving is employed in a different form than in developed countries. Rather than storing money in a bank, a farmer will try to buy livestock or invest in housing material (Pers. comm. Kor Voorzee, December 2009). In the model, investment is directly linked to soil quality. In reality the security of owning a larger livestock is likely to be preferred by a farmer over having terraces on his land. It takes considerable effort to create terraces or built another soil conservation structure, while it takes just a bit of effort to dismantle the structure. In other words, when a farmer would be able to invest, he probably would prefer to invest in other things than soil conservation.

4. There is just one crop

In the model the single crop can be interpreted as a portfolio of crops. Subsistence farmers usually produce a large variety of goods, which has advantages and disadvantages. The quantity per crop is often too small to go to the market or have contracts with supermarkets or middle men. Therefore, this way of producing brings in little to no cash. Some cash is needed to pay for instance school fees, taxes and medication (Tanui 2009). However, production for own consumption, and diversifying production are at the same time insurance mechanisms. Different crops can satisfy different nutritional needs and different crops can survive different circumstances. Different crops do also have a different effect on

soil quality. Some trees have the ability to bring nitrogen in the soils, other trees need little rain and nutrients and other crops deplete the nutrients from the soil quickly. The soil type, rain fall and slope determine which crops are suitable for a certain location. The United Soil Loss Equation describes how a variety of factors influences soil quality and one of those factors is the cropping system. Modeling the distinction between subsistence crops and cash crops is a possibility that could be added in the model. When the transition from maize to vegetables would require a large investment but would lead in return to higher returns and less degradation, the trap mechanism of lumpiness that will be discussed in section 5.2 can play a role.

5. The only production factor is land quality

Production functions can have different functional forms. Usually the relation between labor and capital is described in a Cobb-Douglas production function. Returns to labor in different sectors and activities can have an influence on the described poverty trap mechanism. Earlier research suggests that when farmers can earn an income on other farms or in a different sector, this can have either positive or negative effects on soil quality and on farm production (Semgalawe 1998). They can earn an income with which they can hire others to work on their land. However, the opposite view is that a farmer will not have time enough to also take care of his own land (Jones 2002).

6. There is a minimum consumption that is constant over years

Minimum consumption varies per person and over time (Dasgupta 1997). The idea of a minimum level of consumption can also be interpreted as a minimum amount of income with which the necessities of life can be bought, like food and clothing. Although the minimum consumption in the model is rather superficial, it affects the investment outcomes similarly to how it would in reality.

5.2 Lumpy investments

In the previous model, investment was allowed to take any value. However in reality variables can also be integer or semi-continuous, the latter meaning that there is a minimum size attached to the variable. Lumpy inputs are those whose quantity cannot be changed gradually as output increases, but rather must be adjusted in large steps. They require a minimum size. Investment in soil conservation can also require a minimum size. Especially the larger soil conservation structures need considerable time and effort to be created. When certain investments require a minimum size and the investment is indivisible, an investment is said to be lumpy. When a farmer cannot save enough resources to make the lumpy investment, this can lead to a poverty trap situation. In this chapter, two examples are analyzed. Lumpy investments that improve soil quality for a while and investments in permanent terraces that affect the amount of degradation.

5.2.1 The lumpy model

$$\max \sum_t (C_t) \quad (1)$$

$$Q_{(t+1)} = (1 - \delta)Q_t + \beta \cdot I_t \quad (2)$$

$$C_t = \alpha \cdot Q_t - I_t \quad (3)$$

$$I_t = \chi S_t + \gamma D_t \quad (4)$$

$$S_t \leq D_t \cdot I_{\max} \quad (5)$$

$$S_t \geq D_t \cdot I_{\min} \quad (6)$$

Equation (1) is the objective function, maximizing total consumption over time. Consumption depends solely on soil quality (Equation (2)). Soil quality declines over time and can be improved via investment (Equation (3)). Coefficient α tells how consumption relates to soil quality, for α is 1 the function is the same as in the previous model. Equation (4) gives the costs of investing assuming that there are fixed and variable costs, the coefficients χ and γ are given constants. Coefficient χ give the variable costs and γ the fixed costs. There is a minimum size required of investment. If the farmer wants to invest, he needs to spend at least I_{\min} . The variable D_t is a binary variable that determines whether a farmer invests (1) or not (0). The variable S_t gives the size of the investment. When D_t is 0, investment costs I_t are also zero. When D_t is 1, the value of S_t determines the investment costs. The value of S_t is calculated with Equation(5) and (6). S_t is larger than the minimum investment but smaller than the maximum investment. In the year that the investment takes place, soil quality becomes higher. Coefficient β determines the effect on soil quality.

5.2.2 Analysis of the lumpy model

The idea behind the lumpy model is that the poorest farmers are not able to invest in soil conservation whilst the richer are able to do so. In this models the returns to investment are linearly dependent on the investment costs, therefore no non-convexities are expected. The earlier applied procedure with the different starting values did not affect the model outcomes for the lumpy model. Whether or not a farmer invests in his soil quality especially depends on the returns to investment. In this model the soil quality is restored with $\beta \cdot I_t$ in the year that the investment takes place. In the years that no investment takes place soil quality will decline with δ .

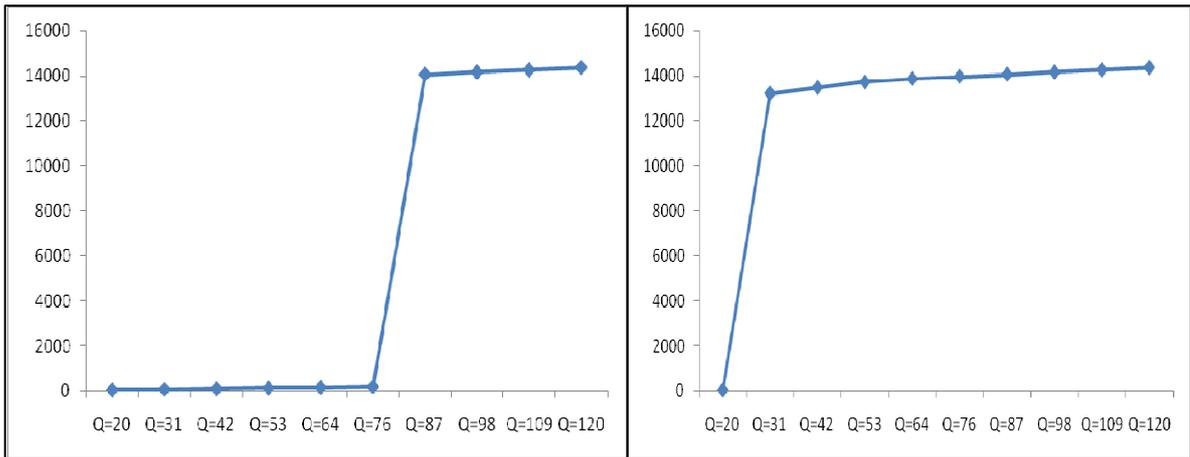


Figure 5.11a & 5.11b: Total consumption in a model with lumpy investments. Minimum investment in figure 5.11a is 15 and minimal investment in figure 5.11b is 5. Initial soil quality varies as can be seen in the graph, maximum soil quality is 1000, $\beta=2$, $\delta=0,4$ and γ and χ are 5.

Figure 5.11a shows a clear distinction between the runs with an initial soil quality below 76 and the runs with an initial soil quality above 76. Although the numbers have little analytical value, the sharp distinction between the two 'equilibria' is important. In the first six runs, there is no investment at all. Consumption declines each year with the degradation factor and depending on initial soil quality the total consumption lays between 50 and 133. In the last four runs the farmer invests each year except from the last year in order to arrive at the maximum soil quality and keep it constant at that level (Figure 5.12). The investment in each period then covers the exact soil loss in that period. The total consumption is much higher in the scenarios in which investment takes place. When the minimum required investment is smaller like in figure 5.11b, also the farmers with a lower initial quality can step over to the positive investment path. The values of the χ and γ have the same effect on investment. The lower their values, the cheaper it is to invest. When the same models are run with a small minimal consumption requirement, the model becomes infeasible for all runs. Although the idea of a minimum level of consumption is important in practice, it doesn't contribute to the analysis of these models. The model becomes infeasible, which means that the variable cannot fulfill the requirements and consumption will be lower than the minimum level required. Of course one can leave the minimum consumption requirement out the model, but analyse the values for consumption in each year to check whether the requirement is fulfilled or not.

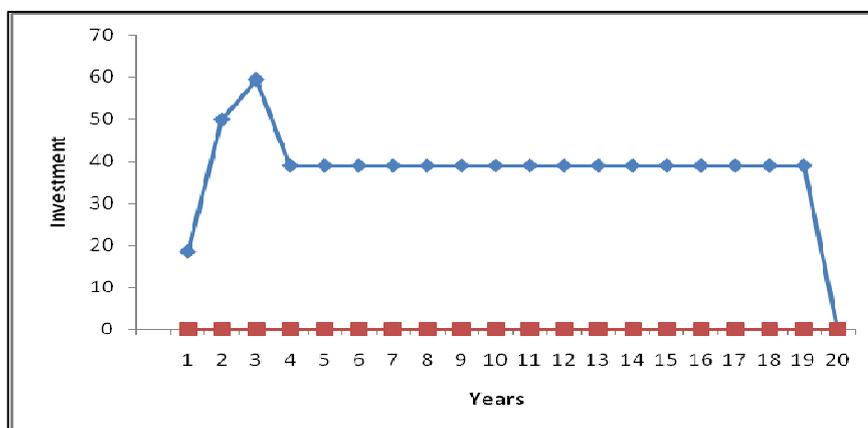


Figure 5.12: Investment when initial quality is 100 (blue) and 20 (red)

5.2.3 The terrace model

In the previous model, the degradation factor didn't change after investment. The investment changed soil quality in the year after the investment but didn't affect the degradation factor. Those investments are exogenous. The soil quality is restored but degradation continues at the same speed. Endogenous technologies ideally decrease the speed with which degradation occurs. The next version of the lumpiness model looks at the creation of permanent terraces. The terraces are created only once. Therefore the large lumpy costs are only made once. After a terrace is created, the degradation factor is substantially lower from that year on.

The model now looks like this:

$$\max \sum_t (C_t / (1+r)^t) \quad (1)$$

$$C_t = \alpha Q_t - I_t \quad (2)$$

$$Q_t = Q_{t-1} \cdot (1 - \delta) + S_{t-1} \quad (3)$$

$$I_t = p_{\min} T_t \quad (4)$$

$$\sum_t T_t = 1 \quad (5)$$

$$B_t = B_{t-1} + T_t \quad (6)$$

$$S_t \leq B_t p_{large} \quad (7)$$

$$S_t \leq \phi Q_t \quad (8)$$

C_t = Consumption , Q_t = Soil quality , I_t = Investment Costs , S_t = Improvement of soil quality , T_t = Binary variable for terraces (1) or no terraces (0), B_t = Binary variable that affect soil degradation after terraces are created

The parameters α , δ , ϕ , p_{\min} and p_{large} are given, just as the initial soil quality. Parameter α gives the relation between soil quality and consumption, δ is the rate of soil degradation without terraces, ϕ is the decrease in the rate of soil degradation when terraces are constructed, p_{\min} gives the investment costs required to build a terrace and p_{large} is an upper bound to help GAMS solve the model. T_t is a binary variable for the decision to create terraces (1) or not create terraces (0). The decision to put T_t at 1 or 0 is determined in the model by giving the minimal costs of building a terrace. The farmer can only create the terraces once. The binary variable T_t is used for the investment costs which appear only once, the binary variable T_t gives the presence of a terrace and is therefore linked to the permanent decreased degradation factor. That B_t is binary follows from the fact that T_t is

allowed to be equal to one just once. Variable B_t leads in the following way to a lower degradation:

$$B_t = 1 \text{ than } Im_t \leq \phi \cdot Q_t \text{ (Equations (7) and (8))}$$

$$Q_t = Q_{t-1} \cdot (1 - \delta) + \phi \cdot Q_{t-1} \text{ (Equation (3))}$$

Which implies that

$$Q_t = Q_{t-1} \cdot (1 - \delta - \phi)$$

In such a way the creation of terraces lowers the degradation factor and improves consumption over time. GAMS calculates S_t first with equation (7). If B_t is zero, then S_t is also zero and the value for S_t also satisfies equation (8). When $B_t = 1$, the value of S_t is restricted by equation (8). In such a way T_t , B_t , p_{\min} , p_{large} are connected. Appendix II lists the exact GAMS code.

5.2.4 Analysis of the terrace model

Permanent terraces are created only once. The investment has a considerable size, therefore the poorest farmers might not be able to create them. However, after the first investments soil quality decline is less or absent. In figure 5.13 a similar picture as in the previous analysis is depicted. Total consumption grows slightly when initial soil quality is larger but makes a large jump to a higher path when a certain initial quality is reached.

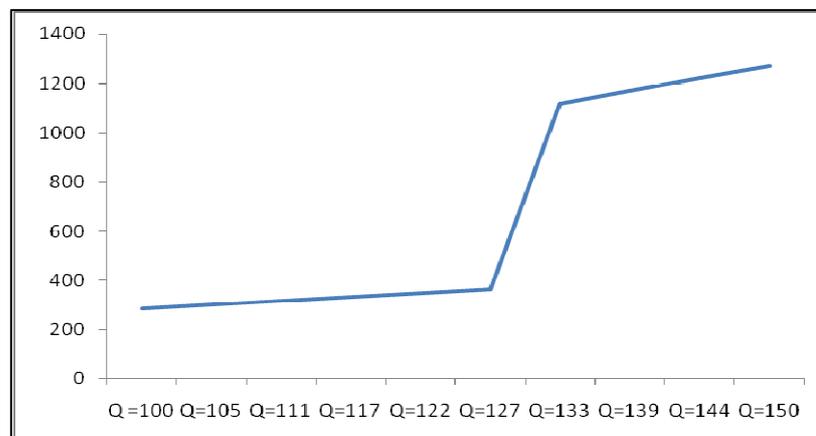


Figure 5.13: Total consumption in a model with investments in terraces. The model has been run 10 times, in each run the initial soil quality increased slightly. In other words, the farmer started in a better or wealthier situation. The consumption of all years in a run was added up, resulting in the total discounted consumption per run. Those total consumption amounts are depicted in this graph which clearly shows a sharp increase in total consumption between a soil quality until 127 and higher.

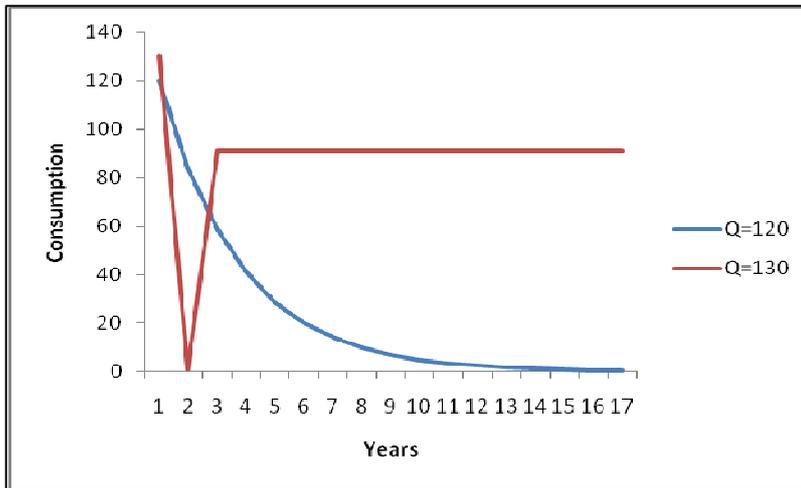


Figure 5.14: Two consumption paths with different initial land qualities. In this figure two different initial land qualities are compared.

In figure 5.14, two consumption paths are depicted with a different initial soil quality. The red line shows the consumption path in which no investment takes place. The blue line shows that in the second period terraces are created. Soil quality stays constant afterwards. A small increase in initial land quality can thus result in a radically different consumption path. When a farmer invest in terraces, the investment takes place in the second period. In the first year consumption is set aside and after the second year soil decline becomes zero.

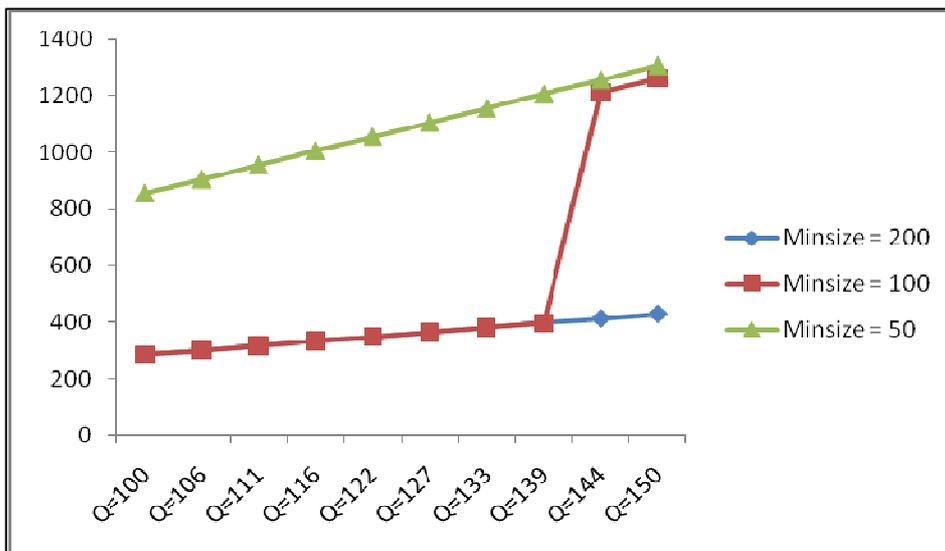


Figure 5.15: Total consumption depending on minimum costs terrace

Figure 5.15 shows the influence of the minimum required size of investment on the total consumption. The green line shows all total consumption when the minimum size of the investment is small enough to make the investment. The blue line shows all total consumption when the investment was too high to make it. The red line illustrates that when the initial soil quality is high enough, lumpiness can be overcome.

5.2.5 Assumptions and relevance

Lumpiness or imperfect divisibility implies that for the use of a certain technology or input a minimum amount is needed. It is for instance impossible or ineffective to build a half terrace or partly construct gullies. Also inputs that can be applied in very small units, like fertilizer or pesticides, can sometimes only be bought in larger bags. In the case of a lumpy investment, the farmer has to put money or labor aside to make the investment. In the absence of financial institutions or time to spend on soil conservation, those lumpy investments can sometimes not be made, even if they would have increased net income. For the models discussed in this part, the same assumptions apply as for the first model. Below new assumptions and relevance are discussed.

1. Terraces don't take land out of production and are efficient

It has been assumed that terraces are efficient. The increase in soil quality outweighs the costs of creating terraces and the loss in land surface that can now be planted. In reality this might not be the case. Terraces take land out of production and when the plot is already small it can be the case that the yields are too low to finance the investment and feed the family. Conservation structures might furthermore take cultivable land out of production or shade food crops. There are opportunity costs for the area occupied by conservation structures, and those costs are implicitly higher when there is a minimum consumption target (Shively 2001). Lumpiness can be the cause of underinvestment, but rational considerations like the ones mentioned above should not be forgotten.

2. A terrace is a one-time investment without further costs

The only costs of creating a terrace were the initial investment costs. In reality, there are also costs to maintain the structure. There is also a risk as it takes considerable effort to create terraces but it is very easy to remove or destroy them. Farmers in earlier research have said that terraces are too labor intensive to maintain (Jones 2002). Therefore, specific studies after the efficiency of certain technologies and the maintenance costs are needed to work with accurate data in the model simulations. The variable costs can easily be put in the model to extent the analysis.

6. Tanzania as a case study

In the previous chapter important poverty trap mechanisms were modeled. Many simplifications could be made, just because markets for labor, land and goods are malfunctioning in the developing setting discussed. Whilst the poverty trap mechanism could be explained with the models, the link with reality could be sharper. In order to analyze whether the poverty trap concept is useful for development workers or policy makers, the theory is now applied to the highlands of Tanzania. In this chapter, the findings from literature, modelling and the experts come together. As mentioned briefly in the introduction, this thesis runs parallel to a large research project on scaling up sustainable land management in the highlands of Kenya and Tanzania. East-Africa has the largest mountains in Africa and poverty is substantial. Tanzania, rather than Kenya has been chosen as a case study in this thesis, because the country is relatively quiet and peaceful in a region with much political and civil unrest. The country is also praised for its economic progress. Research suggests that the majority of farmers in Tanzania is aware of the fact that soil degradation leads to declining yields on their agricultural fields (Semgalawe 1998, Jones 2002). Although the farmers acknowledge the problem and are aware of some technological or management solutions, no large steps have been undertaken to deal with the problem. Land degradation is still a large problem, which decreases harvests at the farm level and on a larger scale influences the regional water quality and quantity.

The United Republic of Tanzania is located along the Indian Ocean in East Africa. Tanzania is the largest country in East Africa, covering 940.000 square kilometers, of which 60.000 are inland water (NBS 2008). Tanzania lies south of the equator and shares borders with eight countries: Kenya and Uganda in the north; Rwanda, Burundi, Democratic Republic of Congo, and Zambia in the west; and Malawi and Mozambique in the south. There are six land locked countries that have access to Tanzania ports (WTO 2005).



Source: Oxfam Tanzania, 2009

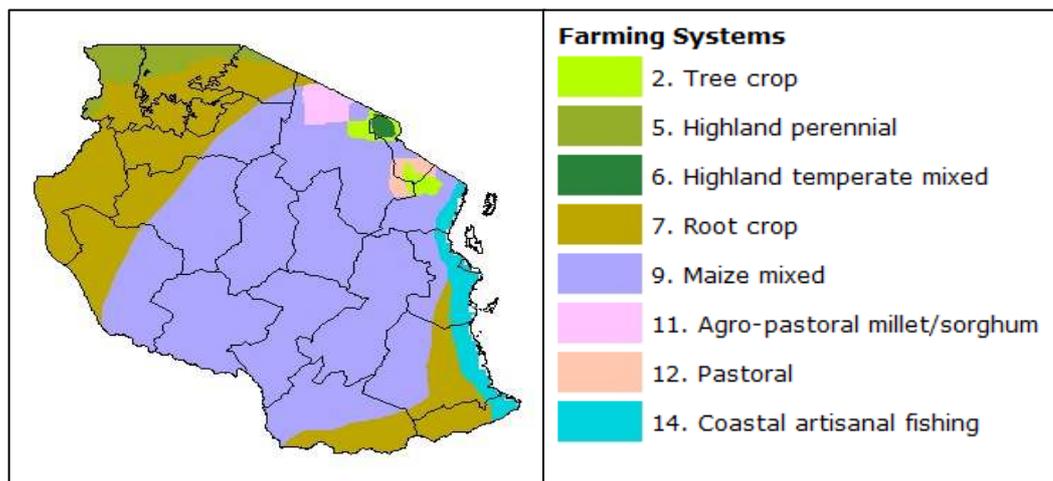
Figure 6.1: Tanzania, with capital Dar es Salaam

Tanzania is a political stable country but its neighbors are not. Due to conflicts in neighboring Rwanda, Burundi, and the Democratic Republic of Congo, Tanzania hosts Africa's largest refugee population (FAO 2007). Malaria and HIV/AIDS are widely spread in the country. While much has been achieved to limit the spread of the HIV/AIDS pandemic in Tanzania, prevalence rates remain high (FAO 2007). Poverty is substantial in the rural areas of Tanzania. Since 2000 the Gross Domestic Product of Tanzania has grown with seven percent each year (WTO 2009). For 2009 and 2010 those percentages are estimated somewhat lower, 5 and 6 percent (IMF 2009). Tanzania is praised for its macro-economic success. The IMF study: *Tanzania, a story of a African transition* (Nord et al. 2009) gives several graphs and tables showing macro-economic progress in Tanzania. It has to be said, however, that the export of gold and receiving substantial foreign aid contributed to the large macro-economic growth (pers. comm. Kor Voorzee 2009). Temu and Due (2000) note that there has been an apparent lack of tangible benefits to many of the poorest sections of Tanzanian society. It is in general very difficult for the poorest working in agriculture to benefit from economic growth in the cities (Christiaensen 2010), especially when the infrastructure is poor.

According to estimates of the World Trade Organization, the population size of the country was 42 million in 2008 (WTO 2009) of which around 30 million live in rural areas (IFAD 2010). According to the 2002 *Population and Housing Census*, the life expectancy at birth for Tanzanians is 51 years. Around 80 percent of the population works in agriculture. Although the country has abundant rivers and lakes, frequent and severe droughts threat a large fraction of the rural poor. In 2006 a period of severe drought left an estimated 3.8 million people in need of food aid and production rates fell significantly (IFAD 2009). The country has a dry season from May to October followed by a period of rainfall between November and April. The main rainy season along the coast and the areas around Mount Kilimanjaro is from March to May, with short rains between October and December. The raining season is predictable, but the rain showers are erratic. Which means that a farmer has little time to prepare his land (Pers. comm. Kor Voorzee 2009). In the Northern and Western part of the country, around Lake Victoria, rainfall is well distributed throughout the year, with the peak period between March and May (NBS 2008). The mountains in Northeast Tanzania provide their ecosystem services to millions of people. The region is densely populated and provides a livelihood to farmers and pastoralists, but the area also supplies water to cities like Dar es Salaam. The Kilimanjaro Mountain is a touristic hotspot as it is the highest mountain in Africa. The Kilimanjaro region is especially used for coffee production.

The Worldbank emphasizes the role of agriculture in the development of the country. The agriculture sector plays a major role in the economy and employs nearly 80 percent of the workforce. The dependency on this sector renders the economy particularly vulnerable to adverse weather conditions. The low level of industrial development makes the negative economic impacts associated with agricultural dependency even more severe (Worldbank 2010). Agriculture in Tanzania is performed in a labor intensive way. Traditionally people are not bound to a homestead. Tanzania has no tradition in building terraces like in China. As rainfall is erratic, time to prepare the land for production is short. Technology use is limited. Most smallholder households cultivate using the hand hoe and less than 40,000 smallholder

households own a tractor (Oxfam 2007). Around 2% of the people perform a pastoral way of living. In the north-east this fraction is larger. A farmer in Tanzania owns on average 4 to 5 hectare. The plots are usually spread over the area. Over the last few years food security and livelihoods of vulnerable farm households in Tanzania have been threatened by poor rainfall, outbreaks of the crop-pest, armyworm and tick-born livestock diseases such as East Coast Fever (FAO 2007). The map below shows the different farming systems in Tanzania. In the North-Eastern mountains pastoral livestock keeping is preformed and also tree cropping can be found here.



Source: FAO 2007

Figure 6.2: Farming systems in Tanzania

It is difficult to give accurate estimates of the production of subsistence farmers in Tanzania. The main agricultural products in Tanzania are coffee, sisal, tea, cotton, pyrethrum (which is an insecticide made from chrysanthemums), cashew nuts, tobacco, cloves, corn, wheat, cassava, bananas, fruits, vegetables. The animals that are kept are especially cattle, sheep and goats (Nation Master 2009). The statistics from the statistical agency in Tanzania demonstrate the marketed agricultural products over the last 4 years as well as the goods exported.

Table 6.1: Major marketed crops in '000 metric tons

	2004	2005	2006	2007	2008
Sisal fiber	27	28	31	33	34
Coffee	39	34	46	55	44
Tobacco	44	57	51	51	55
Cashew nuts	80	90	88	91	98
Pyrethrum	1	3	2	2	1
Green tea leaves	127	133	123	159	148
Seed cotton	140	378	131	131	201

Source: NBS 2008

Table 6.2: Major export in billion Tanzanian shilling

	2003	2004	2005	2006	2007	2008
Coffee	51.2	53.2	83.6	92.8	143.3	122.2
Cotton	42.4	54.3	127.2	56.8	49.8	95.6
Sisal	6.9	7.4	8.2	9.3	7.4	18.5
Cashew nuts	43.4	74.1	54.2	62.7	33.8	82.0
Tobacco	47.3	61.6	91.4	129.1	116.9	208
Tea	25.7	32.5	28.8	41.7	48.3	49.6

Source: NBS 2008

A comparison between figure 6.2 and table 6.2 and 6.3 shows that whilst maize is the major crop in the largest part of the country, the crop does not show up in the official market or export statistics. Ngo's nowadays focus especially on market access for smallholders (Pers. comm. Kor Voorzee 2009, Pers. comm. Izaak van Melle 2009).

6.1. Tanzania's history of land management

Land degradation is a substantial problem in the highlands of Tanzania. About 80% of Tanzania is semi-arid (Quinn et al. 2003 in Slegers 2008). Land degradation has long been considered to be the major factor limiting agricultural growth in semi-arid Tanzania (Hella 2002 in Slegers 2008, p.20). Although good management practices can improve crop yields, climatic circumstances can make it extremely difficult to do so (Okalebo et al. 2005). In studies of nutrient cycles in African farming systems, several authors found that the outflow of nitrogen, phosphorus and potassium often exceeds inflows (Sanchez et al. 1997, Smaling et al. 1997, Shepherd et al. 1996 in Okalebo 2005), leading to a negative nutrient balance and decreasing yields. In several parts of Tanzania the top soil is washed away, showing a poor and unproductive red colored subsoil. In 1990, researchers estimated the annual loss of nitrogen and phosphorus in Tanzania to be 27 kg/ha and 4 kg/ha (Stoorvogel and Smaling 1990 in Semgalawe 1998, p.4).

That the soils are sensitive to erosion is not a recent discovery. In the beginning of the 18th century the north eastern mountains were covered with forest. Several clans owned and distributed the land among clan members. Indigenous tribes made their living in the hills and mountains. The Masai till today perform a pastoralist lifestyle in the region. Farmers cultivated land for a few years, after which new parcels were opened, using slash and burning techniques. The highest yields occurred on the cooler high altitude and high rainfall areas (Okalebo et al. 2005). Population growth increased and in 1936 all arable land was under cultivation (Semgalawe 1998, p.19). Farmers started to clear forests and produce on steep slopes and in the lower located areas. Soil quality and productivity declined. In 1947 the British rulers introduced several soil conservation technologies. Their projects, regulations and restrictions were successfully implemented around 1950 (Semgalawe 1998, p.19).

When the country became independent in 1961 and dr. Nyerere became president. President Nyerere introduced African socialism and put a lot of attention on self-reliance. A large agricultural program was introduced. The Ujamaa-villages in which around 12 million farmers would live, were designed to be the centre of daily life. Education and health care were supplied in those villages. The result was a strong centrally planned economy. "Agricultural producers were implicitly contract farmers to the government" (Hyden 1980; Temu and Due 2000 in Jones 2000). The rules and regulations for soil conservation of the colonial rulers received little attention. The soil conservation program of the British had been top-down enforced, leaving aside the traditional knowledge of the rural and indigenous people. The local people were said to associate conservation efforts with the colonial oppression (Sheinmann 1986, Sianga 1994 in Semgalawe 1998), and several structures like terraces were removed. The result was alarming soil degradation.

Since 1986, the government has undertaken economic reforms, together with the Worldbank and the International Monetary Fund (Temu and Due 2000 in Jones 2000). The severe suppression of the private sector made that Tanzania had a different start position than other Sub-Saharan African countries. Until today the culture of self sufficiency can be found in certain villages: "Yet the people continue to cultivate maize without making investments in the land that it needs, because of the persistence of a strong self-sufficiency ideology in this area, inherited from the time that Nyerere was in power" (Jones 2002).

In the 1980's, programs to reduce soil erosion were introduced by the Tanzanian government and several European NGO's. Nyerere was neutral in his foreign politics and had good foreign relations, resulting in a large funding of projects in Tanzania (Pers. comm. Kor Voorzee, 23 January 2010 and Izaak van Melle 2009). Several NGO's started to work in Tanzania and continue to do so until today. "There are around 140 Dutch groups do 'something' in Tanzania, without cooperation or coordination" (Pers. comm. Izaak van Melle 2009).

6.2 Poverty and erosion in Tanzania

Semgalawe (1998) investigated the factors that influence the investment in soil conservation in Tanzania. Based on an extensive survey and a statistical analysis she distinguished the factors from table 3.3. Land ownership was on the right side in the version of Semgalawe, but is placed at the left side in this thesis. As Semgalawe writes on page 87: "Full ownership of land increases the sense of responsibility due to a long time planning horizon and concerns about the soil quality on the farm". The surprising factor in the table is off-farm income. When a farmer or his family members can gain income outside the farm, the money can be used for soil conservation, but if all time is spend on the job outside of the farm and there is no time left for soil conservation the relation works the other way around. Different research in different countries and regions show contradicting outcomes for off-farm income (Semgalawe 1998, Jones 2002, Okalebo et al. 2005).

Table 6.3: Factors influencing the adoption of soil conservation technologies in the highlands of Tanzania

Factors with positive influence	Factors with negative influence
Education level	Age
Income	Investment costs
Farm size	Risk aversion
Labor size	Discount rate
Credit	Farming experience
Involvement in soil conservation programs	Off-farm income
Perception of erosion	
Perception of erosion problem	
Social rank	
Membership of networks	
Land ownership	

Source: Semgalawe 1998

Jones (2002) investigated soil conservation behavior of farmers in Mgeta, located 200 kilometer west of Dar es Salaam in Tanzania, and in Thailand. In a survey of 60 families in Mgeta she found that 47.5% of people felt that yields on their fields were declining and 95% of the families attributed the decline to erosion and exhaustion. The families knew on average 3 solutions to stop the decline in productivity. "All farmers said that they would keep pigs and manure their fields if they were financially able to do so" (Jones 2002). She concludes that land shortage was the main reason that people were unable to implement erosion prevention methods (mentioned by 43%), as trees and terraces both absorb land and trees further shade crops this land is preferably used for production rather than for conservation (Jones 2002).

Jones (2002) finds that farmers invest when they have healthy and productive soils, but that they invest little in already low productive soils. There is especially little investment in the steep slopes, even when ownership is secure. According to her research, the steep soils are located further away from the homestead and are used to grow especially beans and maize. Investment in those hills is little, "this is because maize can be purchased more cheaply on the market than it costs to cultivate" (Jones 2002). Yet they continue to cultivate maize "because of the persistence of a strong self-sufficiency ideology in the area" (Jones 2002). The poorer households do grow maize because they have a low access to cash income that would enable them to buy crops on the market. Those poorest people try to offer their labor to other farmers or non-agricultural sectors, as they are in need for cash income. This leaves little time left to cultivate their own lands. This lack of sufficient time, makes also that local people will not convert their ladder terraces into more permanent terraces 'because they say they would be too labor intensive to maintain'(Jones 2002). When the poor own the better lands on which legumes or other more profitable crops can be produced, they often lack the money to make the initial investments. "Vegetable production requires much investment to be profitable, which can rarely be afforded" (Jones 2002). Therefore fertile land is frequently rented to wealthier farmers. Jones concludes that poverty is a significant constraint to soil improvement in the Uluguru Mountains. According to Jones, agriculture

production and soil conservation are to some extent competing. In her research she finds that this additional income earned in other sectors may be instrumental in facilitating the investment in agriculture needed for it to be profitable in Tanzania (Jones 2002).

6.3 Poverty traps in Tanzania

To test whether or not the idea of poverty traps as analyzed with the models, has analytical value for development workers or consultants in the field of poverty and development, three qualitative interviews have been conducted about this idea of poverty traps. Combined with scientific literature the following results were obtained. The basic conditions that were discussed in the models are relevant for rural Tanzania. Land holdings are very small, people own little assets and financial services are basically absent despite the popularity of microfinance (Pers. comm. Izaak van Melle 2009). Severe droughts and erratic rains cause an uncertain environment, just as a system in which land property is owned by the government.

Increasing returns

Model findings

- Initial conditions matter
- Non-convexities cause multiple steady states
- The notion of minimum consumption influences the optimal outcome

In practice

The non-convexities in the first model discussed in chapter 5, can be found in Tanzanian reality as well. The state in which soils are degraded can be seen as a stable equilibrium. The other, preferred equilibrium can only be reached with considerable investments. The red degraded soils in the equilibrium with no soil cover can be found in many developing countries, and also in Tanzania. Improving the soil condition is not easy. The farmers have always solved the problem of degrading soils by moving to another piece of land. This becomes more difficult due to population pressure (pers. comm. Kor Voorzee 2009). The returns to investment in soil conservation will not run linearly but have non-convexities. This corresponds with the findings of Antle et al. (2006) that agricultural systems can exhibit equilibria with corresponding low or high levels of soil degradation. Once the soil is in the equilibrium in which soil degradation is large, it can become economically inefficient to invest in the soil. In the two period analysis of the increasing returns model, we saw that initial soil quality determined whether a farmer was able to invest or not. Antle et al. (2006) found the same: "...the effects of soil conservation depend on the initial conditions of the system, in other words the state of the soil productivity at the site at the time the investment is made". Increasing returns to scale are found in the large tea plantations Tanzania has. The foreign farmers have leased considerable pieces of land and use the latest technologies to improve the production and returns to investment (pers. comm. Kor Voorzee 2009).

Lumpiness

Model findings:

- Due to an initial low land quality and subsistence requirements, lumpy investments are out of reach for the poorest
- Due to lumpiness there is a convergence between the poorest and those able to step out of poverty
- When terraces effectively prevent soil degradation, farmers should create them as soon as possible

In practice:

An important aspect of Tanzanian agriculture is the fact that rain is erratic. Family labour is often inadequate during the rainy season where there is a lot of work on plots spread over the area and malaria is most active (Tanui 2009). Exogenous technologies to improve soil quality like using fertilizer or ploughing with the hand hoe, improve soil fertility but contribute to erosion. There is an exchange between short term consumption and long term soil quality (pers. comm. Kor Voorzee 2009). Those technologies are more applied than the ones that include a minimum investment (Jones 2002). There is furthermore a large demand for firewood so that a lot of forest is cut, leading to substantial leaching of essential minerals.

"I recognise the negative spiral for the farmers, the tension between long term production and short term consumption, endogenous and exogenous investment and land use for soil conservation or fire wood and food production. When nothing changes, erosion progresses and the poor will continue to be poor. The question is how to break the negative spiral. Somewhere money is needed." (Pers. comm. Kor Voorzee 2009). Tanzanian farmers indicate in the research of Jones (2002) that they would buy animals to use the manure on their fields if they were financially able to do so. The application of artificial fertilizer can, when fertilizer is only sold in large bags, include lumpiness just as buying animals. The same lumpiness takes place when farmers want to start producing more profitable legumes (Jones 2002). Poorer farmers lease their land to richer farmers that can make the initial investments to grow legumes (Jones 2002).

Risk

Findings from literature

- The feeling of insecurity can materialize itself in a poverty trap (Dercon and Christiaensen 2007; Shively 2001)
- Weather risk and tenure insecurity can prevent farmers from investment in soil conservation (Shively 2001)

In practice:

Insecurity and risk are important in determining farmers' choices. Dercon (1996) finds that farmers in western Tanzania grow lower return but safer crops. Jones (2002) finds the same. The experts see this in practice. Moving from subsistence to cash crops is new for rural farmers in Tanzania with a pastoralist culture. There is a substantial risk and a lack of knowledge and information about new possibilities which leads to a feeling of high

perceived risk (pers. comm. Kor Voorzee 2009). A subsistence portfolio can be safer than stepping over to some higher return crops (Kostov and Lingard 2004). Insecurity in Tanzania stems from several resources. At first the erratic rainfall and droughts should not be underestimated. Surviving in a dry and unpredictable environment is extremely hard, especially for those not wealthy enough to self insure themselves against income shocks. Second, according to the experts, tenure security is a problem in East Tanzania. The Tanzanian government owns all land, and leases it for a certain period. Many small farmers use land they have used for a long time, and this property is accepted via a system of customary right. However, the district commissioner can easily lease out the land to a foreign farmer or company. Land conflicts, especially between pastoralists and governmental bodies decrease the feeling of tenure security (pers. comm. Kor Voorzee 2009).

6.4 Policy recommendations

The first lesson from this thesis is that developing workers should focus on productive assets when aiming to reduce poverty, rather than on daily income. The farmers in a poverty trap need other, more severe and long term interventions than farmers who are close by the poverty trap or suffer from temporally poverty. The groups continue to be hard to distinguish. More research is needed to take a look at the division of those groups (Carter and Barrett 2004). The second lesson is that policies that stimulate farmers to invest in soil conservation are needed. None of the experts interviewed neither the other consulted developing organizations that were asked to participate in this research, were involved in or knew projects concerning the prevention of soil degradation in Tanzania. Recent research by Christiaensen and colleagues (Christiaensen et al. 2010) suggest that the poorest of the poor in Sub-Saharan Africa can be helped best by improving agricultural productivity. And as numerous research about degradation, population growth and rural poverty suggest, wise land management is of major importance in this. The Tanzanian government should improve infrastructure in order for the distant farmers to have access to larger output markets. The third lesson is that some farmers are unable to invest due to the lumpiness of investments or increasing returns to scale. Access to credits in rural areas might overcome such problems. The ex-ante production decisions of farmers which are based on risk-aversion, can be changed by influencing the perception of risk. Micro-insurance can play a role in this (Barnett et al. 2008). Technical assistance whether from the government or NGO's should aim at providing information about technologies, high yield crops and the risks associated with them in order to reduce the feeling of risk. "The farmers themselves should be able to make the investment decision" (Pers. Comm. Kor Voorzee 2009). As the largest risk in the highlands of Tanzania comes from drought, investments in irrigation and drip technologies can also help to reduce the risk of a lost harvest (Pers. Comm. Izaak van Melle 2009).

7. Conclusion

Soil degradation continues to be a substantial problem in the highlands of East Africa, threatening the livelihood of millions of people. Earlier research mentions that there is a category of farmers that is aware of soil degradation and willing to prevent it, but is not able to do so. In this thesis possible reasons for this underinvestment have been examined, using poverty trap theory and simulation modelling. The aim of this research was to unravel the trap mechanism and bring structure into the causes of poverty and degradation. Lumpiness and increasing returns to scale, the absence of financial markets and the risk associated with this absence, can create severe poverty traps in the highlands of developing countries. Especially in the light of an increasing population and an insecure environment with erratic rains and severe droughts. Policy makers should look for solutions to overcome lumpiness and decrease the feeling of risk. Developing organizations should put more effort in the improvement of soil quality and productivity.

Causes for poverty traps

According to standard economic theory, the optimal investment in soil conservation lays at the point where the marginal costs of preventing erosion are equal to the marginal benefits of implementing soil conservation. Some suggest that the poorest farmers are caught in a poverty trap which prevents them from investing in soil improvement. A poverty trap is any self-reinforcing mechanism which causes poverty to persist (Azariadis and Stachurski 2004; Barrett 2008). In this thesis the poverty trap was analyzed in which multiple equilibria exist but the low level equilibrium is enforced. The neoclassical economic assumptions lead to unique equilibria. The main deviations from those assumptions are non-convexities in technology use, absent or malfunctioning financial markets, information problems and insecurity. The poor are less willing to take risk and have a limited access to the resources that smooth out risk like insurance or credit. Risk aversion is further increased by imperfect information.

Models in earlier research

Data requirements to proof the existence of a poverty trap are strict. Empirical research in which a poverty trap has been identified is therefore scarce. Earlier research with simulation models focus especially on risk and critical thresholds in asset levels (Sylwester 2004; Barrett 2008). Multiple equilibria are caused by non-convexities, which can in this kind of problems be caused by increasing returns to investment and lumpiness of investment. Non-convexities can be overcome by borrowing money or saving. Therefore two other conditions are necessary to arrive in a poverty trap. The first is the assumption that a minimum level of subsistence consumption is needed in each period which makes it impossible to perform autarchic saving. The second is the absence of access to insurance and credit which make it difficult to make the initial investments in new technologies or bare the risk associated with a new technology or farming orientation.

Results from simulation models

In the small models discussed in chapter 5, two mechanisms increasing returns to investment and lumpiness were analyzed. In the first model initial conditions were proven to be important. A farmer that starts off with a higher soil quality can make the investments in soil conservation, a farmer that starts in a worse situation will chose to consume everything now. The dynamic model was sensitive to the starting values which made the analysis difficult. Future researchers in the poverty trap field should take this into account when looking for modelling techniques and software. The models in which lumpiness was modeled showed the implications of a large minimum size of investment. Again the poorer household couldn't make the investments, resulting in a decreasing consumption. Whereas the farmers starting with a higher initial quality could invest each period so that soil loss was resolved by investment. Modelling a level of minimum consumption larger than zero in GAMS led to infeasible solutions. Therefore the analysis of a level of minimum consumption level was not as convenient as assumed in advance.

Poverty traps in Tanzania

In the last chapter the findings from literature and the models were combined with expert knowledge on Tanzania. The poorest in Tanzania haven't benefited from the macroeconomic growth in the country. Farmers till today have a strong self-reliance attitude and are less focused on specialization, technological innovation and producing a surplus (Due 1982, Jones 2002, Pers. comm. Izaak van Melle 2009, Pers. comm. Kor Voorzee 2009). This is said to be a result of the presidency of Neyere. Tanzanians are traditionally not bounded to a certain piece of land and do not have a culture of terracing. However, today's reality forces the people to produce on a small plot of land. As there is a tradition in which sons receive the land after the parents die, plots become smaller and smaller (Semgalawe 1998). Opportunities in other sectors are limited. Migration to the city is one of the solutions to find a job. Although micro-credit is also popular in Tanzania, it continues to be extremely difficult for the poorest working in agriculture to obtain a loan (pers. comm. Kor Voorzee 2009) or insurance. Agricultural systems can exhibit equilibria with corresponding low or high levels of soil degradation. In the low equilibrium, it can become economically inefficient to invest in the soil. Foreign farmers show how the latest technologies and large scale production can increase returns substantially (pers. comm. Kor Voorzee 2009). The application of artificial fertilizer can, when fertilizer is only sold in large bags, include lumpiness just as buying animals. The same lumpiness takes place when farmers want to start producing more profitable legumes (Jones 2002). Poorer farmers lease their land to richer farmers that can make the initial investments to grow legumes (Jones 2002). Moving from subsistence to cash crops is new for rural farmers in Tanzania with a pastoralist culture. There is a substantial risk and a lack of knowledge and information about new possibilities which leads to a feeling of high perceived risk (pers. comm. Kor Voorzee 2009) and the choice to stick with the subsistence portfolio.

Important lessons from the poverty trap literature are:

- The poverty trap argument should not be used to implement one-size-fits all measures. Although it is easy to use the poverty trap argument to pledge for money transfers to the poorest, literature shows that the mechanisms leading to a poverty trap are more complex and diverse. Understanding those mechanisms, together with the notion that each specific location is different in terms of cultural structure, institutional arrangements and environmental conditions, can lead to better policy decisions.
- The distinction between endogenous and exogenous investments in soil degradation is important. Farmers are more likely to invest in harvest improvement rather than soil improvement. However, in the long term the latter is also important.
- Increasing returns to investment and lumpiness of investments are essential in the decision making of poor smallholders. Although possibilities to improve land quality and production possibilities exist, those possibilities can due to earlier mentioned reasons be out of reach for the poorest.
- Natural systems can have more than one stable state. In the case of the highlands of Tanzania, a degraded state in which the roots of plants cannot capture rainfall and cannot grow and a state in which trees and plants capture the soil and the rainfall is brought into the soils.
- The need to fulfill a minimal level of nutritional intake or to earn a minimal level of income that can be used to buy necessities should always be incorporated in economic models for subsistence households.
- The focus on productive assets is important. Poverty estimates should be based on assets rather than daily income. Policy makers and development workers should try to investigate which poor are in a poverty trap or which ones have enough productive assets to grow out of poverty.
- Access to micro-credit and micro-insurance can be a step forward to step out of the poverty trap. Credit should not be used for consumption or to repay other loans, it is the challenge for credit cooperations and micro-credit companies to make sure their clients invest in productive assets. Also investments into infrastructure (good roads, telecommunication) are important to help the poor step out of poverty.

8. Discussion and recommendations

The objective of this thesis was to give insight in poverty trap mechanisms that prevent subsistence farmers from improving their soil quality. The concept poverty trap was given a central place. The literature review, modelling exercises and a case study were combined to show how this concept can help to understand the poverty related to soil erosion in highlands of developing countries. In this chapter the shortcoming of the research, the recommendations to development workers and policy makers and the subjects that need further investigation are discussed.

8.1 Poverty and soil degradation

There is not necessary a causal relation between poverty and soil degradation (Prakash 1997, Sylwester 2004, Worldbank 2008b). Those that produce for subsistence on a field with a good soil quality are likely not to exhaust the soils. Subsistence farmers who own many small plots spread over the area are often not able to prepare all of the plots, and the resulting fallowing of some can result in more fertile plots (Jones 2002). The farmers that move from subsistence to commercial farming, are more likely to try to get the most out of their soils without having the resources to invest in the improvement of the soil. Wealthier commercial farmers might have the resources to invest in their land quality. Therefore the relation between soil degradation and poverty depends on what a farmer does to produce his required production (Sylwester 2004). Helping people out of poverty does therefore not necessarily imply that the soil quality will also improve. Improving the soil quality will not necessarily help people out of poverty. Both are extremely complex problems by themselves. However, Christiaensen et al. (2010) show that investments in agriculture can help the poorest out of severe poverty.

Certain economists have suggested that poverty traps do not exist. This reasoning is often connected to the development aid discussion held at the macro-scale, in which the concept poverty trap has been used to predict strong, one size fits all, and planned intervention. On the micro-scale, the argument goes that rather than being caught in a poverty trap, farmers make rational and efficient decisions. Soil conservation structures take land out of production and might not be efficient in attacking the soil conservation problem. In chapter three an example was given that agrees with this vision. However, there is overwhelming anecdotic evidence that households that depend on natural resources for their subsistence can be trapped in poverty (Sylwester 2004, Bowles et al. 2006, Worldbank 2007, Barrett 2008). It is complicated to prove empirically the existence of poverty traps. The data requirements for such an analysis are substantial. Theoretical models are able to proof that multiple equilibria can exist, but in real life people prove to be better able to find solutions for their situation than such models predict. One could ask the question: why it is so important to prove the existence of a poverty trap? In some articles, the answer is: for reasons of academia. Other researchers have a more promising vision. When the poverty trap mechanism is understood, policy makers can benefit from this knowledge. When policy

makers are able to detect the people already caught in a poverty trap and those close by such a trap, policies can be better directed to help those people (Barrett 2004, Carter and Barrett 2004). As seen in the models, the line between being trapped and being on a growth path can be very thin.

8.2 Modeling poverty traps

Determining the optimal investment path given declining soil quality, can be done in different ways. The problem can be treated as a dynamic optimization problem, which can be solved with a Current Value Hamiltonian function. The soil quality is then viewed as a stock of a non-renewable natural resource and the optimal investment path in infinite time is calculated. The caveat of this approach is that it works only when there is a unique optimum, which is preferably an interior solution. A poverty trap appears when there are multiple equilibria. The non-convexity characteristic of such models suggest that corner rather than interior solutions are optimal. This was demonstrated in chapter 5, in the part about increasing returns. It is furthermore unlikely that a subsistence farmer will decide at a certain time $t=0$ how he is going to invest for the infinite following years. Since the focus was on poverty traps, simulation modelling turned out to be the best method.

In this thesis the presence of poverty traps was investigated using two simple simulation models. All model assumptions have been discussed in chapter 5. Large simplifications have been made. Some of the points left aside, are worth examining in detail and the models themselves can be extended with more realistic functions and calibrated with real life data. There is place for substantial discussion about the decisions made in the models, like the absence of prices, labor as a production technology, a labor market etcetera. However, even though the models were so simple, complex trapping situations appeared. In order to understand those mechanisms, the models had to be kept as simple as possible. The findings from the modelling chapter, can help students and researchers who are planning to model poverty traps in the future. Non-convexities can be difficult to analyse with techniques that are created to find unique equilibria. This is important to take into account in future research.

Increasing returns to investment can lead to non-convexities. Non-convexities can cause the existence of multiple equilibria as demonstrated in chapter 5. A spreadsheet model helped to understand the model behavior of the increasing returns model in a two period-setting. Corner rather than interior solutions were found to be optimal and the initial soil quality influenced the optimal equilibrium. In a dynamic model the starting values strongly influenced the model outcomes. Different starting values, that should only help GAMS iterate towards the optimal solution, gave different optimal solutions. Starting values should not be confused with initial values. Initial values are values that are used in the calculations, they have a meaning in the model. Starting values are the values at which GAMS starts the iterations they have no meaning in the model. Although in this kind of models different investment paths can lead to the same total outcome, the optimal outcome should be unique. In the model with increasing returns there were more outcomes. In chapter 5 was shown how complicated it can be to analyse a model that is sensitive to starting values. Computational Dynamic Programming, for instance with MATLAB, has potential for this type of problems.

The assumption of lumpiness has proven to be very important in the poverty trap. Earlier research suggested that large fixed costs, sunk costs and transaction costs can influence a farmer's decision. The same was found in the lumpy and terrace model. The difference between the models was that in the terrace model the degradation rate changed permanently and in the lumpy model the soil quality was only affected in the year of the investment. Although the model outcomes are based on artificial numbers, the sharp distinction between the negative consumption path and the positive path is also likely to appear when real life data are used for the calculations. The remarks about earlier researchers that terraces might not be efficient have to be taken seriously and therefore the long term costs of terraces and the benefits should be used in such an analysis.

After an attempt to model risk in GAMS it was decided to focus on the first two cases in chapter 5. Risk and uncertainty are however of importance determining the way people perceive new technologies and opportunities. The anecdotal explanation of a poverty trap based on ex-ante risk goes as followed: farmers do not invest in a conservation or harvest improving technology because there are sunk costs involved and there is a chance that the harvest will be low despite the investments. The costs are then already made and cannot be earned back. This situation is however difficult to model in GAMS. In such a model a stochastic variable should influence soil quality independent of the level of investment. Investment should at the same time also influence soil quality. Modelling a decision tree in such a model, especially when more periods are considered, is labor intensive and complex. It is more elegant to use a Bellman equation in for instance MATLAB to analyse models with a stochastic component.

8.3 Policy recommendations for Tanzania

The case study about Tanzania puts the findings from literature and the modelling exercises in perspective. The case study about Tanzania was not a policy advice in the sense that the researcher went to Tanzania to analyse the exact situation in a specific area. It is rather so that the main mechanisms studied offer important knowledge to those working in development. Increasing returns, lumpiness and risk were also present in Tanzania. Research after those factors should be done in specific areas to come up with concrete advice. One might conclude that the solution to poverty trap situations is simple, namely donating money to those farmers so that initial lumpiness can be overcome. This would not be correct. The different examples of poverty traps made clear that the institutional environment and risk attitude of people plays a very important role as well. All three experts interviewed in the study said that too much aid and aid from different organizations that do not cooperate can lead to a trap of aid dependency.

The three experts interviewed in the thesis all work or have worked in developing organizations and have work experience in Tanzania. Three experts are not enough to make significant conclusions, but that was not the goal of the case study. The experts represent two small NGO's and one large one. None of them worked with or knew projects directed to soil degradation or erosion. Other experts on Tanzania contacted for the interviews preferred not to cooperate, exactly because they didn't have experience with erosion. Therefore the three were not an exception in that they didn't work with erosion and soil

degradation. The poorest of the poor are dependent on their natural surroundings and a careful management of the resources in that surrounding is extremely important. As the dependency on erratic rain and a limited amount of fertile soil will not disappear, the development of connections to other markets in rural areas is important. Creating good infrastructure is thus very important (Christiaensen et al. 2010). However, Moyo (2009) argues that governments should make such investments rather than development organizations (Moyo 2009).

Increasing returns, lumpiness and risk are the main mechanisms behind poverty traps. Access to micro-credit and micro-insurance can help people step out such traps, provided that credit is used to build up a stock of productive assets. One of the systems to provide credit with an incentive to invest in production improvement is the warehouse receipt system. In which farmers can safely store their produce, receive a pre-determined price for 70% of the production and can wait to sell it when they prefer to do so. The warehouse receipt system, introduced through the IFAD-supported Agricultural Marketing Systems Development Programme in Tanzania, is now being mainstreamed by the government throughout the country (IFAD 2009). The supply of micro-insurance is difficult because of information problems and high transaction costs in poor, rural already. However, there are already solutions for these problems. The Economist (11 march 2010) writes about a micro-insurance system via mobile phones and local weather stations in Tanzania. Such solutions to deal with lumpiness and risk are promising in the light of poverty traps.

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Appendix I: Increasing returns

sets

```
t time / year1*year7/  
t_first(t)  
t_last(t)  
sol List of all solves / solve1*solve8 /  
;
```

```
t_first(t) = yes$(ORD(t) eq 1);  
t_last(t) = yes$(ORD(t) eq CARD(t));
```

parameters

```
p_beta Effectiveness of investment / 1 /  
p_delta Land degradation / 0.2/  
p_quality Initial land quality / 100/  
p_maxinvest Maximum investment / 100 /  
p_maxquality Maximum land quality / 100 /  
*p_minconsump Subsistence level of consumption / 10 /  
;
```

*\$ontext

* Deze tabel geeft later in de loop startwaarden voor
* investment. Het zijn dus hulpjes voor het model!

table p_invsol(t,sol)

	solve1	solve2	solve3	solve4	solve5	solve6	solve7	solve8
year1	0	5	10	0	0	5	10	100
year2	0	5	10	0	0	5	10	0
year3	0	5	10	0	0	5	10	0
year4	0	5	10	5	10	0	0	0
year5	0	5	10	5	10	0	0	0
year6	0	5	10	5	10	0	0	0
year7	0	5	10	5	10	0	0	0

```
;
```

*\$offtext

variables

```
v_consumption(t) maiskolven kg p jaar  
v_totcons maiskolven kg p jaar  
;
```

positive variables

```
v_investment(t) maiskolven kg p jaar  
v_quality(t) productie maiskolven kg p jaar  
;
```

```
v_quality.up(t) = p_maxquality;  
v_investment.up(t) = p_maxinvest;
```

```
*v_consumption.lo(t)= p_minconsump;  
v_quality.fx(t)$t_first(t) = p_quality;
```

Equations

```
q_objective
```

```
q_consumption(t)
```

```
q_quality(t)
```

```
;
```

```
q_objective..
```

```
v_totcons =e= sum(t, v_consumption(t));
```

```
q_consumption(t)..
```

```
v_consumption(t) =e= v_quality(t) - v_investment(t);
```

```
q_quality(t)$ (not t_last(t))..
```

```
v_quality(t + 1) =e= v_quality(t)*(1-p_delta) + v_investment(t)**p_beta;
```

```
model farm / all /;
```

```
parameter p_totcons(sol);
```

```
loop(sol,
```

```
v_investment.l(t) = p_invsol(t,sol);
```

```
*In de regel hierboven geef je GAMS advies over de startwaarden van investment*
```

```
v_quality.l(t + 1)$ (not t_last(t)) = v_quality.l(t)*(1-p_delta) + v_investment.l(t)**p_beta;
```

```
v_consumption.l(t) = v_quality.l(t) - v_investment.l(t);
```

```
solve farm maximizing v_totcons using nlp;
```

```
p_totcons(sol) = v_totcons.l;                    )
```

```
* to save data in Excel use this:
```

```
execute_UNLOAD 'farm9.gdx', p_totcons;
```

```
execute 'GDXXRW.exe farm9.gdx par=p_totcons' ;
```

Appendix II: Lumpy

Sets

t time /2001*2020/

t_first(t)

t_last(t) ;

t_first(t) = yes\$(ORD(t) eq 1);

t_last(t) = yes\$(ORD(t) eq CARD(t));

display t_first;

Parameters

p_alpha constant /1/

p_delta soil degradation /0.4/

p_gamma variable costs /5/

p_lapda fixed costs /5/

p_soilqual initial soil quality /20/

p_maxsoilqual maximal soil quality /1000/

p_beta effect of investment on soil loss /2/

p_maxinvest maximum investment possible /100/

p_mininvest minimum investment possible /10/

p_mincons minimum consumption /5/

*p_discount Discount rate /0.05/

;

Variables

v_totcons objective variable

Positive variables

v_invest(t) size of investments

v_invcosts(t) total investment costs

v_quality(t) soil quality

*v_discon(t) Discounted value of consumption

v_consumption(t) consumption;

v_quality.up(t)= p_maxsoilqual;

v_quality.fx(t)\$t_first(t) = p_soilqual;

v_consumption.lo(t)= p_mincons;

Binary variable

v_decision(t) Investment decision;

Equations

Q_Quality(t) Function describing soil quality

Q_Consumption(t) Function describing consumption

Q_Invcosts(t) Investment costs

Q_maxinvest(t) Specifying boundaries on investment

Q_mininvest(t) Specifying boundaries on investment

*Q_discon(t) Function to calculate discounted consumption

```

Q_Objective    Object function
Q_onetimeinv  Function making sure invetsment is done once;
;

Q_Quality(t)$ (not t_last(t))..
  v_quality(t + 1) =e= v_quality(t)*(1-p_delta) + p_beta*v_invcosts(t);

Q_Consumption(t)..
  v_consumption(t)=e= (p_alpha * v_quality(t)) - v_invcosts(t);

Q_Invcosts(t)..
  v_invcosts(t)=e= p_gamma*v_invest(t)+ p_lapda * v_decision(t);

Q_maxinvest(t)..
  v_invest(t) =l= v_decision(t) * p_maxinvest ;

Q_mininvest(t)..
  v_invest(t) =g= v_decision(t) * p_mininvest ;

Q_onetimeinv..
sum(t,v_decision(t)) =l= 1 ;

*Q_discon(t)..
* v_discon(t)=e= v_consumption(t)/((1+p_discount)**ORD(t));

Q_Objective..
  v_totcons =e= sum(t,v_consumption(t));

Model lumpy /all/;

set run / run1*run10 /;

parameter p_totcons(run);

loop(run,
v_quality.fx(t)$t_first(t) = p_soilqual+100*((ORD(run)-1)/(CARD(run)-1));
solve lumpy maximizing v_totcons using MINLP;
p_totcons(run) = v_totcons.;
);

parameter
cons(t) parameter saving the values of the variable consumption;
cons(t) = v_totcons.;

execute_UNLOAD 'lumpycom.gdx', p_totcons;
execute 'GDXXRW.exe lumpycom.gdx par=p_totcons' ;

```

Appendix III: Terrace

Set

t time /2001*2020/

t_first(t)

t_last(t) ;

t_first(t) = yes\$(ORD(t) eq 1);

t_last(t) = yes\$(ORD(t) eq CARD(t));

Display t_first;

Parameters

p_alpha relates soil quality to consumption /1/
p_soilqual initial soil quality /500/
p_maxsoilqual maximal soil quality /1000/
*p_mincons subsistence cons /70/
p_degr % soil degradation without terraces /0.3/
p_lessdegr % soil degradation decreased after terraces /0.3/
p_lesseffect % degradation of terrace effectivity /1/
p_heelveel constant /10000/
p_mininvest costs of building terraces /90/
p_discount discount rate /0.05/
;

Variables

v_totcons objective variable

Positive variables

v_consumption(t) consumption

v_quality(t) soil quality

v_improved(t) factor improving soil quality

v_invcosts(t) Total costs of terraces per period (de kosten zijn eenmalig zeer hoog)

v_invest(t) Decision to invest or not

v_discon(t) Discounted value of consumption

v_terbuild(t) Degradation when terraces are created (deze zorgt ervoor dat de kosten weliswaar eenmalig zijn maar het effect op degradatie blijvend)

;

Binary variable

v_terrace(t) Terrace or not a terrace

;

* Attach boundaries

v_quality.up(t)= p_maxsoilqual;

v_quality.fx(t)\$t_first(t) = p_soilqual;

v_terbuild.fx("2001")= 0;

*v_consumption.lo(t)= p_mincons;

Equations

Q_consumption(t) Function describing consumption
Q_Objective Object function
Q_onceinv Function making sure investment is done only once
Q_quality(t) Soil quality
Q_invcosts(t) Costs of building terraces
*Q_mininvest(t) Giving the minimum costs
Q_improved(t) Giving the effect of terraces on soil quality
Q_lessdegr(t) Less degradation
Q_discon(t) Discounted value of consumption
Q_terbuild(t) Geeft aan dat de effecten op soil quality langdurig zijn
;

*Define equations

Q_consumption(t)..
v_consumption(t)=e= p_alpha*v_quality(t)- v_invcosts(t);

Q_onceinv..
sum(t,v_terrace(t)) = 1 ;

Q_quality(t)\$ (not t_first(t))..
v_quality(t)=e= v_quality(t-1)*(1-p_degr) + v_improved(t-1);

Q_invcosts(t)..
v_invcosts(t)=e= p_mininvest * v_terrace(t) ;

Q_terbuild(t)..
v_terbuild(t)=e= p_lesseffect*(v_terbuild(t-1)+v_terrace(t));

Q_improved(t)..
v_improved(t) = v_terbuild(t)* p_heelveel;

Q_lessdegr(t)..
v_improved(t) = p_lessdegr * v_quality(t);

Q_discon(t)..
v_discon(t)=e= v_consumption(t)/((1+p_discount)**ORD(t));

Q_Objective..
v_totcons =e= sum(t, v_discon(t));

Model terrace /all/;

set run / run1*run10 /;

parameter p_totcons(run);

loop(run,
v_quality.fx(t)\$t_first(t) = 100+50*((ORD(run)-1)/(CARD(run)-1));
solve terrace maximizing v_totcons using MIP;

```
p_totcons(run) = v_totcons.l;  
);
```

```
parameter
```

```
cons(t) parameter saving the values of the variable consumption;
```

```
cons(t) = v_consumption.l(t)
```

```
;
```

```
execute_UNLOAD 'terrace3.gdx', p_totcons;
```

```
execute 'GDXXRW.exe terrace3.gdx par=p_totcons' ;
```