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Technology Adoption in Small-Scale Agriculture: The Case of Cameroon and Ghana

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Abstract

This study explores one of the most important questions for alleviating poverty in sub-Saharan Africa, why are advancements in agricultural technology not taking root in this region? Using data from deep interviews of 42 small-scale farmers in Ghana and Cameroon, a conceptual analysis of drivers and factors of agricultural technology adoption in this region is made and represented as causal loop diagrams. Interviews also provide a basis for weighting factors that farmers consider before adopting a new technology. These weights are then used to run a system dynamics model with a hypothetical population of 10.000 farmers to see the effects of different drivers of technology adoption on the adoption rate and number of adopters over a 25 year period. Results show that most farmers have a bet-hedging strategy as they try to minimize risks of production failures. While certain factors like scale of production, long-term considerations, the history of success of past technologies, and the endorsement of technologies by opinion leaders may be important, many other factors do influence decisions to adopt new technologies. This limits any silver bullet strategy towards solving the problem of limited diffusion of agricultural technologies in this region. Addressing such a problem therefore calls for a much more holistic approach.

1 Introduction

Small-scale farming forms the backbone of agricultural production in sub-Saharan Africa. Historically, productivity of small-scale farming systems has been plagued by a number of structural and policy issues that have led to slow increases in yields and even stagnation in some parts and for some crops. The absence of technology, limited access to or the use of inappropriate technology are among some of the factors blamed for food deficiency in many parts of the developing world (von Braun et al. 2007; McCalla 1999). It seems to be taken for granted that with the right technology in place (better seeds, fertilizers, tools, techniques, and others), agricultural production will routinely be increased and challenges of food security overcome in areas with some physical and social limitations to food production. Such assumptions are based on the expectation that if there is a solution to a problem, then it is rational that people who know of the existence of such a solution, have access to it, and are facing problems for which the solution is appropriate will use it to find a way out of their problem (Beckford 2002).

International agencies, national governments, regional authorities and local concerned groups do attempt at different scales to make agriculture more productive and profitable by introducing technologies to meet or reduce some of the constraints of farm production. These constraints include soil erosion, depleted soil nutrients, low quality of seeds, over-grazing, the use of rudimentary farming tools and techniques, among others. The outcome of these efforts has largely been modest (Ahmed 2004). Some of the basic technologies have not yet reached many of the farmers of this region, especially those of small-scale production (Gallup et al. 2000). Where outside extension agents have introduced new technologies, initial adoption rates have been low and the low adoption rates have largely failed to spread spontaneously beyond the communities into which such introduction is made (Moser et al. 2006). In areas where some of these technologies exist, the adoption rate has been very low and hence their spread has been limited and their intended benefits unachieved (Lado 1998).

Improving agricultural productivity in the developing world in general and sub-Saharan Africa in particular has become an urgent need, dictated by population growth, uncertainty in global food markets, changing consumption patterns of food commodities, as well as the desire to meet important milestones in food and nutrition in the region such as those of the millennium development goals. There is the desire of achieving this improvement in productivity while facing up to the contemporary challenges of global environmental change: global warming, land degradation, water pollution and scarcity, and biodiversity loss (World Bank 2007; McCalla 2001; Blackman 1999). Properly tailored incentives and policies will be needed to ensure that future efforts to increase agricultural productivity do not compromise environmental integrity, public health, and the ability for future generations not to be over-burned by our present day actions (Tilman et al. 2002). Access to and the use of appropriate technologies may be one of the tools needed to meet these production challenges in sub-Saharan Africa (McCalla 2001).

2 Study Objectives

While technology is constantly being developed at almost all levels of the food production, distribution and retail chains, the need to provide small-scale agriculturalists (especially in developing countries confronted with problems of food deficiency) with basic appropriate technology needed to improve their production capacity seems to be overwhelmingly supported (World Bank 2007; Pinstrup-Andersen et al. 1998; McCalla 1999). Understanding the factors that influence the adoption or non-adoption of technologies at the production end of small-scale agriculture can therefore have important implications in the planning of technology-related projects for meeting the challenges of food production for this category of producers.

This study aims to explore some of the insights of the process of decision-making by some of the most important but vulnerable group of agricultural producers in the world - small-scale farmers in Sub-Saharan Africa (World Bank 2007). Using tools of systems dynamics (causal loop diagrams (CLD)[1] and quantitative modeling) the study seeks to understand the process of decision-making from a more holistic perspective. Insights into the process of decision-making may provide clues to the long-standing question of why technology-related assistance has in many cases failed to take root in this part of the developing world (Ahmed 2004).

3 The baseline model and its shortcomings

Technology adoption has been investigated by a number of diffusion of innovation theories. The most influential has been by Rogers (1995) who framed the adoption of innovation as a life-cycle made of five categories of adopters: innovators (brave people ready to take risks and try out new things), early adopters (opinion leaders who are ready to try out new things but exercise a bit more caution than the innovators), early majority (people who are careful but ready to accept change more quickly than the average), late majority (skeptical people who will use new ideas or products only when the majority is using it), and laggards (traditional and conservative people, slow to change and critical towards new ideas, will only accept or use them if the new ideas have become mainstream or even tradition) (see Figure 2).

This theory (like the Bass diffusion model (Bass, 1969)) sees technology spread as the outcome of two main factors: innovation which refers to the desire of people to try out new technologies, and imitation which refers to the influence of those that have tried out a technology in drawing in others who have not yet tried this technology to trying and using it. The innovation adoption curve developed by Rogers (1995) therefore seems to suggest that trying to quickly and massively convince the bulk of people of a new idea or product is useless. It takes time for innovation to diffuse through a society and it makes better sense to start with convincing innovators and early adopters first before expecting other groups of adopters to follow suit.

3.1 Interaction between Actual and Potential Adopters: the Bass Diffusion Model

A well tested theory of the diffusion of technology is the Bass diffusion model (Bass 1969). This model sees the adoption of new products as an interaction between a population of would-be users (potential adopters) and the population currently using the product (actual adopters). Mathematically, the Bass diffusion model is represented as:

Equation 1:

$$N_t = N_{t+1} + p(m - N_{t-1}) + q\frac{N_{t-1}}{m}(m - N_{t-1})$$

Where N_t is the number of adopters at time t; m is the market potential (potential adopters) or the total number of people who may eventually use the product; p is the coefficient of innovation (external influence) or the probability that someone who is not yet using the product will begin using it because of advertisement; q is the coefficient of imitation (internal influence) or

[1] A characteristic causal-loop (influence or cause-effect) diagram is used to define positive and negative causal links (or influences). Positive (+) and negative (-) polarities are used to define the nature of influence from one factor to another. A has a positive influence or effect on B if A adds to B, or if a change in A results in a change in B in the same direction. In the same light, A has a negative influence or effect on B if A subtracts from B, or if a change in A results in a change in B in the opposite direction.

the probability that someone who is not yet using the product will start using it because of "word-of-mouth" or person-to-person communication.

It is generally assumed that the timing of the first time purchases is somewhat distributed over the general population (meaning the role of the innovators and early adopters is very important in determining the speed of the adoption process and hence the time the innovation adoption cycle will run). Hence the diffusion rate at time t is generally expressed as (Sultan et al. 1990):

Equation 2:

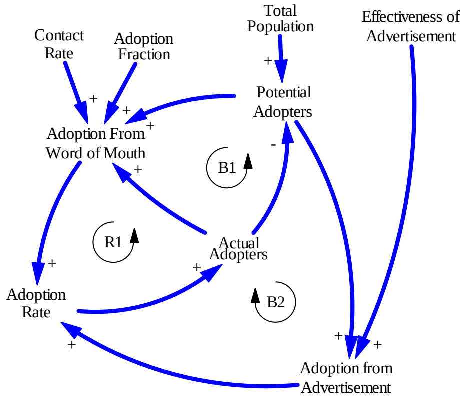
$$\frac{dN(t)}{dt} = g(t)[N* - N(t)]$$

Where *dN(t)/dt* is the rate of diffusion at time t, $N(t)$ is the cumulative number of adopters at time t, *N** is the total number of potential adopters in the population, and g(t) the probability of adoption for individuals who have not yet adopted.

3.2 Test-runs with the baseline model

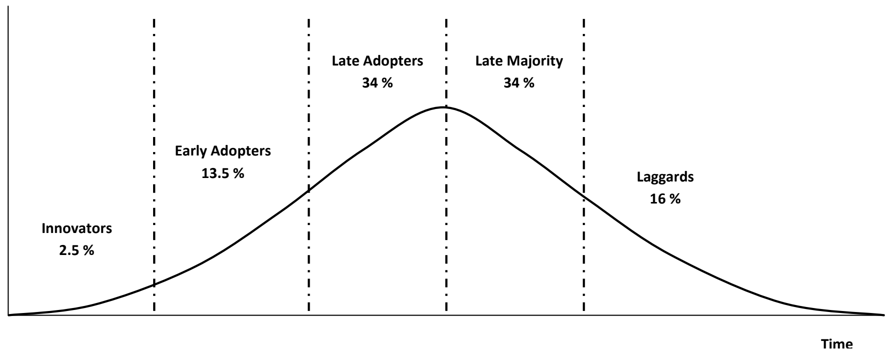
The baseline model of technology adoption assumes no constraints of purchasing power, willingness to pay, access to information, and access to the new technology. The main factors driving adoption are the roles of advertisement and the word-of-mouth. These factors are illustrated in the causal loop diagram of the baseline conceptual model of technology diffusion (Figure 2). It is basically the translation of the Bass model into stocks, flows and feedback loops carried out by Sterman (2000). The role of advertisement and word-of-mouth in influencing adoption rate is determined by the effectiveness of advertisement and contact rate respectively (loop R1). The degree to which these two factors will determine adoption rate is however limited by the population of potential adopters (loop B1 and B2)

Figure 2: A causal loop diagram of the baseline model of technology adoption that takes into account the roles of advertisement and spread by word-of-mouth



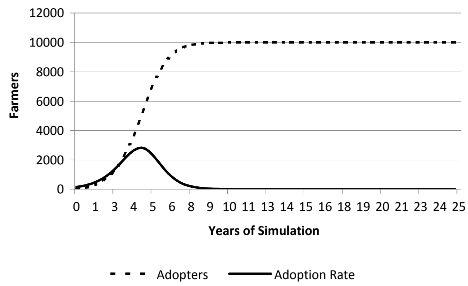
Using a hypothetical farming population of 10.000 (constituting the population of potential adopters), the initial model is run for 25 years with Euler's integration method. The model replicates the role of the influence of internal (word-of-mouth), and external (ad-

Figure 1: Rogers' adoption/innovation cycle showing the distribution of different categories of adopters of a new technology over time.



vertisement) factors on the diffusion of new technologies are based on Equation 1 (Figure 3).

Figure 3: The traditional logistic curve of the adoption rate of a new technology



The conceptual models represented as causal loop diagrams (CLDs, see Figure 6-13 in Chapter 4) and the weights attributed to these factors in influencing technology adoption (Table 1) are used to further develop the baseline model that characterizes the system of decision-making in the case studies.

3.3 The Importance of Internal and External Influences

Different studies have established different levels of importance on the role of internal and external factors (q = the coefficient of imitation, and p = the coefficient of innovation respectively in the Bass diffusion formula above) in influencing the process of innovation adoption. Mansfield (1961) sees the role of internal influence (personal communication through word-of-mouth, personal recommendations, and experiences of others using and being successful with an innovation) more important in determining the rate of diffusion of innovation. Hence $g(t)=qF(t)$, where $qF(t)$ is the coefficient of person-to-person (internal or word-of-mouth) influence - a function of the number of previous adopters which increase with time.

Fourt and Woodlock (1960) on the other hand, believe that the roles of external influences (advertisement, mass media, and other forms of outreach that enable potential users to be influenced by imitation to adopt an innovation) are more important in driving the diffusion process. The model $g(t)=p$ is suggested to explain the singular role of external factors in influencing the technology diffusion process. Here, p signifies the coefficient of external influence (i.e. the role of mass media and other forms of advertisement).

Diffusion of technological change over a population of potential adopters is often characterized by two well-known facts (Cabe 1991): the length of time required by the diffusion is often significant and the time often varies considerably among innovations. Moreover, threshold effects are also important, where drastic changes can happen when a threshold is passed. One example of such a technology spread within the agricultural sector is drip irrigation (Fichelson *et al.* 1989).

4 Methods to improve the baseline model

4.1 Additional factors

Several factors have been advanced as determinants of the adoption and diffusion of technology among small-scale farmers in developing countries. Earlier research established the importance of access to financial resources for investment and size of farm holdings (Feder 1980; Feder *et al.* 1985; Sunding et al. 2001; Lee 2005). More recently, research has also identified the role of learning in the diffusion of pineapple production technology in Ghana (Conley et al. 2003), and the role of social networks on hybrid seed adoption in India (Matuschke et al. 2009). In developing conceptual models for individual determinants of technology adoption and diffusion in the case studies, farmers are asked to identify factors that would make them adopt a new technology introduced through normal channels of technology introduction in the communities (using field agents of technology production companies, agricultural extension workers, farmers' social networks). Through further discussions, drivers of these factors are identified and presented as cause-effect relationships in causal loop diagrams of individual sub-systems.

4.2 Interviews with farmers

The study develops a theoretical understanding of the system of decision-making with regards to agricultural technology adoption through a review of literature and field observations. A total of 42 small-scale farmers were questioned in open interviews: 12 in the Western High Plateau Region of Cameroon and 30 in the Asebu Kwamankese District of the Central Region of Ghana. The farmers were asked questions with reference to technology adoption between 1990 and 2009. These questions were related to the adoption of improved seeds, inorganic fertilizers, pesticides, and farm tractors (technologies that have been introduced in these communities over the last 19 years).

Farmers were selected based on a number of factors. Leaders of local community groups helped identify respondents who must have resided in their respective communities for over 15 years during which time they must have been practicing farming. They must be practicing farming at a small-scale. The term "small-scale" used in this study is in line with the definition given by Beckford (2002) which describes such farming as being labor-intensive and characterized by a high degree of fragmentation, low resource base, and mixed cropping. For the purpose of this study, the definition further restricted interviewees to individuals with farm holdings of less than two hectares dedicated mainly to the production of food crops. Even though the study intended to uphold a balanced gender representation, women proved to be more co-operative and available for interviews than men and hence we had more women respondents (24) than men (18). Respondents were aged between 35 - 65 years and included people who owned their own farms as well as those who were renting farm plots. Results of the interviews were used to develop a general conceptual framework of the system of decision-making concerning agricultural technology adoption in these regions.

Using an example of the new maize seeds that were introduced in both study regions in the early 1990s, farmers are brought in to discuss the importance of different factors to their motivations for adopting or not adopting these seeds. These were seeds developed by PANNAR, a South African seed producing company based in the KwaZulu-Natal Midlands. They were high yielding maize seeds that began entering markets in Central and West Africa in the early 1990s. An initial enthusiasm for high yielding cultivars prompted a great deal of trials by many small-scale farmers. This enthusiasm quickly died less than five years later due to a number of reasons. Small-scale farmers who produce primarily to feed their households complained that the maize produce from these seeds did not have the taste of maize they have been familiar with. Farmers also complained that the produce was difficult to manage – the cobs grew longer than the ears, exposing the maize grains to elements of weather. As a result, the maize grains became soaked by rain soon after maturation and rotted or molded on the farms before they could be harvested. Lastly, farmers observed that replanting PANNAR maize from previous harvests as they had been doing with traditional varieties did not produce good harvests. They had to continuously buy new seeds from the seed distributors every planting season. For households who cultivated mainly for consumption, they needed to be able to raise money for these purchases which was not without problem for many.

4.3 Factors identified by interviewees

Farmers identify eight main factors as being important when they make the decision on either to adopt or not to adopt a technology (Figure 4). These factors are:

1. *Ability to pay* which refers to farmers' capability of paying for and owning or using the newly introduced technology. This depends on farmers' level of income, access to credit, and other sources of financing for agricultural activities.
2. *Vulnerability* refers to the susceptibility of farmers to adverse conditions that may result from using a new technology or from deviating from their usual agricultural practice. This susceptibility may reduce the farmers' ability to turn out the produce they have been relying on for their sustenance. There is therefore some threat of production failure (*risk)* involved in adopting a new technology.
3. *Scale of production* refers here to farmers' range of production possibility. One can distinguish between the physical range of this possibility which will be how much land the farmer actually has and can bring to production and the range in terms of diversity, meaning the number of different production associations the farmer practices at any given time. Each of these possibilities is taken to refer to farmers' scale of production in this study wherever applicable.
4. *Adaptability to local conditions* refers to the ability of new technology to be used with minimal disruptions in the formalized system of functioning of local agriculture. It includes the ability for new technology to be flexible and adjustable enough to facilitate its integration into the local agricultural system.
5. *Long-term considerations* refer to the assessment made by farmers of how sustainable this technology can be. It is a consideration of the dependability of a new technology.
6. *Suspicion towards new technologies* is born from a history of failed attempts at introducing viable innovations in small-scale agriculture in the study areas. It refers to a misgiving about the true intentions of the new technology.
7. *Endorsement by opinion leaders* refers to the backing or approval or the new technology given by people who matter in the communities and lives of small-scale farmers.
8. *Access to information* refers to the ease of having information on the new technology under consideration. Information here refers to knowledge about the existence of a technology, knowledge of what the technology can or cannot do, its limitations, and so on. Information in can be tainted or biased when small-scale farmers receive it (even from

Figure 4: Percentage of farmers advancing different considerations for adopting improved maize seeds in Ghana and Cameroon (N=12 in Cameroon and N=30 in Ghana)

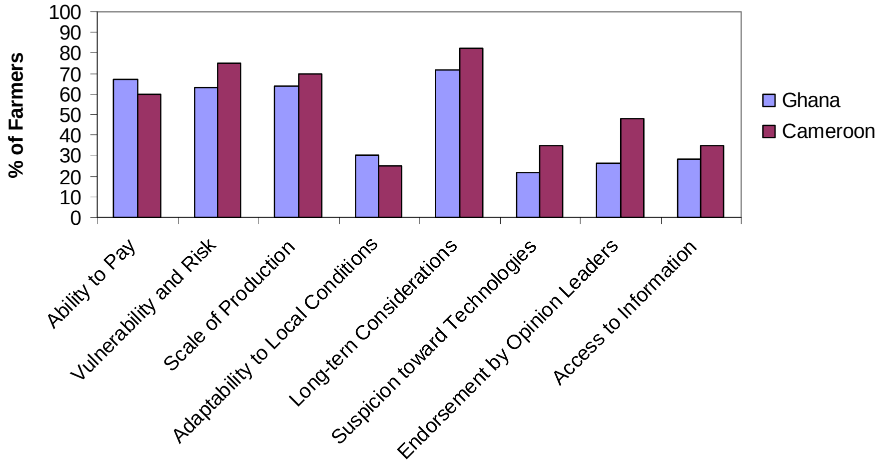


Table 1: Summary of the Qualification of Different Factors of Agricultural Technology Adoption Derived from Interviews

Factor	% Ghana	% Cameroon	% used in the Model
Access to information	25 {Low}	30 {Low}	30 {0.30}
Endorsement by opinion leaders	24 {Low}	49 {Average}	49 {0.49}
Scale of production	63 {Average}	69 {Average}	69 {0.69}
Ability to pay	68 {Average}	60 {Average}	68 {0.68}
Adaptability of technology to local conditions	28 {Low}	24 {Low}	28 {0.24}
Vulnerability and risk	63 {Average}	76 {High}	76 {0.76}
Suspicion towards new technologies	20 {Low}	34 {Low}	34 {0.34}
Long-term considerations	72 {Average}	83 {High}	83 {0.83}

Factors are qualified as low <40%, average 40-75%, and high >75% (columns 2 and 3). They are used in converting the conceptual model into the quantitative model. The higher percentage for each factor from either Cameroon or Ghana is used as a weight for the influence of the factor in determining rates of adoption in the model (last column with weights represented in curly brackets where the maximum is 1 and the minimum 0).

their trusted sources – agricultural extension workers and other opinion leaders) for a variety of reasons.

Four of these factors stood out as important factors considered by farmers when they make decisions to adopt a new technology. These are: farmers' ability to pay for the new technology, their assessment of the degree of vulnerability and risk associated with adopting the new technology, farmers' scale of production, and long-term considerations. Less prominent factors were the adaptability of the new technology to local conditions, suspicion of the technology, endorsement by opinion leaders, and access to information. The percentages of farmers who identified different factors as important are represented in Table 1.

4.4 The refined model of systems dynamics

Other factors that affect the adoption of new technologies (besides advertisement and word-or-mouth) are incorporated into the conceptual baseline model to give a more integrated system that illustrates the system of decision-making among small-scale farmers (Figure 5). In the baseline model of the diffusion of new technologies (shown in bold in Figure 5), individual sub-systems (which comprise other factors identified by farmers as being important in considering the adoption of new technologies) are in boxes and are connected to the baseline model (in bold) with dotted lines. These boxed variables are different from the non-boxed variables in that they are the outcome of cause-effect relationships of smaller sub-systems. The absence of polarity (+ or – signs) in the arrows that link them to the baseline model (in bold) indicates that they can have both a positive and negative influence on the Adoption Rate and Adoption from Word-of-mouth in the baseline model.

R1 represents the reinforcing effect of the adoption of the technology from word-of-mouth and from advertisement. This reinforcing loop give rise to the rising limb of the traditional logistic growth curve of technology diffusion (see the adopters curve in Figure 3; and also Morecroft 2007; Sterman 2000; and Bass 1969). R1 therefore represents the potential of an unlimited growth in an infinite number of potential adopters.

However, the population is always a limiting factor to the number of potential adopters, hence the flattening top of the curve of *adopters* (Figure 3). In the small-scale farming system of sub-Saharan Africa, the effectiveness of advertisement, adoption from word-of-mouth, and the adoption rate also have limitations (shown in the boxes accompanied by dotted arrows) which determine the eventual speed of technological adoption and shape of the adoption rate curve.

5 The Role of Other Factors from Conceptual Analysis

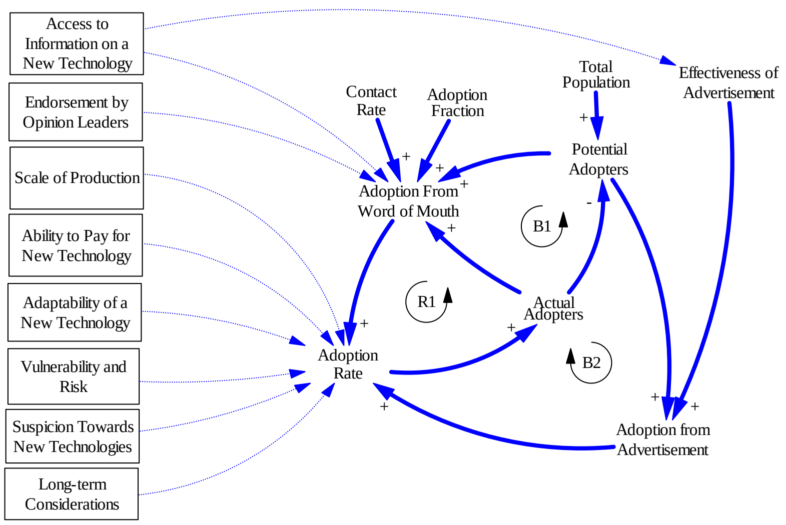
We discuss here the results of both interviews and quantitative modeling of the decision-making process of agricultural technology adoption among small-scale farmers in the case studies. The results of interviews are represented as causal loop diagrams which represent feedback processes of individual factors of decision-making in agricultural technology adoption. These can be illustrated in a three-stage model of drivers of factors that determine adoption, the factors that determine adoption, and the decision to adopt the new technology (Figure 6). The decision to adopt a new technology is determined by a number of factors which are themselves the outcome of several drivers. The main factors of adoption in the baseline model (advertisement and spread by word-of-mouth) are omitted. It must be noted that some factors of technological adoption in one system become drivers of factors in other sub-systems.

Given that the baseline model takes the role of advertisement and word-of-mouth in the spread adoption of technology for granted, the role of other factors in determining the process and speed of technology spread are discussed. Results of the quantitative modeling are an application of the understanding of the decision-making process to a hypothetical population of farmers to see the effects of individual factors on the rate of adoption of a new technology.

5.1 Access to Information

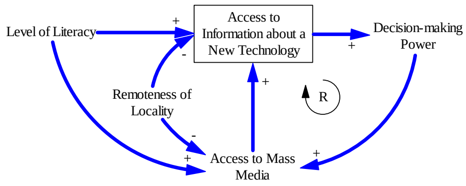
Farmers need knowledge about the benefits of a pice of technology to be able to make decisions on whether or not to adopt it (Beckford 2002). In many parts of sub-Saharan Africa, the availability of this knowledge to farmers may be constrained by a number of challenges: the remoteness of an area may limit the availability of information on a piece of technology; and limited economic resources may mean that farmers or farming communities may not have access to information through certain forms of mass media like television, print media, internet, and others. In many cases, the literacy rates

Figure 5: A more integrated CLD illustration of the system of decision-making



are low and potential users may not be able to access needed information even if it is available (Figure 7). This form of knowledge about a piece of technology which allows potential users to be able to make decisions on whether to adopt it is termed by Abdulai et al. (2005) as "*schooling*". Some of the common means through which information is brought to small-scale farmers in developing countries is through farmers' cooperatives and common initiative groups, rural development field staff, churches, farmers' representatives, and extension staff of the Ministry of Agriculture.

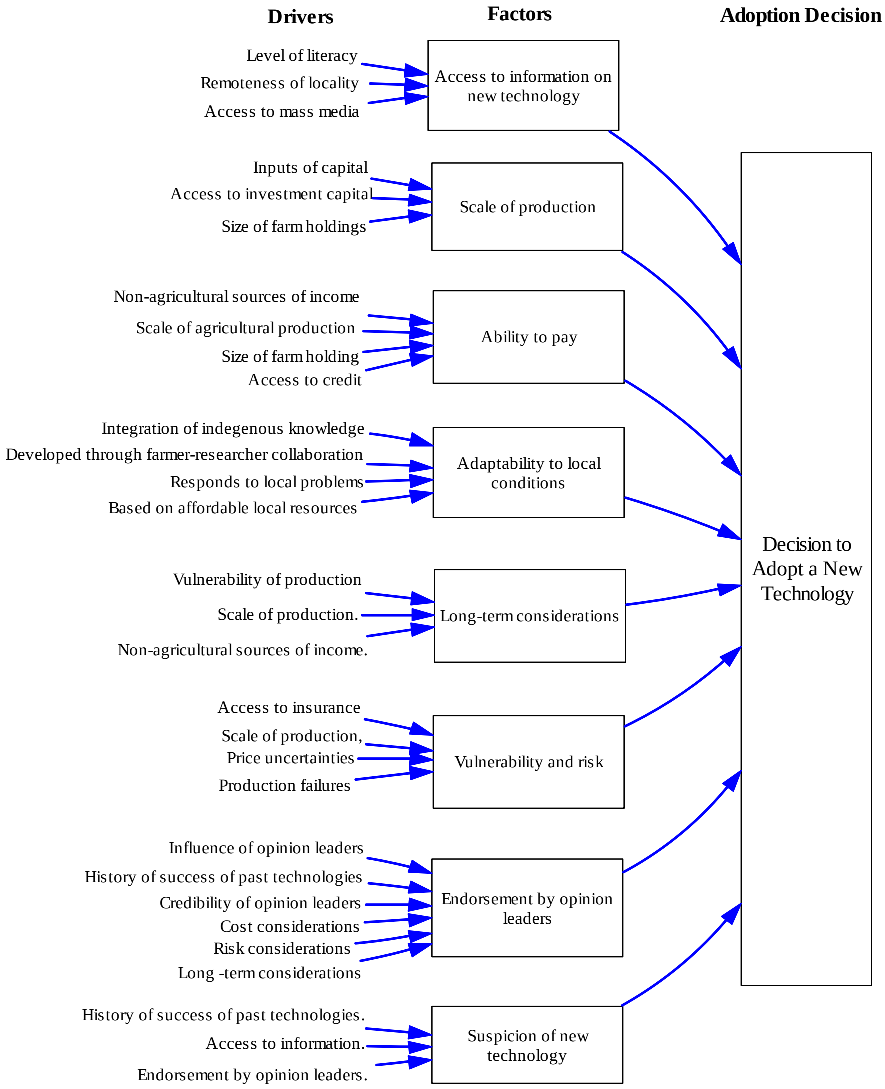
Figure 7: CLD of drivers of access to information on a new technology on its adoption



5.2 Scale of Production

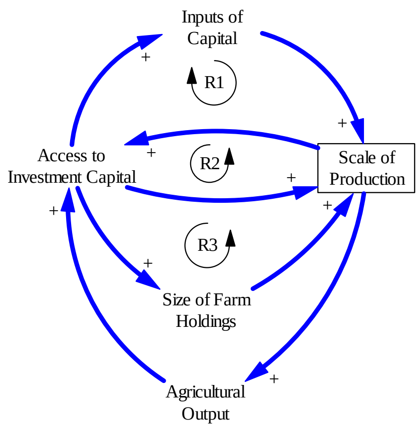
In sub-Saharan Africa where agriculture employs more than 60 percent of workforce, and contributes to more than 35 percent of the gross domestic product, small scale farming con-

Figure 6: A three-stage model of the adoption of a new technology based on studies of the adoption of maize seeds in the case study



tributes more than 80 percent of total agricultural outputs (FAOSTAT 2009; Gallup et al. 2000). Small-scale agriculture here is characterized by small farm holdings, low capital inputs, low outputs, and vulnerability to production failures, price shocks, and loss of income. The low outputs implies a limited ability to raise investment capital through savings, while the vulnerability of farmers prevents them from taking production risks that may otherwise be profitable. The small and fragmented nature of their farm-holdings also prevents them from investing in and using technologies (especially machinery) that may save labor and increase output and productivity (Figure 8). By increasing access to capital, a number of reinforcing processes (R1, R2, and R3 in Figure 4) are set in motion, that can lead to a sustained increase in the scale of production in different ways.

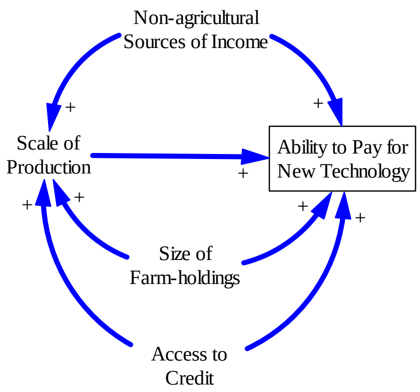
Figure 8: CLD of drivers of scale of production in the adoption of a new technology



5.3 Ability to Pay

Most of the small-scale farmers in sub-Saharan Africa are subsistent producers with small farm holdings ranging from 0.5 hectare to about 4 hectares, and producing food mainly for their household with little surplus for sales in local community markets (UNDP 2007). Although all farmers interviewed may like to invest in new technologies that may save labor and increase productivity, they can neither raise the necessary capital to do so through meager savings, or be approved for bank loans which they have no adequate collateral. Their limited farm-sizes and limited access to credit imposes a small-scale of production which sustains a state of inability to pay for new technology (Figure 9; also see Abdulai et al. 2005). In many parts of the continent, farming has therefore remained underdeveloped, labor intensive, and producing comparatively low yields per capita for almost all of the major cereals and oil crops (FAOSTAT 2009; UNDP 2007). It is reported that in cases where farmers may have land but lack the financial means to develop it for agriculture, they tend to lease it out and even sell some of the little inputs they have to the few non-financially constrained farmers who can buy (Ahmed 2004).

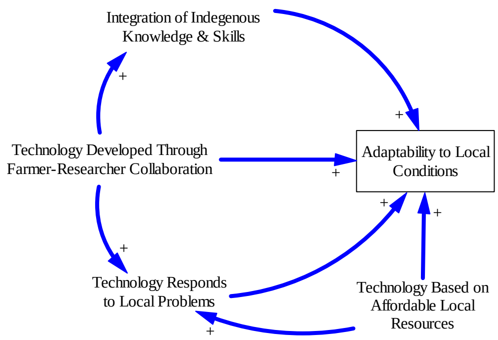
Figure 9: CLD of drivers of ability to pay for a new technology in the adoption of that technology



5.4 Adaptability of New Technologies to Local Conditions

The adaptation of new technologies to reflect farming practices and traditions of a community requires recognition of existing indigenous know-how, skills and technologies (Norton et al. 2003; Lado 1998). When new technology is adapted to local conditions, it builds on such existing skills and technological capacities as well as maximising use of local resources (Figure 10). This gives farmers the opportunity of experiencing a less steep learning curve as they attempt to familiarize themselves with the new technology. It also reduces the level of dependence of farmers on external sources of inputs, spare parts, and other resources that are associated with the use of this technology. Lastly, locally adapted technology should strive towards solving vitel problems (Figure 10). This calls for a revision of the paradigm of science being developed by experts at international or national levels, and then disseminated for use by farmers at local scale (Tilman et al. 2002).

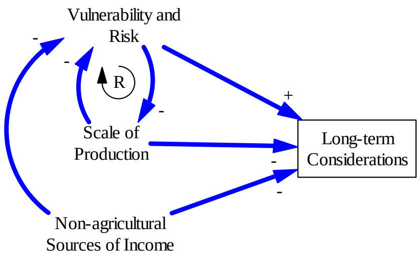
Figure 10: CLD of drivers of the adaptability of new technologies to local conditions



5.5 Long-term Consideration

Farmers interviewed were unanimous in the belief, that they take into account the long-term effects of their actions when they make decisions regarding the adoption or non-adoption of new technology. Farmers' vulnerability to risk (discussed abovebelow) is an important factor when assessing the long-term implications of adopting new technology. Farmers who are more vulnerable to risks prefer taking less risk and so will tend to be the late adopters of laggards in Roger's innovation adoption cycle (Figure 11). The scale of production is also an important consideration. The smaller the scale of production, the more risk averse the farmer is (Figure 11). This is because a decision that leads to bad harvests will have a larger negative impact on small scale farmers than on large scale farmers. The last important factor taken into long-term consideration is the amount of income made by the farmer from other sources (non-agricultural income). When non-agricultural activities provide more income to farming households, they can afford to try out new technologies, safe in the knowledge that if such technologies should fail, they may not be entirely out of income or livelihood.

Figure 11: CLD of drivers of long-term considerations on the adoption of new technologies



5.6 Vulnerability and Risk

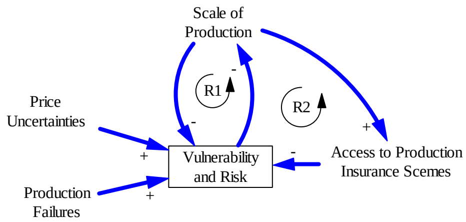
Most farming in sub-Saharan Africa (especially small and middle-scale farming) is not covered by any form of insurance against production failures. Farmers are therefore fully responsible for every one of their decisions, which may mean a total loss of food, income, and livelihood in times of poor harvest. They therefore tend to be more risk-averse and will question the level of their exposure to risk more, before deciding on the adoption or rejection of new technology (Feder et al. 1985). To estimate the extent to which new technology may expose them to production risks, farmers would generally ask the following questions:

1. Would the adoption a new piece of technology make them dependent on another subsidiary of this technology which they may not be able to afford?
2. Is the new technology going to substantially change their production system in such a way that they may have to undergo a major adaptation process to cope with the change?
3. Will they be able to continue with production as before if this technology ceases to be available?

4. How easy is the process of procurement, and how reliable is the source of the new technology?

These questions and others make small-scale farmers in the developing world, and sub-Saharan Africa in particular, generally more conservative and less enthusiastic in adopting new technologies (Beckford 2002). When asked if farmers may be willing to receive a new piece of technology, of which payments can be made after they sell their produce, they seem to be less enthusiastic, arguing that the prices of farm produce are not stable. If such prices fall (given that they are usually quite volatile) they may be left with a burden of debt that may strain their livelihoods in the future (Figure 12). It seems by increasing the scale of production, and giving farmers access to some form of insurance against production failures, their vulnerability to risks would be reduced. This means increasing the reinforcing effect of the loop R 1 and R2 in Figure 12.

Figure 12: CLD of drivers of vulnerability and risk on the adoption of a new technology



5.7 Role of Opinion Leaders

In the rural communities, which are homes to the small-scale farmers studied, the traditional rulers, educated elites, church leaders, and others still play the role of opinion leaders in their communities. These are generally people with access to the media, and have a better understanding of media content. They are therefore regarded as the group that can understand the benefits and dangers of innovations though their greater awareness and experience. The role that they play in the process of technology diffusion is therefore greater than just being risk-takers and innovators in the Rogers' cycle of technology/innovation growth. Their decisions on the adoption of new technology are usually determined by cost, risk and long-term considerations, and the effectiveness of their position is determined especially by the history of the successes or failures of previous technologies which they supported (Figure 13). The communities view them as leaders who can assess, understand, explain and diffuse the content and understanding of new technologies to others. Their endorsement or non-endorsement of an innovation is taken seriously by the farmers, and can influence the effectiveness of the diffusion of the information through word-of-mouth and even of advertisements (see Figure 5).

5.8 Suspicion Towards New Technologies

In certain parts of the region, past innovations in agriculture brought distress to farmers and have sown seeds of suspicion towards new technologies. Some of these innovations include the structural adjustment programs in sub-Saharan Africa, and the introduction of genetically modified strains of cotton from Monsanto in India (McGregor 2005; Shiva et al. 2000). In such cases, new technologies or other forms of innovations in agriculture are viewed with distrust and farmers would prefer to adopt a wait-and-see attitude towards them. This could be especially pronounced when information about these new technologies is insufficient to enable farmers and opinion leaders to make a judgment with regards to the different considerations that would suit the farming community (Figure 14).

5.9 Interim conclusion

The covariates discussed above do not function in isolation. Instead, they form part of a more complex decision-making process in the lives and communities of small-scale farmers (Beckford 2002; Wigley 1988). The decision to adopt any specific new technology at

Figure 13: CLD of drivers of the endorsement of a new technology by opinion leaders in the adoption of that technology

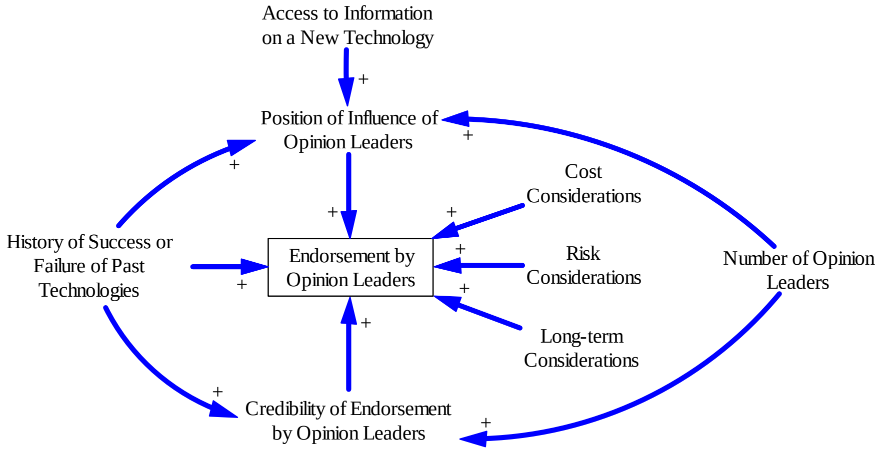
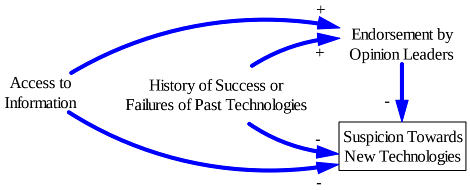


Figure 14: CLD of drivers of suspicion of a new technology in its adoption



any given time is unique, dependent on the outcome of the analysis of these factors at that particular time and place. Hence farmers may take the decision to adopt new technology today based on the circumstances of the time, but the same technology at a different time or place with a different state of covariates may be rejected. The adoption of each new technology therefore has to find a perfect balance of the combination of individual covariates that suit the circumstances.

The socio-economic realities of sub-Saharan Africa and other parts of the tropical developing world gives small-scale farming a unique character which unlike large-scale farming (especially in the developed world), is influenced by factors more important than the market (Wigley 1988). However, their problems can be summarized into two main categories over which they have little or no control: natural constraints to production, and a limited socio-economic power to change their production status or their level in the agricultural production value chain. This explains why flexibility and adaptability in decision-making is often a necessary approach to permit farmers to cope with the habitually changing economic and physical conditions (Davis-Morrison et al. 1997). The production decisions (including decisions of adopting or not adopting new technologies) of small-scale farmers are therefore much more complex and cannot be evaluated on the same scale of rationality as those of farmers in the developed world.

6 Results of Simulations

When different weights are attributed to factors identified by farmers as being important in driving their adoption or non-adoption of a new technology and included in the baseline model of technology adoption, three groups of factors emerge (Table 2). These groups are derived on the basis of how heavily they decrease the adoption rates of new technologies among small-scale farmers in the case studies.

6.1 Factors that heavily decrease adoption rates

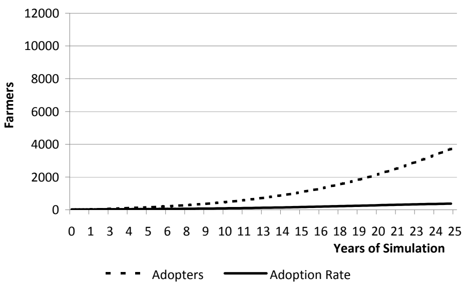
Long-term considerations stand out as the most important factors that may decrease the desire to adopt new technology (Figure 15). With a generally small

Table 2: The effect of different factors in decreasing the rate of adoption of a new technology

Factor	**Adopters in Year 15**	**Adopters in Year 25**	**Effect on Adoption Rates**
Long-term considerations	1071	3814	***Heavily decrease adoption rates***
Vulnerability and risk	1620	5645	
Scale of production	2541	7668	
Adaptability of technology to local conditions	3444	8291	***Decrease adoption rates***
Ability to pay	4332	8940	
Endorsement by opinion leaders	8482	9976	***Have minor effects on adoption rates***
Suspicion towards new technologies	8487	9979	
Access to information	9917	9999	

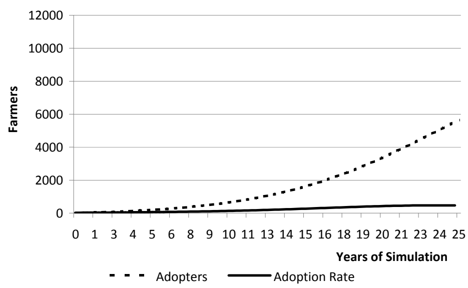
scale of production, limited financial means, and low credit opportunities, farmers would tend to consider long-term implications in their decisions to adopt new technology. Including long-term considerations in the model gives rise to a delayed start of adoption which eventually is sustained at a rate lower than that resulting from the effect of vulnerability. It seems most of the potential adopters may adopt a wait-and-see attitude to the new technology, but once they are sure that its long-term credentials are good, the adoption process may then accelerate.

Figure 15: The effect of long-term considerations on the adoption rates of new technology. Long-term considerations heavily decrease the rate of adoption.



The level of vulnerability and risk is determined by farmers' scale of production, price uncertainties, the frequency and number of production failures and especially farmers' access to insurance against production failures (Figure 6 and 12). When farmers are exposed to a high vulnerability and risk (76%), the result is an adoption rate that starts late and grows steadily (Figure 16). The number of adopters correspondingly remains very low for a long time before increasing.

Figure 16: The effect of vulnerability and risk on the adoption rates of new technology. Concern over greater vulnerability and risk from adopting new technology heavily decreases its rate of adoption.

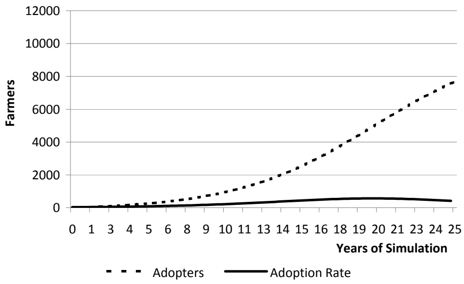


While long-term considerations, vulnerability and risk may be important factors that may decrease the adoption of any new technology, their importance in this case must be seen in the light of the example of technology being studied. The maize seeds being introduced were affordable – farmers with small production scales and limited incomes could buy as little as half a kilogram and try it out in a small portion of their farms. Therefore financial burden and production scale were no longer an issue. Information on the existence and benefits of the new seeds was spread by agricultural extension workers (present in most local communities), hence knowledge of the product in question increased. It had to take time (several seasons of cultivation) for the farmers to assess whether the maize seeds were adapted to the local conditions. Given that the seeds were actively being promoted by agricultural extension workers (who are opinion leaders in the small-scale farming world of both case studies and whom the farmers expect to know what is good for agriculture) the importance of suspicion towards the new technology and effect of endorsement by opinion leaders in decreasing the adoption rate declined. The adoption of other technologies that influence the lives of small-scale farmers through different channels, which are promoted in different ways, may have different acquisition costs (much higher or much lower) and may therefore be heavily influenced by different factors.

6.2 Factors that decrease adoption rate

Farmers' scale of production is a factor which decreases the adoption rate of new technology. It leads to a late start of adoption with a rate which peaks about 20 years into the simulation period (Figure 17). Given that about 80% of farming in the case studies are small-scale farmers and the backbone of national food security in developing countries is the small scale farmer (Khor 2006), the influence of scale on technology adoption is very important. Scale of production is not as important in decreasing adoption rates as long-term considerations and vulnerability partly because of the production under study (maize seeds) can be bought in quantities small enough to be tested on small patches of farmland.

Figure 17: The effect of scale of production in decreasing the adoption rates of new technology. When the scale of production is small, farmers tend to be less inclined to adopting new technology.



The ability to pay decreases the adoption rates of new technology among small-scale farmers in the case studies (Figure 18). This means that the greater the affordability of a pice of technology, the greater the tendency for famers to adopt the technology. As discussed earlier, some farmers may not like to take loans to purchase new technology. They prefer investing for such technologies with their own income. The rate of adoption, when the ability to pay is average, peaks in about 16 years into the simulation period (Figure 18). Most technology has to be bought and therefore entail the availability and accessibility of money to small-scale farmers. Most small-scale farmers in developing countries however have low purchasing power and limited access to credit facilities which make them unable to afford many of the types of technology that are introduced. In the case of the maize seeds farmers could not rely on continually paying for new seeds every planting season. It however seems that the ability to pay is not as important a factor as long-term considerations and farmers' vulnerability and risk of production failures. This may partly be explained by the fact that the maize seeds that are used as a case study is comparatively affordable (at least in the short-term). Hence farmers can at least afford them on retail basis for trial. The outcome may be different if the new technology were a more expensive piece of machinery or other technology.

The adaptability of the new technology to local conditions leads to a decrease in rates of adoption of almost the same magnitude as scale of production and ability to pay (Figure 19). Adaptability here could be in terms of the system of farming, method of storage, manner of storage, preparation, etc. In the case of the maize seeds, they were ill-adapted to their environment in terms of not being harvestable and storable in ways farmers were familiar with. They were also ill-adapted in terms of their taste (see Section 4.2).

Figure 18: The effect of the ability to pay for new technology in decreasing the adoption rate of that technology. The ability for farmers to pay for new technology decreases their adoption rate of the technology.

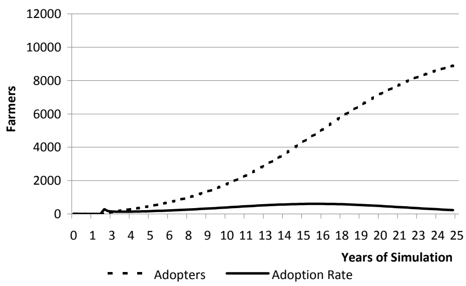
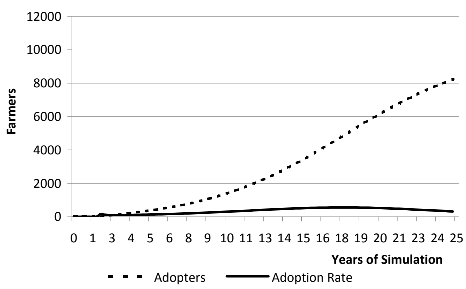


Figure 19: The effect of adaptability of new technology to local conditions in decreasing its adoption rate. When a technology is not adapted to local conditions, it decreases the adoption rate of the technology.



6.3 Factors with only minor impact on adoption rates

While present, other factors seem to play a less important role. They include access to information, suspicion of new technologies, and the effect of endorsement by opinion leaders.

Access to information is seen to play a minimal role in decreasing the adoption rate. The peak of the adoption rates is easily attained in about 5 years and about 9.000 adopters in a total population of 10.000 potential adopters is reached by the 7^{th} year (Figure 20). In terms of the maize seeds under study, information on the seeds was spread by agricultural extension workers whose operations reach some of the most remote areas of the case study. Knowledge about what the new technology intended to accomplish had been disseminated through people whom the farmers apparently trust to deliver correct news and information on innovations. Farmers therefore had the necessary knowledge to guide their decisions on whether to adopt or not to adopt the technology. Access to information therefore had a minimal impact on the adoption rates of the technology in questions. The absence of information may seed doubts in farmers minds as to what exactly the new technology may stand to benefit them, thereby reducing adoption rates. In the same light, access to sufficient information may also reveal weak points about a new technology and reduce its adoption rates. The information disseminated to farmers in the case of the maize seeds for example was more focused on the higher yields per hectare. Farmers were to discover problems with taste, storage and seed preservation later. Figure 20 should therefore be understood within the context of the case study in question.

Suspicion towards the new technology is seen to be a minor factor in decreasing adoption rates. As discussed earlier, the maize seeds under consideration benefited from positive "public relations" through agricultural extension workers who are seen as trusted and

Figure 20: The effect of access to information in decreasing the adoption rate of new technology. Access to information is seen to have a minor impact in decreasing adoption rates.

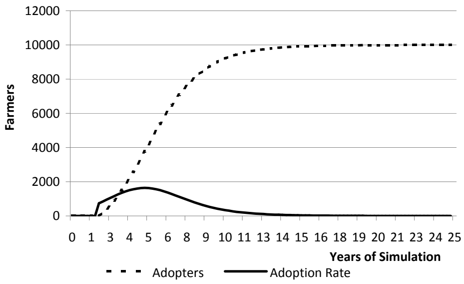
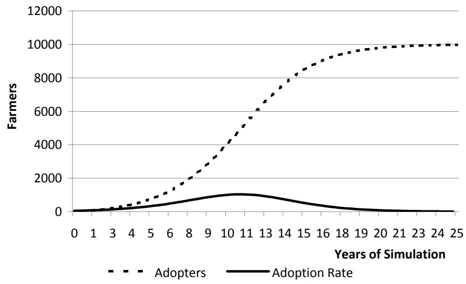
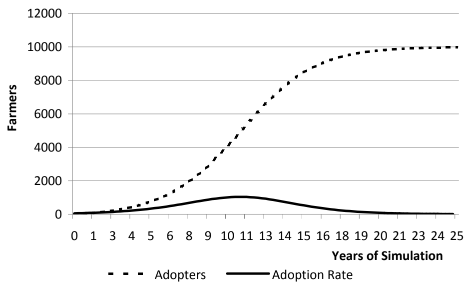


Figure 21: Effect of suspicion of new technology in decreasing its adoption rate. Suspicion of a new piece of technology has only limited impact in decreasing its adoption rate.



knowledgeable agents of agricultural change in rural areas of the case studies. Being agricultural opinion leaders in their own right, the endorsement of the technology by agricultural extension workers co-opted other opinion leaders (village elders, leaders of agricultural common initiative groups and cooperatives, and others) into their ranks. This decreased the role that endorsement by opinion leaders would have played in decreasing adoption rates of the maize seeds. Like the effect of suspicion towards new technologies, of the endorsement by opinion leaders generates a peak adoption rate by the 12^{th} year and a total of about 9.000 adopters in a potential population of 10.000 by the 15^{th} year (Figure 21 and 22). The close resemblance of the adoption rates resulting from the effects of endorsement by opinion leaders and the suspicion of new technology results from the relationship between the two factors. When opinion leaders endorse a technology, suspicion farmers may have over this technology is allayed. The two factors are therefore closely coupled.

Figure 22: The effect of endorsement of new technology by opinion leaders in decreasing its adoption rate. The endorsement of new technology by opinion leaders has only a minor impact in decreasing adoption rates of the new technology.



7 Policy Implications

The transfer of technology to encourage development of Africa's agriculture is seen as an essential ingredient in attaining sustainable rural development in the continent, raising many of the agriculture-dependent population out of poverty, and contributing to global food security (World Bank 2007; Pinstrup-Andersen *et al.* 1998; McCalla 1999). The challenges for policy makers are many and stem from the social and economic realities of alot of sub-Saharan Africa's rural landscape. Besides low levels of literacy, limited access to information, and low purchasing power, these areas have fewer agricultural support services than they had 25 years ago, and have tended to distrust some of the advice and innovations being proposed by decision makers in the sector (Blackman 1999; Ahmed 2004; World Bank 2007). To meet these challenges agricultural development policy may have to streamline their efforts to:

- Improve basic education which raises the level of literacy and improves farmers' ability to access needed information (Figure 7). Access to information then empowers farmers in that they are able to make informed choices offered by new technologies.
- Improve agriculture-related infrastructure (farm-to-market roads, and other communications infrastructure) which can enable farmers to have affordable access to farm technology, agricultural inputs and markets for their products. This enhances mobility of people and products and can affect the adoption of technology in a number of ways: information on new technology can easily reach areas remote from cities at lower costs if mobility were limited; mobility of farmers to structures and services that can be useful in meeting their production needs is increased, e.g. financial structures for investment capital (Figure 3 and 4).
- Provide basic protection and minimum standards for agriculturalists (especially small-scale farmers) with a low capacity to compete with large-scale subsidized agriculture from many parts of the developed world. This can reduce the vulnerability of small-scale farmers to production risks and empower them to venture into increasing their scales of production (Figure 6). Small-scale farmers would be more willing to try new technology, knowing that they have some protection in the event of a production failure resulting from the new technology.
- Recognize the importance of indigenous skills and technology and integrate their beneficial traits into new technology solutions at local level. Adapting new technologies to local level realities may involve the development of technology that is based on affordable local resources, responds to local problems, and is developed through farmer-researcher collaboration (Figure 5). Small-scale agriculture should be part of the beneficiaries of the resulting new technology and innovations that may result from this effort.

To attain the above objectives, the process of technology transfer may require an integrated approach which brings together all sectors related to agricultural development rather than offer a piecemeal solution to the introduction of technology in improving agricultural production. This is because, while technologies may be important in promoting the development of agriculture in sub-Saharan Africa and other parts of the developing world, it has not been very successful so far in achieving this change (Ahmed 2004). In few areas where they have succeeded on the continent, efforts have been made to adapt such technologies to new settings (Norton et al. 2003). Sound decision-making with regards to appropriate technology that can meet some of the sustainability challenges faced by agriculture in sub-Saharan Africa, has to therefore be a bottoms-up approach where technology that enhances decision-making for small-scale farmers is derived through an active interaction between scientists and farmers at a basic level (Tilman *et al.* 2002). Therefore participatory research and collaborative initiatives among relevant stakeholders at the local level, should serve as a forerunner to the introduction of new technologies within the small-scale agricultural sector in order to stimulate better policy outcomes.

8 Conclusion

When the baseline factors, used in many models of diffusion of innovation (the role of advertisement and spread of technology by word-of-mouth), are applied to small-scale farmers in the Sub-Saharan Africa, the result is the traditional logistic S-shaped curve of growth of adopters which is the same as with the spread of other technology in different sectors around the world. However, there are some important factors which need to be considered to get a more complete picture of the drivers of innovation diffusion among this group of producers. These include: the role of opinion leaders, long-term considerations, the vulnerability of farmers to production risks, farmers' scale of production, the history of success of past technologies, and others. These covariates contribute in different ways and to different degrees in shaping the speed and magnitude of the diffusion process. They are the outcome of the socio-economic and political framework within which small-scale agriculture in this region operates. They therefore constitute important considerations to be taken into account when designing policies of innovation-based agricultural development in the region.

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