Economic Analyses of Maize Storage Innovations in Southern Benin

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This thesis is dedicated to my wife Elisabeth, to my kids, to my mother Micheline and the memory of my late father Adegbola

ABSTRACT

Maize is a staple food and an important source of income for farmers in southern Benin. It is stored at village level in traditional storage structures and treated with conservation products. To improve control pest damage in stored maize, improved wooden granaries and a new product, Sofagrain®, were introduced in 1992. On-farm trials indicated that after six months of storage, the losses were reduced from 30% to only 5% for maize treated with Sofagrain® stored in an improved wooden granary. Although the effectiveness of storage innovations against pests is well documented, little is known about the socioeconomic aspects of promotion of these innovations in southern Benin. Using appropriate econometric models, this study investigates the perceptions of farmers regarding the characteristics of storage innovations and the causal effect of participation in extension on their formation, the adoption of storage innovations and effect of sources of information on the determinants of adoption, the impact of adopting storage innovation on schooling expenditure and the factors that affect the abandonment of storage innovations. First, the empirical results show that the effectiveness against pests and the length of the storage are the most important preferred characteristics and are provided by the storage innovation. Second, farmer's participation in an extension program on these storage technologies has an important effect on the probability that positive perceptions of the quality of effectiveness against insects are provided by the improved wooden granary and the Sofagrain®. Third, there are differences in adoption and modification decisions between farmers who are informed by extension agents and those informed by other farmers. Fourth, adoption of a storage innovation increases the schooling expenditure of adopters. Finally, the study highlights the effect of road conditions, availability of family labor and availability of the protection measure Sofagrain® on the probability of abandonment of storage innovations.

Key words: Storage innovations, maize, information sources, farmers' perceptions, adoption and modification, treatment effects, sample selection bias, correction function approach, technology abandonment, cross-sectional and panel data, Benin.

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Patrice Ygue Adegbola

Wageningen, December 2009

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Population increases are at a high rate in Sub-Saharan Africa where poverty and hunger are widespread. Diffusion of improved agricultural production technologies and policies aiming to improve transportation, storage and information infrastructure and/or regulatory frameworks are mostly applied to increase food production and improve food security. However, in many developing countries crop production and harvesting are carried out during the wet season, when it is difficult to dry and store grain properly. Traditional post harvest systems are often not equipped to dry and store such large quantities properly, and therefore post harvest losses are often aggravated during storage (Goletti and Wolff, 1999). At household level, food security may thus be affected by the magnitude of the physical grain loss. Moreover, household incomes may be affected by lower grain prices due to quality losses. These losses can be reduced through new drying and pest management systems (Goletti and Wolff, 1999).

Maize is a major staple food and an important source of income and employment for many farmers in southern Benin. It accounted for 34% of total cereal area and for 47% of cereal production in 2000. The estimated per capita annual consumption was 114kg in 2002 (Arouna, 2002). Almost all maize produced in southern Benin is from the first rainy season and harvested in the wet season. Drying and storage of the grain is therefore difficult because the moist grain attracts more insects than properly dried grain. Maize is stored in traditional storage structures at village level and treated with protectant products. Although these structures and conservation products in some cases seem to be adapted to the prevailing environmental conditions, they are not always effective in protecting maize against pest infestation leading to storage losses. Estimates of losses after six months of storage range from 17% to 40% of the total maize production (Kossou and Aho, 1993; Affognon et al. 2000). Such losses seriously affect food security and household income.

To reduce pest damage in stored maize, several projects have been implemented in southern Benin since 1960. Most of the projects implemented up to 1990 failed because of the lack of adoption of the storage innovations whilst pest attacks remain an important storage constraint for maize producers. Since 1991 projects dealing with post harvest losses use participatory approaches to develop appropriate storage innovations. A package of complementary innovations including an improved wooden granary and Sofagrain®[1] was designed and promoted in southern Benin. On-farm trials indicated that after six months of storage, losses were reduced from 30% to only 5% for maize that was treated with Sofagrain® and stored in the improved wooden granary (PADSA, 2000). Although these storage innovations were shown to be effective against pests, their adoption by farmers and the persistence of the adoption process provide challenging questions for scientists, policy makers and donors. Despite several years of storage innovations research and diffusion in southern Benin, there remains a dearth of empirical information on their behavioral impacts. It is important to understand by whom, how and when the storage innovations are used and what their impact is (Doss, 2006). Such information is essential to researchers and the national agricultural extension service to measure the persistence of the adoption process and the social relevance of the storage innovations.

1.2 Problem statement

Technological change in agriculture is considered as an important means to foster economic growth at the early stage of development and to improve the well being of poor households (Doss et al. 2003; Self and Grabowski, 2007; Tiffin and Irz 2006). Adoption of agricultural innovations has been studied intensively since Griliches' (1957) pioneering work on adoption of hybrid corn in the United States. Feder et al. (1985), Feder and Umali (1993) and Sunding and Zilberman (2001) provide excellent surveys on the technology adoption literature. To improve agricultural productivity and the welfare of farmers, policy makers need information on the adoption pattern of agricultural innovations to formulate policies for their dissemination and diffusion (Dimara and Skuras, 2003). Furthermore, since the declaration of the Millennium Development Goals in 2002, policy makers and donors have increased their interest in the impact of agricultural innovations on the livelihood of poor peoples in sub-Saharan Africa (Alwang and Siegel, 2003). Understanding the adoption process of

[1] The symbol ® stands for 'Registered trade mark'. Sofagrain is an insecticide protectant constituted of 0.2% Delmethrin and 1.5% Pyrimiphos-Methyl. It's used to control pests in stored grains, notably cereals and leguminous.

agricultural innovations and their impact on the welfare of farmers is therefore a challenge for social scientists (Doss, 2006).

Following an expected profit maximization framework, most of empirical economic studies on technology adoption use a probit, logit or tobit model to identify the specific factors that affect adoption or intensity of adoption of an agricultural innovation at a point in time. However, the expected profit maximization framework does not condition the adoption decisions on the information acquired by the producer (Dimara and Skuras, 2003). Moreover, Rogers (2003) argues that the adoption-decision process starts when an individual is exposed to an innovation's existence and collects information necessary to use it properly (Rogers, 2003; p. 172). Accordingly, a farmer who is not exposed to the existence of an agricultural innovation is excluded from the subsequent adoption decisions. Hence, adoption studies not controlling for such exposure yield non-consistent estimates of the effects that explanatory variables have on adoption (Saha, et al., 1994; Dimara and Skuras, 2003; Diagne and Demont, 2007). Most farmers rely on information from the near peer adopters, because their (subjective) opinions of the innovation are accessible and convincing to them (Rogers, 2003). The role of early adopters in information dissemination on new technologies is recognized in the literature on copying behavior in technology diffusion (Bevan et al., 1989:109-122; Pomp and Burger, 1995). However, it is often not explicitly known whether farmers adopted after contacts with extension agents or whether they copied adoption decisions from others. This makes it difficult to assess the role of copying in the diffusion of innovations. Another neglected aspect is that copying may involve modifications of the technology. Farmers that imitate their neighbors in adopting a certain technology may modify it, thereby adapting the innovation to their circumstances.

At a given point in time, the decision to adopt or reject an innovation or to defer this decision is postulated to be influenced by the attitude towards the technology and the beliefs about that technology (Fishbein, 1967). In addition, the intensity of having a certain attitude is a major determinant of anticipated behavior (Lemon, 1973). These insights led to an increased attention towards the role of farmers' perceptions on innovation characteristics in recent work on adoption of agricultural innovations**.** Recent studies show that perceptions of various attributes of an innovation influence the expected relative value of the innovation and subsequent adoption decisions (Adesina and Zinnah, 1993; Batz et al. 2003; Negatu and Parikh, 1999; Llewellyn, et al., 2004). However, a drawback of these studies is that they neglect the factors that determine the formation of perceptions among farmers. Few studies dealt with the influence of the source of information on the farmers' perceptions of the characteristics of agricultural innovations (Guerin, 1999). Awareness of the factors that influence perceptions would contribute to development and transfer of appropriate innovations.

Assessing the impact of adopting agricultural innovations on farmer welfare is a major concern to policy-makers and donors. The surplus method in a partial equilibrium framework is often used to assess the economic impact of agricultural research (Marasas et al., 2003; Mather et al., 2003). This method requires additional assumptions on the prices of output and consumed commodities, and income of the farm household to compute the measures of changes in a target outcome. To avoid these assumptions and extend the impact assessment of adopting new technologies on behavioral, efficiency and well-being outcomes, recent works have used the treatment effect approach (Vella and Verbeek, 1999). Assessing the impact of agricultural innovations is complicated by the lack of experimental design in this field. One of the challenges in impact assessment of agricultural innovations is therefore how the changes in peoples' welfare can be attributed to a specific new technology. Changes in poverty indicators such as income, expenditure, nutrition and health may arise from changes in the external environment that have nothing to do with the new technology.

Treatment effects estimators are based on the counterfactual (potential outcomes) framework in which each individual has an outcome with and without treatment (Wooldridge, 2002, p. 603). This framework also underlies the standard methods for establishing causal treatment effects on observed outcomes in natural experiments. Recently developed econometric treatment effect estimation strategies can help to distinguish impacts of single interventions and thus bring a solution to the evaluation and attribution problems encountered in assessment of the impact of an intervention. Nevertheless the major drawback of the applications of this method is the assumption of homogeneity of the impact of the "treatment" being evaluated (Blundell and Dias, 2002). Therefore the major focus in this recent microeconomic policy evaluation literature is to design and estimate models in which the heterogeneity in responses to treatment among observationally identical people is assumed. Since the change of government objectives toward poverty reduction, there has been growing concern to assess the adoption impact of agricultural innovations on poverty indicators such as income, expenditure, food, nutrition and health at farmer's level. Expenditure levels are generally recognized as a better measure of economic status than income, since income does not reflect permanent wealth and can be seasonally variable (Waters, 2000). Many of the agricultural innovations impact assessment studies have been concerned with the effect on the income of adopting farmers (Bravo-Ureta et al., 2006; McBride and El-Osta, 2002). According to our best knowledge, to date very few studies on the effect of adopting agricultural innovations on expenditures on food staples and non-food items such as children schooling have been performed (Adekambi et al., 2009). Recent literature on development shows that schooling expenditure is an effective means to increase labor productivity and to improve the income distribution and individual well-being (Groot and Maassen van den Brink, 2007). Therefore schooling expenditure is an important outcome on which the impact of adopting agricultural innovations could be assessed.

Most empirical studies on agricultural technology adoption only use cross-section data to analyze adoption decisions. They divide a population into adopters and non-adopters, and analyze the reasons for adoption or non-adoption at a point in time. However, a simple classification of farmers as adopters and non-adopters may not be adequate to understand the adoption process fully. Besides, adoption of agricultural innovations is a dynamic decision-making process in which farmers move from learning to adoption to continued use or abandonment of the technology over time. In addition, decisions in one period may depend on decisions made in previous periods. This dynamic decision-making process is characterized by the time pattern of factors such as information gathering and updating, learning by doing, or accumulating resources that may affect the farmer's decision (Feder et al., 1985; Sunding and Zilberman 2001). Accordingly, changes in these variables would help in explaining why individuals choose to adopt an agricultural innovation at different periods (Koundouri et al. 2006). The dynamic aspect of agricultural innovation adoption decisions has been recognized in the theoretical literature (Cameron, 1999). To understand the dynamics of adoption, the decisions of the farmers and the factors related to these decisions need to be followed over a period of time. This is best done using panel data. Because of commitment of time and resources that are required to develop panel data sets, few economic adoption studies estimate dynamic models to analyze the adoption decisions of agricultural innovations. Exceptions to this are Cameron (1999) and Moser and Barrett (2006). Moser and Barrett analyze the factors affecting the decisions of rice producers to adopt, expand and abandon a system of rice intensification (SRI) in Madagascar. One of their main finding is that learning effects play a major role in the adoption decisions of the SRI. Moreover, they analyze the factors that affect farmers' decisions to discontinue the use of the SRI, one of the aspects of the adoption process that is rarely studied. However, due to a lack of panel data, Moser and Barrett (2006) used data based on a recall procedure on each farmer's adoption history as proposed by Besley and Case (1993). Cameron studied the dynamic process of learning in the adoption of a new high-yielding variety cotton seed in India. Using a panel data set of households in India, she estimated a fixed effects model including the one-period lagged profit differential to reflect the farmer's knowledge on the seeds. She applied a linear probability model to avoid estimation problems related to the use of fixed and random effects probit, logit and tobit models (Maddala, 1987; Greene, 2002; Greene, 2008: 796-806). However, the linear probability model also has serious shortcomings such as heteroskedasticity, constant marginal effects and the fact that predicted probabilities are not always between 0 and 1 (Cameron, 1999).

1.3 Objectives of the thesis

The general objective of this thesis is to analyze the adoption patterns of the maize storage innovations promoted in southern Benin since 1992 and assess the impact of their adoption on the well-being of adopters. This objective is based on the issues raised in the previous section. In more detail, the specific objectives of this thesis are to:

i. Examine the extent to which the storage innovations have characteristics that match the needs of the maize producers;
ii. Evaluate the impact of farmers' participation in the extension program on their perceptions of the quality of characteristics provided by the storage innovations;
iii. Determine the factors influencing the adoption and modification of maize storage innovations and to assess the role of the sources of information;
iv. Assess the impact of adopting storage innovations on schooling expenditures in rural areas of southern of Benin; and
v. Analyze changes in adoption status and factors that affect the discontinuation of storage innovations use.

1.4 Methodological approach and data

This section presents the general analytical framework which guides the whole study. In addition, the specific theoretical background and empirical approaches used to achieve each specific objective of this thesis are introduced.

1.4.1 General analytical framework

The theoretical framework that underlies this study is the agricultural household model as illustrated in Taylor and Adelman (2003). This framework provides a behavioral model of the farm household acting simultaneously as producer and consumer. The agricultural household model assumes that the farm household makes its consumption and production choices to maximize the utility of consumption subject to a set of constraints including the production technologies and full income constraints. Adoption of new agricultural technologies allows the household to alleviate the constraints related to the production technologies. The decision to adopt or reject versus the decision to adopt with or without modifying a new agricultural technology is based on a comparison of expected utility**.** The expected utility maximization framework makes explicit the role of the information in the adoption decisions making process (Dimara and Skuras, 2003). Moreover, the budget of the farm household is in part determined by the profit realized from the production activities and can be increased with the adoption of new agricultural technologies. An increased budget leads to changes in the demand for food and non-food commodities as given by the consumer maximization problem and thereby in its welfare outcome.

This study is based on a complete analytical framework presented in Fig. 1.1. The conceptual representation describes the adoption of decision-making process for agricultural innovations and related factors. In addition, the conceptual framework shows the impact of technological change on the poverty indicators such as (schooling) expenditure at the farm household level and the exogenous factors that may affect the (schooling) expenditure. At each period of time, the decision to adopt or reject an agricultural technology versus the decision to adopt it with or without modifications can be viewed as one element in the total decision making process of the farm household. Similarly, following the agricultural household model, the impact of technological changes on schooling expenditure can be assessed at each point in time.

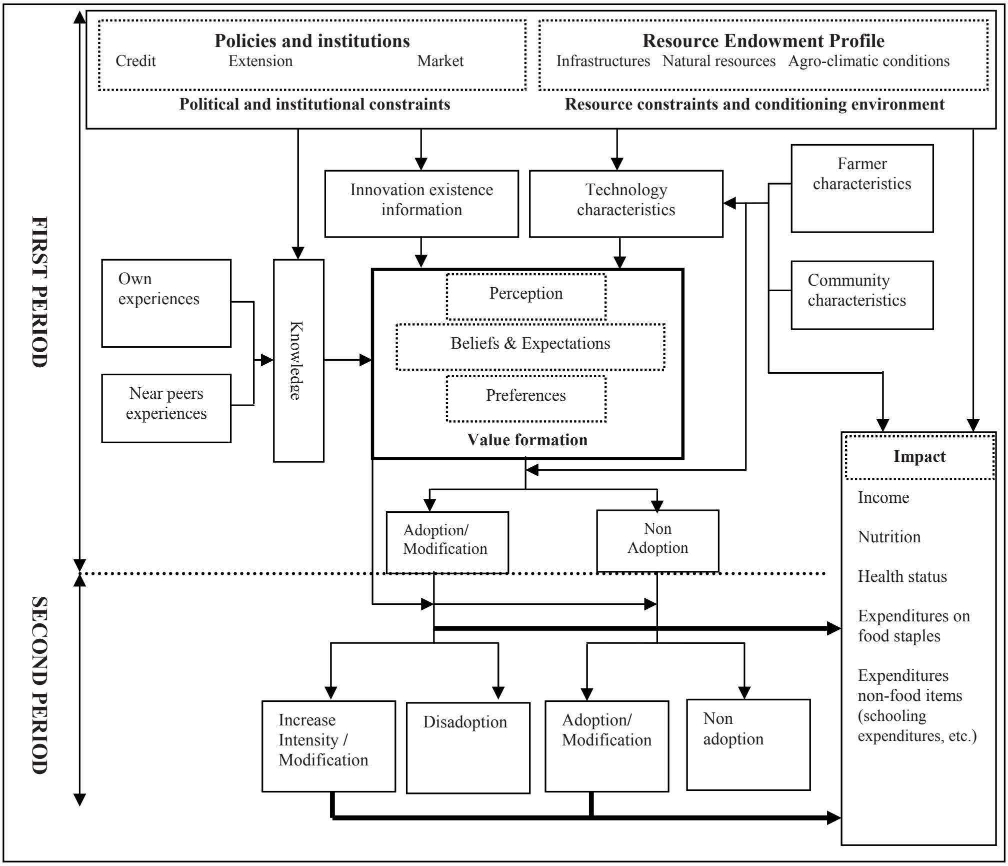

Figure 1.1 A Conceptual framework of agricultural innovations adoption process and the pathway of adopting impact at the household level.

When a farmer is exposed to the existence of a new technology and collects information to use it properly, he develops a perception or belief about it and decides whether to adopt or reject the technology or defer it for a decision to be taken on it later. The decision to reject or to defer it may result from an inadequate level of information to use the new technology properly. Whatever decision is taken, in the next period the farmer gathers new knowledge and experience from learning-by-doing as well as observing performance of near peer adopters. According to the decision to adopt or reject, the subsequent decisions may follow two pathways. First, a decision to adopt may be followed by a decision to increase intensity and/or modify the new technology or to discontinue the use of the new technology. Second, following the decision to reject the farmer modifies his initial perception or belief about the new technology based on his new knowledge and/or observed performance from the adopters. Accordingly he takes a new decision about the adoption of the new technology.

At each time-period, based on his knowledge and experience the farmer forms an attitude towards the technological innovation. An individual's decision in a time-period is a joint function of his attitude towards the new technology and his beliefs about what is expected for that situation (Fishbein, 1967). The attitude of a decision-maker towards an innovation depends on his valuations of the set of characteristics of that innovation (Wossink et al., 1997). Beliefs of the farmer about his adoption behavior in a given period are influenced by his socio-economic characteristics such as resources endowment and characteristics of his community at that time (Feder et al., 1985; Sunding and Zilberman, 2001). Impact of adoption of a new technology on outcomes such as income, expenditures, food security at the farm household level can be assessed at each time-period. Figure 1.1 shows that the same factors can determine both adoption and the outcome leading to selection bias in estimating impact of adoption of a new technology. Agricultural household models provide useful guide to researchers for deciding which variables should be treated as endogenous and which are to be held exogenous in impact evaluation of new technologies. Drawing from the agricultural models, adoption variable is assumed endogenous in equations of factors related to individual and household behaviors such as production (farm and nonfarm) decisions, consumption decisions, investment and saving decisions. On the other hand, human resources such as labor, health, knowledge are exogenous factors.

1.4.2 Specific theoretical background and empirical approaches

This subsection presents an overview of the specific theoretical frameworks and related estimation methods used to achieve each specific objective of this study.

Analysis of farmers' perceptions

To achieve the first two objectives of this thesis, farmers' perceptions of the characteristics of the improved wooden granary and Sofagrain® are analyzed in two ways. Firstly, an empirical analysis adapted from Reed et al. (1991) is used to evaluate the extent to which, each of the storage innovations provides characteristics that meet the expectations of the maize producers.

The approach is based on the calculation of demand, supply and attainment indices, respectively. The demand index measures the importance that farmers give to each characteristic of the storage innovation they desire. The supply index assesses the farmers' perception on the achieved level of each desired characteristic in the storage innovation. The attainment index evaluates how the perceived importance of a characteristic matches with the extent to which this characteristic is supplied in the storage innovation. Secondly, following Wooldridge (2007a) a bivariate probit model is applied to correct for endogeneity of farmer participation in the extension program and evaluate its impact on their perceptions of the quality of characteristics provided by the storage innovations. The total marginal effect of participation in extension program is obtained following a method developed by Bartus (2005). Data used in this analysis is obtained from an exploratory survey followed by cross-section data collection carried out in 2002.

Analysis of adoption and modifications of maize storage innovations and effect of sources of information

To achieve the third objective of this study, the adoption decision on maize storage systems by individual farmers is modeled following Saha et al. (1994) and Dimara and Skuras (2003). These authors recognized that farmers can only adopt a new technology if they are sufficiently informed about it. Moreover, after having decided to adopt an innovation or not, adopters also decide whether to modify the innovation or not. In the empirical analysis probit specifications are used to estimate equations for information, adoption and modification decisions, respectively. The probit specification for adoption is corrected for sample selection since the adoption decision is only relevant for those who heard about the innovation component (Saha et al. 1994). Similarly, the probit equation for modification is corrected for sample selection bias since this decision is only relevant for the non-random subsample of farmers who decided to adopt the innovation. Maximum likelihood is used for model estimation. The models are also estimated according to the sources of information and the results are compared to see whether having information from the extension service that promotes the storage innovations affects the determinants of adoption and modification differently than having information from peers. Cross-section data collected in 2002 as indicated earlier is used for the empirical investigations.

Assessing adopting impact of storage innovations on schooling expenditure

The fourth objective of this study is to assess adopting impact of storage innovations on schooling expenditure. The correction function approach developed by Wooldridge (2007b) is used in this study to address the issues of selection bias, correlation between adoption variable and unobserved gain from adoption, and heterogeneity of adopting impact of the storage innovations. In the correction function approach, the main equation estimated by instrumental variable methods is augmented by a "correction function," which depends only on exogenous variables. All model parameters are estimated using the general method of moments approach (GMM). Estimated parameters are used to estimate the conditional average adoption impact on schooling expenditure over the data set which is averaged over adopters to get a consistent estimation of impact on adopters. The data used in empirical investigations are drawn from a cross-sectional survey organized in 2003.

Dynamic decisions-making process of storage innovations adoption

To address the fifth objective of this thesis, an empirical model is used that considers the effect of changes over time in factors such as knowledge level and asset of resources on the adoption behavior of an individual (Koundouri et al., 2006). To control for unobserved producer heterogeneity, a conditional logit model with fixed effects is used to investigate the relationship between the changes in adoption status and the changes in time-varying variables. The fixed effects logit model is estimated separately for improved wooden granary and Sofagrain®. The panel data used in the empirical analysis were derived from two surveys of maize producers in southern Benin. The same farmers surveyed in 2002 for the adoption study were visited again in 2008 using a very similar questionnaire to facilitate analysis of interannual dynamics of adoption.

1.5 Outline of the thesis

The remainder of this thesis is laid out as follows. The next chapter describes the study area and summarizes the data used in the empirical analyses as well as the sampling procedures and data collection strategies. In chapter three the analysis of farmers' perceptions on the characteristics of the storage innovations is presented. Moreover, this chapter discusses the impact of the farmer participation in the storage innovations promotion project, on the farmers' perception of the effectiveness of the storage innovations against pests. The fourth chapter deals with the factors that affect adoption and modification of the storage innovations and the effect of the source of information on these determinants. Chapter five presents the assessment of the impact of adopting the storage innovations on schooling expenditure. The sixth chapter analyzes the dynamics of the storage innovations focusing on the effect of shift in some explanatory variables on change in adoption status and the factors that determine abandonment of storage innovations. General conclusions and implications of the research undertaken in this thesis follow in the last chapter.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA, POST HARVEST SYSTEMS AND SURVEY DATA

2.1 Introduction

This chapter presents an overview of the study area, the data used in estimation and the data collection techniques. The next item is the study area which is described in terms of physical and human environments. Section 2.3 presents the maize post-harvest system at farm level. The specific maize storage and conservations technologies used in southern Benin are outlined in the section 2.4. Following this is the development and promotion of storage innovations which is presented in section 2.5. In section 2.6 the data used to fulfill each objective of the study are presented as well as collection and sampling techniques.

2.2 Description of the study area

Southern Benin is approximately located between latitude 6°20 and 7°30 north and between longitude 1°35 and 2°45 east. It covers a land area of 17,920 km², approximately 16% of the national territory. It is bordered on the south by the Gulf of Benin, on the East by the Federal Republic of Nigeria, on the West by the Republic of Togo and on the North by the community of Dassa. Administratively and according to the new territorial division, southern Benin covers the departments of Ouémé, Plateau, Littoral, Atlantique, Mono, Couffo and Zou. Southern Benin is subject to the influences of a humid tropical climate or sub-equatorial Sudano-guinean type of climate. The rainfall regime is bimodal characterized by two rainy seasons and two dry seasons. The annual rainfall varied between 800 and 1400 mm in the period 1991-2000. The beginnings of the first long rainy season and the end of the second short rainy season are variable. The long rainy season begins in March, April or May and ends in July whereas the short rainy season covers the months of September, October and sometimes November. The short dry season observed in August is gradually disappearing thus increasing the problem of drying farm products such as maize. Moreover, the high relative humidity during a long period of the year and the temperatures varying between 22°C and 33°C are very favorable to insect pests' proliferation and mould. Therefore, drying and storing grains such as maize is a major challenge. The ferallitic and hydromorphic soils dominate in southern Benin. It is estimated that 70% of the soils in southern Benin have a good farming potential for food crops including maize.

Southern Benin is one of the most populated regions in Benin and even in West Africa. According to the general population and housing census of 2002, the southern Benin has a population of approximately 4 million inhabitants (INSAE, 2002). This region has about 60.4% of the total Beninois population living on 16% of the national territory. The population density is therefore 227 inhabitants per km² against 60 for the whole Benin. Agriculture and fishing are the main activities of the rural population in southern Benin. The soil and agro-climatic conditions allow the population to grow most of the food and cash crops. Maize, cassava, cowpea, groundnut, rice, cotton and pepper are the major crops grown. The major types of livestock are goats, sheep, and poultry but pigs, cattle and rabbits are also common. Fishing activities are carried out in the form of traditional fishing, processing and production activities through ponds or fish holes, enclosures or branches ("acadja"). These activities thrive in the regions where there are permanent water bodies or rivers. Other activities such as processing of agricultural products and non agricultural activities such as small trade and handicrafts are undertaken mainly in the major dry season. Cassava, groundnut and palm nuts are the main agricultural produce which are transformed into different products and by-products. These activities are also important sources of income for the rural population.

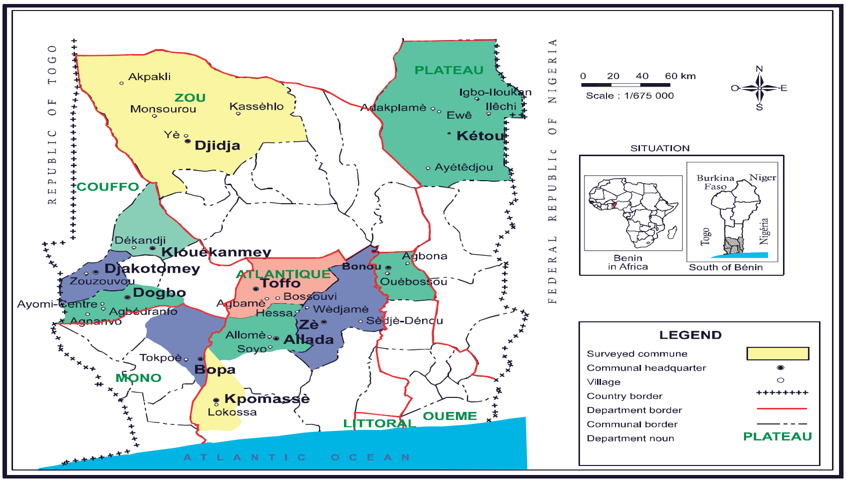

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Figure 2.1 Southern Benin and the geographical locations of surveyed villages

2.3 Overview of maize post-harvest system at the farm level

The post-harvest system in southern Benin is depicted in Figure 2.2, which shows some elements of the system and the interrelations among them. Maize is stored at the farm level and comes mainly from farmers' own production. A share of grown maize is sold before harvest but only when there is an urgent need for money or in case of loan reimbursement contracted during the previous lean period. After harvest, part of the maize is sold to cover current cash needs whereas another part of the harvest is used to pay (in-kind) the external labor used for harvesting and transportation activities. Moreover, when the maize kept in stock is unloaded, about one fifth of the maize is used to pay the labor for dehusking and shelling. Among relatives, friends or neighbors, there is also maize donation. The remaining quantity of maize is then stored in storage facilities. The quantity of maize stored in the granaries varies a lot. Usually the maize used for home consumption and the maize destined for sales are stored in separate granaries. In granaries where the maize intended for consumption is stored, grains are shelled less regularly to feed the family. On the contrary, granaries with maize intended for sale are unloaded during February to March. Depending on financial problems the producer is facing, unloading may also take place earlier. In one of our surveys it was found that maize producers perceive the separation of maize for consumption and maize for sales to be associated with lower insect damages in stocks that are left intact. However, financial problems may lead to breaking this rule.

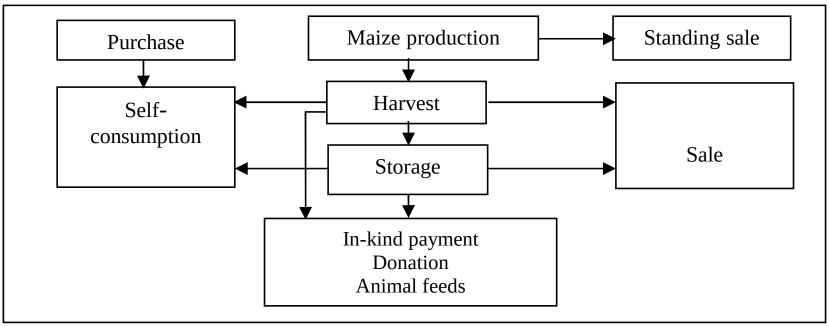

Figure 2.2 Maize post-harvest system on the farms

2.4 Maize storage technologies

In Benin rural areas, farmers frequently use diverse technologies to store their grains. Storage structures commonly referred to as granaries, vary in shape and capacity and also from one place to another based on agro-climatic conditions, ethnic and some socio-economic factors (FAO, 1992; Fiagan, 1994; Gwinner et al. 1996). They are generally made from local materials (branches, graminaceous stems, combretacees, clay and straw). According to availability and use of materials, FAO (1992) classifies granaries into wooden made and earthen made. The wooden granaries are classified into two groups with locally named 'Ago' and 'Ava'. 'Ago' granaries are common everywhere in the study zone. The conical roofing of these structures is made of straw (*Imperata cylindrica*). Their rectangular or circular body is made from palm branches (*Elaeis guineensis*). The 'Ava' granaries have only one form of structure and straw roofing. But, maize cobs are assembled and arranged in layers to form the body of the granary. Storage structures are traditionally built by farmers. Sometimes they may be assisted, especially by family members and neighbors. Farmers also use hired labor. The life span of these structures does not exceed three years.

In contrast to wooden made granaries, the earthen made granaries are found both in southern and northern Benin. However they are mainly used in the north, the hills province and the middle belt. Diop et al. (1997) indicate that these granaries are always associated with dry climate zones especially the Saharan zone or Sudano-Saharan zone where grain drying to 11 and 12% moisture content is not a problem. The roofing of the earthen made granary is also made from straw. Its body is erected using kneaded termitarium (termite mound) earth strengthened by chopped tendered grasses. The life span of this granary is usually more than fifteen years. Maize is stored in the earthen made granaries in the form of grains with a moisture content less than or equal to 13%. Hence, maize is subject to drying in a pre-storage structure.

The conservation technologies include a diversity of indigenous protection measures of stored maize acquired through generations. These measures, which vary from one place to another, have a preventive and curative nature of pest damages. The most common ones include: wooden ash, kerosene, diesel oil, leaves and by-products of neem. Grains are sometimes exposed to the sun, not only for drying but also to get rid of adult insects. Moreover, farmers in southern Benin store maize harvested from the first raining season over the fireplace because the smoke from the fire helps to keep the cobs dry and repel insects (Foua-Bi, 1989; Gansou et al., 2000). Besides being very effective, this method is also easily affordable for resource-poor farmers. In other respects, farmers often use inappropriate cotton insecticides to protect their stored grains because they are obtained on a credit basis (Hell et al., 2000). However, cotton insecticides have a higher toxicity and persistence so that they constitute a danger to both farmers and consumers especially when ingested soon after treatment. Cases of death due to misuse of cotton insecticide are periodically reported in Benin (Adda et al., 2002).

In the tropics, stored farm products are vulnerable to diverse biotic and abiotic agents causing damages with severity varying from one place to another and depending on the presence of *Prostephanus truncatus*. *Prostephanus truncatus* is a major storage insect pest that affects maize and cassava and very destructive over long periods of time. Fiagan (1994) indicated that in southern Benin where there is a high destructive insect pressure coupled with inadequate post-harvest practices and poor storage structures, very high damage rates are observed over a cropping year. After six month of storage these rates are estimated at 10 to 15% for maize from the second raining season and over 25 to 30% for maize from the first raining season after which storage is difficult as grain moisture content is high (generally above 20%). Occurrence of damage depends on the storage system used and the presence of *Prostephanus truncatus*.

2.5 Development and promotion of storage innovations

The first attempts to reduce maize post-harvest losses started in the end of 1960 with the "Institut de Recherches en Agriculture Tropicale" (IRAT). Since then various containers for storage (jars, bags, casks and silos made of galvanized iron, etc.) combined with insecticides have been experimented with (Diop et al., 1997). In the early 1970s, US Peace Corps volunteers, with financial assistance from the United State of America for International Development (USAID), promoted new silos made of cement, dryers and cribs. These storage innovations have been less adopted whilst the attacks of pests remain an important storage constraint for maize producers. Drawing from these experiences the new post-harvest projects used a participatory approach to develop storage innovations. To increase the probability of adoption, research has been concentrated on the improvement of local maize granaries identified by the farmers as most effective against pests. This approach led to the development and dissemination of improved wooden granary and Sofagrain® which started in 1992 with a project funded by the Food and Agricultural Organization (FAO).

The improved wooden granaries are traditional structures that are designed in various respects. This granary is made from bamboo or mallotus, which are turned to laths and woven into a cylinder of varied diameters (1.5 to 3 meters). This is afterwards put on a wooden platform with stacks (7 to 9 in number) that are applied with waste oil and rat poison before being fixed in the ground. Its capacity varies from 2 to 6 tons of maize cob. The roof is made from straw and has an opening for loading. The cylinder is endowed with an opening so as to ease unloading.

The conservation measures recommended storing grains in the improved wooden granaries include some preventive measures and the use of chemical, biological, even integrated control methods. In Benin, chemical control of stored maize is carried out using recommended chemicals such as Sofagrain®, Actellic and K-Othrine. But, since the introduction of *Phostephanus truncatus,* the recommended treatment includes combination of Actellic[1] with K-othrine (two sachets of Actellic plus a sachet of K-othrine are used for 300kg maize) or a sachet of Sofagrain® for 100kg maize grains. Since control using Sofagrain® is easiest, this has been largely disseminated. The results from the on-farm trials indicate that these storage and conservation innovations are effective against insect pests when used as recommended. According to PADSA (2000), the improved storage structures introduced have induced significant reductions in loss rates to 5% and 1% respectively for improved wooden and earthen made granaries. Fiagan (1994) reported that in zones with two raining seasons, the improved wooden made granaries had:

- a good drying of stored maize reducing grain moisture content from 20% at harvest to 14% and 12.5% after 3 months and 6 months of storage, respectively;
- a loss by insect attack to 1% and 2.67% after 3 and 5 months of storage, respectively;
- a very moderate infestation by microorganisms (*Aspergillus flavus* and *Penicillin* spp.), causing loss rates of 0.4 to 4%.

The construction cost of a wooden granary depends on its capacity and the type of building materials. However, irrespective of the capacity of the granary, the construction costs of improved wooden granaries are higher than those of traditional ones. For example, building an improved wooden granary of a capacity of 3700 kg costs US$73.32 while the construction of a traditional granary of the same capacity costs US$ 63.71 (Table 2.1). Moreover, application of Sofagrain® to treat stored maize costs US$ 6 to US$ 9 per ton of maize.

[1] The symbol ® stands for 'Registered trade mark'. Actellic is an insecticide protectant constituted of 2% Pyrimiphos-Methyl. It's used to control pests in stored grains, notably cereals and leguminous.

Treating stored maize with Sofagrain® costs approximately 4 to 6 times more than the treatment with traditional conservation methods.

Table 2. 1 Average construction costs of maize storage wooden granaries (FCFA)

Type of granary	Granary average capacity (kg)			
	700	1400	2250	3700
Improved wooden granary	40.30	51.36	67.89	73.32
Traditional granary	21.39	35.46	47.83	63.71

Source: Arouna (2002)

Despite the higher construction costs of the improved wooden granary and the high application costs of Sofagrain®, it is more profitable to store maize with the storage innovations than the traditional storage technologies (Table 2.2). Furthermore, storage of maize in the improved wooden granary treated with Sofagrain® as protection measure is the most profitable system irrespective of the capacity of the improved wooden granary. Storing maize either in an improved wooden granary using the traditional protection measure or protect the stored maize with Sofagrain® is also more profitable than the use of the traditional storage technologies. The profitability of the use of other insecticide protectants is low because they are over- or misused due to inadequate labeling and lack of farmer knowledge. Interestingly, Table 2.2 indicates that storing maize in traditional granary without the use of a protection measure is not profitable.

Table 2. 2 Net margin of maize storage systems (FCFA/ton of stored maize)

Type of granary	Protection method	Granary average capacity (kg)			
		700	1400	2250	3700
Improved wooden granary					
	Sofagrain®	36.99	52.27	54.76	60.06
	Other chemical products	21.18	34.46	40.96	46.25
	Traditional products	27.93	43.21	45.71	51
	Without treatment	20	35.32	37.82	43.11
Traditional granary					
	Sofagrain®	22.25	35.93	43.33	47.99
	Other chemical products	4.55	17.83	23.83	29.54
	Traditional products	12.24	24.32	29.52	34.36
	Without treatment	-2.99	-16.14	19.3	26.93

Source: Arouna (2002)

As a follow up of the FAO's project, a second post-harvest project started in 1997 within the Agricultural development program (PADSA) supported by the Danish International Development Agency (DANIDA). Field demonstrations and trials were conducted to improve the visibility of the storage innovations. Credit was provided to farmers who desired to construct an improved wooden granary and treated the stored maize with Sofagrain®. Moreover an extension component is included in the projects to increase the effectiveness of the post-harvest research**.** These projects have been implemented within the governmental agricultural research and extension services. Furthermore, some Non Governmental Organizations (NGOs) such as HELVETAS, have been involved in promotion of the storage innovations. Table 2.3 reports for each year the adoption rates among farmers who are aware of improved wooden granary and Sofagrain® from 1992 to 2001.

Table 2. 3 Evolution of percent of users of storage innovations within farmers who are aware of these innovations

Storage innovation	Year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Improved wooden granary and Sofagrain®	0.33	0.66	1.32	1.66	6.95	8.28	14.90	24.50	33.44	38.41
Improved wooden granary	1.02	1.02	1.84	2.45	7.14	9.59	15.92	27.55	37.35	44.49
Sofagrain®	8.22	10.53	12.17	13.16	16.78	21.71	30.26	36.51	44.74	48.03

After the first phase of the project, the government did not include the post-harvest activities in the national agricultural extension program as agreed with the donors. In addition, the direction of the project changed during its second phase, and the post-harvest activities were no more a priority. While the adoption rates of the storage innovations increased during several years as indicated in Table 2.3, high disadoption was observed the last years. About 56% of adopters of improved wooden granary in 2002 did not replace their destroyed improved wooden granary. Similarly for Sofagrain® even 73% out of adopters in 2002 had abandoned its use by 2008. Table 2.4 shows farmer's stated reasons for later adoption and disadoption of the storage innovations.

Table 2. 4 Percent of respondents by main reason for changing adoption status

Reason for changing adoption status	Improved wooden granary	Sofagrain®
LATE ADOPTER		
Effectiveness of storage innovations against pests	47	43
High length of conservation	26	57
Good quality of stored product	16	-
Have a thorough knowledge on improved wooden construction technique	8	-
DISADOPTER		
High construction cost of improved wooden granary /Purchase price of Sofagrain®	49	19
Do not have a thorough knowledge on improved wooden construction technique	19	-
Low quantity of harvested maize	18	3
High labor need	9	12
Non-availability of granarys' building materials and Sofagrain®	4	61
Bad quality of "akassa"	-	6

Note: Akassa is a local maize based meal in southern Benin.

2.6 Surveys' description

This section discusses the reasons for focusing on southern Benin in this study and the criteria used to select the surveyed villages. In addition, the sampling and data collection methods applied to achieve each objective of this study are presented.

The choice of southern Benin for this study was based on two main criteria. Firstly, in southern Benin maize is a major source of farm income and the main annual crop, both in terms of its share of total cropped area and its role in direct human consumption. Secondly, because of the atmospheric conditions in this area the pest storage damages of maize are more serious than in the rest of the country. The villages selected for surveys were among those involved in on-farm experiments of maize storage innovations in past and present projects. In addition, the sampled villages also included neighboring villages that were not involved in these projects.

To achieve the first three objectives of the study, a series of surveys were conducted in southern Benin. The first consists of an exploratory survey carried out during the dry season of 2001 in twenty-one villages selected with the support of extension agents. Qualitative data regarding perceptions of farmers on maize storage problems and characteristics of traditional as well as improved maize storage technologies were gathered. Table 2.5 shows the major storage problems of the farmers and the solutions applied before the introduction of the improved wooden granary and Sofagrain®. Information collected from this first step was used to refine the questionnaire for the formal survey conducted in 2002 to document the socio-economic aspects of the storage innovations in Benin. Cross-section data were then collected between March and May 2002 and used to analyze the perceptions of the farmers regarding the characteristics of the storage technologies and the adoption of storage innovations. A random sample of 743 maize producers aware and not aware of the storage innovations was drawn from farmers in 30 villages located in the six rural departments of southern Benin. The dataset contains information on socio-economic characteristics of farmers, their assessment of perceived characteristics of maize storage technologies, their perceptions about severity of maize storage problems and their living villages' characteristics. These surveys were financed by the Agricultural development program (PADSA) supported by the Danish International Development Agency (DANIDA).

Table 2. 5 Major storage problems and applied solutions

Major storage problems		Applied solutions	
Type	Percent of village	Type	Percent of villages
Pest attacks	60 (1)	Diverse products (cotton insecticide, petroleum, alcohol, cinder)	42
		Neem's leaves	37
		Parting of the stock for consumption and sale	11
		Use of resistant varieties	5
Rodents attacks	60 (2)	Cat husbandry	5
Menace of the bush fire	50 (3)	Fireguard	5
Structure precariousness	50 (4)	None solutions	-
Termites attacks	30 (5)	Use of hot cinder	10

() = Rank

The data used to assess the impacts of adopting the storage innovations were collected in 2003. These data were obtained using a two-phase process. In the first stage, focus groups discussions were organized in the selected villages to obtain community and farmers' views on the types (economic, social, etc.) of impact they perceive how they measure or would measure them and the driving forces. The qualitative information from this first step was used to refine the structured questionnaire which was administered in the second step. A random sample of 306 maize producers aware of storage innovations was surveyed in this second step to collect detailed farm-level cross-section data. The sampled maize producers are drawn from the sample of the previous study. The survey provides detailed information on characteristics of the farmers and their villages and on outcomes such as income, expenditures on food and non food products, supply and demand of schooling and health etc. Like the previous surveys, these surveys were financed by the Agricultural development program (PADSA) supported by the Danish International Development Agency (DANIDA).

The data used to study the dynamics of the storage innovations were derived from a two years period survey. The random sample of 743 maize producers of 2002 was surveyed again in 2008 with the financial support of NUFFIC. However, only the 523 maize producers, who were aware of the storage innovations in the survey of 2002, are used to analyze the dynamics of the storage innovations. The same type of data collected in 2002 is included in the questionnaire. Table 2.6 shows the numbers of the surveyed farmers who are aware of the improved wooden granary and Sofagrain®, respectively divided into their adoption status in 2002 and 2008. The data related to later adopters and disadopters are used in chapter 6 to analyze the factors that determine abandonment of storage innovations.

Table 2. 6 Numbers of farmers aware of storage innovations divided into their adoption status in 2002 and 2008

	Improved wooden granary		Sofagrain®	
	2002	2008	2002	2008
Adopter	205	121	229	98
Early adopter	-	81	-	58
Later adopter	-	40	-	40
Missing farmers		19		17
Non adopter	318	352	294	375
Never adopter	-	247	-	223
Disadopter	-	105	-	152
Missing farmers	-	31	-	33
Have changed status	-	145	-	192
Total	523	473*	523	473*

Note: * Sum of adopters and non adopters without missing farmers

CHAPTER 3

ANALYSING FARMERS' PERCEPTIONS OF MAIZE STORAGE INNOVATIONS IN SOUTHERN BENIN[1]

Abstract

This chapter analyzes perceptions of farmers on two improved maize storage technologies. First, an index approach is used to measure the extent to which these improved maize storage systems have characteristics that match the needs of maize producers. Second, it is investigated whether farmers' perceptions on these technologies were affected by participation in extension programs on these technologies. Results show that farmers' perceptions on the effectiveness of storage technologies against pests and the storage length of maize are most important when farmers choose a given storage technology. The improved wooden granary and the conservation method Sofagrain® provide these attributes demanded by producers. Furthermore, farmers' participation in extension has a causal impact on the perceptions that farmers have on these technologies.

JEL Classification codes: C35; O33; Q16.

*Key words***:** Storage technologies, farmers' perceptions, extension participation, sample selection bias, Benin.

[1] Paper by Patrice Ygue Adegbola and Cornelis Gardebroek submitted to *Economic Development and Cultural Change.*

3.1 Introduction

Maize is the major staple food crop and an important source of income for farmers in southern Benin. Pests make the storage of maize over long periods of time difficult, and can compromise food security and lower the quality of grain destined for sale. Therefore, since the end of the 1960's reduction of maize storage losses have been a great challenge for farmers and extension agents, often together with donors. Research and extension projects are funded to develop and diffuse effective storage innovations. However, with the exception of the improved wooden granary developed and disseminated from 1992 together with Sofagrain®, a commercial insecticide for use in stored grain (Fiagan, 1994), none of the storage innovations designed to reduce the losses of maize in southern Benin was widely adopted. Due to this adoption pattern, it has become important to document the factors that encourage adoption of the improved wooden granary and Sofagrain®.

According to Chamala (1987), farmers adopt innovations that are consistent with their needs, their socio-economic status and their attitudes towards the particular class of innovations. Since the development and popularization of the farming systems research and extension approach in the 1980s (Norman et al., 1995), the importance to consider farmers' needs in technology development processes has been emphasized. In other words, the intensity of an individual's attitude towards an innovation is a major determinant of his anticipated adoption behavior (Lemon, 1973). The attitude of a decision-maker towards an innovation depends on his valuations of the set of characteristics of that innovation (Wossink et al. 1997). Accordingly, negative perceptions on innovation characteristics are sometimes mentioned as a main reason for lack of adoption. It also may explain the limited adoption by farmer of some innovations derived from on-station research (Becker et al. 1995). Therefore, a challenge for agricultural researchers is to properly anticipate the characteristics of innovations that will be demanded by farmers in the future and to develop innovations accordingly (Kshirsagar et al., 2002).

In recent work on adoption of agricultural innovations, attention on the role of farmers' perceptions of characteristics of innovations has increased. Studies show that in addition to farmers' socio-economic characteristics and institutional factors, farmers' perceptions of the specific characteristics of the innovation are also important in determining whether or not to adopt it (Adesina and Zinnah, 1993; Negatu and Parikh, 1999; Batz et al., 2003; Llewellyn et al. 2004). But very few studies assess the characteristics perceived by farmers as important if adoption of a new technology is to be achieved. Exceptions are the studies of Baidu-Forson et al. (1997); Hamath et al. (1997); Chen et al. (2002); Kouadio et al. (2003); Ndjeunga and Nelson (2005). These studies used the choice-based conjoint analysis approach to derive the relative importance of attributes of agricultural products in making choices. Another exception is the work of Sall et al. (2000), who assessed the desired characteristics of improved rice varieties and how they match with rice growers needs using an index approach as developed by Reed et al. (1991). However, a drawback of the studies focusing on the relative importance of innovation attributes in decision making is that they neglect the factors that differ in the formation of perceptions among farmers. Awareness of the factors that influence perceptions would also contribute to the development and transfer of appropriate innovations. Some of the attitudes of an individual may be related to the information available to the decision-maker (Kulshreshtha and Brown, 1993). The sources of information available to a potential adopter play an important role in the development of perceptions about the innovation. If the information is gained through trusted sources, then positive attitudes towards characteristics of storage innovations are more likely to develop and their adoption can be expected, because attitude change is a prerequisite for behavioral change (Guerin, 1999). This author also noted that, in addition to their social or economic position, the adopters' perceptions of storage innovations may be influenced by information from extension agents. Government agricultural extension, rural development projects and peer farmers are important sources from which Beninois farmers obtain information on agricultural innovations.

Research and extension of improved wooden granary and Sofagrain® started in 1992 with a decentralized storage project funded by the Food and Agricultural Organization (FAO). As a follow up, a second post-harvest project started in 1997 within the Agricultural Development Program (PADSA) and supported by the Danish International Development Agency (DANIDA). Drawing from the experiences of past post-harvest projects, these projects used a participatory approach to develop the storage innovations. To increase the probability of adoption, research concentrated on the improvement of the local maize granary identified as the most effective by farmers. In addition, field demonstrations and on-farm trials were conducted to enable farmers to have a better knowledge of the storage innovations.

Moreover, an extension component was included in the projects to increase the effectiveness of the post-harvest research**.**

This chapter examines the extent to which the storage innovations provide characteristics that are consistent with the needs of the maize producers. Moreover, the study evaluates the impact of farmers' participation in the project on the quality of their perceptions of the most desired characteristic embodied in the improved wooden granary and Sofagrain®, respectively. We hypothesize that the observed widespread adoption of the improved wooden granary and Sofagrain® can be attributed to the intervention approach of the Danish project. We assert that this approach allowed developing storage innovations whose characteristics coincide with those determining farmers technology choice. To meet the objectives of this study, we first use an index approach developed by Reed et al. (1991) to assess farmers' perceptions of the characteristics of these storage innovations. Next, following Wooldridge (2007a), a bivariate probit model is applied to evaluate the impact of farmers' participation in the project on their perceptions. By jointly estimating this equation with an equation for participation in the project we correct for the potential endogeneity of project participation. Data on farmers' perceptions of storage innovations and on the socio-economic characteristics of these farmers were collected in villages where the storage innovations had been introduced. Results show that farmers' perceptions on the effectiveness of storage technologies against pests and the length of storage time of maize are most important when farmers choose a given storage technology. The improved wooden granary and Sofagrain® provide these attributes demanded by producers. Furthermore, farmers' participation in the project has a causal impact on the perceptions that farmers have on these new technologies.

The rest of the study is organized as follows: The next section (Section 2) presents the analysis of farmers' perceptions on characteristics of granaries and conservation measures. Section 3investigates the causal effect of farmers' participation in the extension program on the three most important characteristics that affect their decision of technological choice. Overall conclusions and implications of the study are given in the section 4.

3.2 Assessing farmers' perceptions on characteristics of granaries and conservation measures

This section deals with farmers perceptions of the storage technological characteristics. It is organized as follows: Sub-section 3.2.1 describes the method to evaluate farmers' perceptions. The survey data are outlined in sub-section 3.2.2. Sub-section 3.2.3 presents and discusses the empirical results.

3.2.1 Evaluation method

An empirical analysis adapted from Reed et al. (1991) is used to evaluate the extent to which the improved wooden garden and the protecting insecticide Sofagrain® provide characteristics that meet the expectations of maize producers. The approach is based on the calculation of three indices for each characteristic of granary and protection method. These indices are aggregate vectors over the sample producers and measure for each characteristic its importance in adoption decisions, the quality of its provision by the new storage technologies and how well it meets an individual farmer's expectation. The values of the three indices depend on two weights and the rankings given by farmers to the importance of each characteristic and to the perceived quality of its provision by each new storage technology.

The first is a demand index (D) that measures the level of importance of each characteristic of either the granary or the protection measure in determining its adoption. The normalized demand index for each characteristic is expressed as:

$$D_h = \frac{1}{d_1 N} \sum_{j=1}^{r} d_j t_j \qquad \text{such that } d_1 > d_2 > \ldots > d_r > 0 \qquad (1)$$

where h is a characteristic of a given storage technology, d_j is the ordinal demand weight and reflects the expectation of the producers for each characteristic of a storage technology. The demand weight comprises eight terms for granaries and seven for conservation measures and each of them indicates the j^{th} level of importance of the characteristic h in the adoption decision of the farmers; t_j represents the number of farmers who rate the characteristic h at the

j^{th} degree of importance and N is the total number of respondents. The demand index for a given characteristic D_h has a value in the interval $[0,1]$ and equals 1 if all farmers perceived characteristic h as most important. The minimal value is obtained when all farmers consider a given characteristic the least important in their choice of a granary or a protecting measure.

The second index is the supply index (*S*), which measures the perception of the farmers of the degree to which each desired characteristic is achieved in the improved wooden granary or in Sofagrain®. The normalized supply index is denoted as:

$$S_h = \frac{1}{s_1 N} \sum_{i=1}^{n} s_i g_i \qquad \text{such that } s_1 > \ldots > s_{n-1} > 0 > s_n \qquad (2)$$

where again h is a characteristic of a given storage innovation, s_i is the ordinal supply weight and reflects for each characteristic its quality as provided by the improved wooden granary or the Sofagrain® in comparison with the current technology. The supply weight comprises three terms and each of them indicates the i^{th} level of the quality of the characteristic h as provided by the improved wooden granary or the Sofagrain®; g_i is the number of the farmers who rate the characteristic h at the i^{th} level of the quality as being embodied in the improved wooden granary or in Sofagrain®. Similar to the demand index, the maximum value of the supply index equals 1, when all the farmers rate the quality of the characteristic h provided by the improved wooden granary or Sofagrain® to be the best. The minimum value of the supply index which is negative is obtained when all the farmers rate the quality of characteristic h of the improved wooden granary or the Sofagrain® as very bad. The restrictions on the demand and supply weights in Eq. (1) and Eq. (2) ensure that the highest (lowest) weights are given to the characteristics which farmers think are very important (not important) and well (badly) provided by the storage innovation (Sall et al., 2000).

The third index is the attainment index (*W*) that measures how farmers' perceptions of the importance of a characteristic match with the extent to which this characteristic is perceived to be supplied in the improved wooden granary or Sofagrain®. The expression of the normalized attainment index is:

$$W_h = \frac{1}{s_1 d_1 N} \sum_{j=1}^{r} \sum_{i=1}^{n} s_i d_j k_{ij} \qquad (3)$$

where h is a characteristic of a given storage innovation; k_{ij} is the number of farmers who rated the characteristic h at the j^{th} degree of importance and considered also that this characteristic h is provided at i^{th} degree of quality by the improved wooden granary or the Sofagrain®. The maximum value 1 of the attainment index indicates a perfect match between the importance that farmers attached to a given characteristic and how they perceive it to be provided by the technological innovation. The minimal value of the attainment index depends on the supply weight s_i.

The three indices are calculated separately for the improved wooden granary and Sofagrain®, using combinations of a set of supply weights s_i and a set of demand weights d_j. These weights are selected to conform to the previous conditions that demand and supply weights must fulfill. Moreover, to test the robustness of the three indices, the results of the attainment index using different combinations of weight are compared by calculating Spearman and Pearson correlation coefficients for each set. The former measures consistency in rating characteristics, while the latter evaluates the linear relation among various attributes.

3.2.2 Data

The data used in this study are obtained from surveys conducted since 2001 on the socio-economic evaluation of post-harvest innovations in Benin. The surveys were financed by the Agricultural Development Program (PADSA) and supported by the Danish International Development Agency (DANIDA). The study is based on data for the crop year 2001 collected in southern Benin from villages where maize storage innovations were introduced from 1992. Farmers' perceptions on maize storage technologies were elicited in two steps. First, focus group interviews were held with adopters and non-adopters of the storage innovations in 26 villages during the dry season of 2001. These focus group interviews generated two sets of characteristics that farmers most frequently regarded as important in their decision to adopt a granary and/or a conservation measure. Overall, this resulted in 8 characteristics for granaries and 7 characteristics for conservation measures. These characteristics are presented in Tables 1 and 2 for storage structures and conservation measures, respectively. The next step of the study is based on farm-level cross-section data collected between March and May 2002 in 21 villages selected among the 26 previous ones. A survey questionnaire presented to all respondents the list of 8 granary characteristics and 7 conservation measure characteristics derived from the focus group meetings. The sample consisted of 523 randomly selected farmers. First, the survey participants were asked to reveal the relative importance of each granary characteristic in their decision to adopt it on an eight-point scale and the relative importance of each characteristic of a conservation measure in their decision to adopt it on a seven-point scale. A score of 1 is assigned for least importance and 8 or 7 for very high importance. Secondly, the farmers were asked to compare, for each characteristic, their current maize granary with the improved wooden granary and their current conservation measure with the protecting insecticide Sofagrain®. For each storage innovation, each characteristic was rated using a scale of 1-3. On this scale, 3 = 'the storage innovation is better than the current technology'; 2 = 'the storage innovation is similar to the current technology'; and 1 = 'the storage innovation is worse than the current technology'.

3.2.3 Estimation results of farmers' perceptions of storage innovations characteristics

Tables 3.1 and 3.2 present the attributes that, farmers appreciate in granaries and in conservation measures, and their perceptions as to the degree to which the improved wooden granary and the protecting insecticide Sofagrain®, respectively provided these characteristics. Following the restrictions in Eq. (1) and Eq. (2), four combinations of demand and supply weights were used to compute the indices and evaluate their robustness. The sets of supply and demand weights used are presented in Table 3A.1 of the appendix 3A. The robustness of the indices is assessed using Spearman and Pearson's correlation coefficients (Sall et al., 2000). The coefficients were highly significant, indicating a high degree of robustness and confidence in the results (Appendix 3A, Table 3A.2 and Table 3A.3). The results presented in this chapter are from the use of demand and supply weights of the first column of Table 3A.1 of the Appendix 3A. The effectiveness against insects, and rodents; and the length of the storage have the highest demand indices and are therefore the farmers' most wanted characteristics for a granary (Table 3.1). They are key characteristics of granaries that need to be targeted if adoption of improved wooden granaries is to be expected.

Table 3. 1 Farmers' perceptions of storage structure attributes

Variable	Demand index	Supply index	Attainment index
Loss rates due to insects	0.915	0.947	0.876
Loss rates due to rodents	0.893	0.976	0.877
Storage length	0.885	0.960	0.855
Loss rates due to rottenness	0.862	0.944	0.816
Quality of stored product	0.769	0.951	0.742
Construction cost	0.347	0.146	0.061
Construction period	0.275	0.638	0.182
Labor need for construction	0.263	0.113	0.028

Several studies found that lack of or poor adoption of new technologies is partially explained by their perceived characteristics (Kshirsagar et al., 2002; Llewellyn et al., 2004; Ndjeunga and Nelson, 2005). The results also indicate that the values of the supply indices for these characteristics are very high and close to 1. We conclude that the improved wooden granary meets the demands of the maize producers' in the southern Benin to a much larger degree than traditional granaries. The high values of the attainment indices for the five most appreciated characteristics confirm that these characteristics give a high level of satisfaction to the producers (Table 3.1). These results on farmers' perceptions of the characteristics of the improved wooden granary are not surprising since pest damage control was the major focus designing this innovation. The wooden granary is provided with an anti-rat device to prevent rodents from entering the maize stocks. Moreover, to protect the maize against termites' damages, the stakes of the improved wooden granary are covered with oil waste before they are fixed in the ground. Bamboo (*Bambusa spp.)* or woven branches of mallotus (*Mallotus oppositifolius)* are used to build the body of the granaries to facilitate air circulation, allowing maize drying to continue in stock. This contributes to the reduction of decaying losses. On the other hand, the values of the supply and attainment indices for the cost of implementation and the quantity of labor required to construct the improved wooden granary are low. This indicates that the maize producers are not satisfied with the cost and labor needs of the improved wooden granary (Table 3.1). Indeed, improved wooden granary construction is labor intensive and the construction period also coincides with the harvesting period and land preparation activities for the second rainy season. The implementation cost encompasses the transportation cost of wooden and the cost of small materials such as nails, galvanized iron and waste oil. If farmers perceive a new technology to be inferior to indigenous technologies in terms of one or more attributes, they are unlikely to adopt such a new technology (Kshirsagar et al., 2002). In other respects new technologies that are beyond the resource capacities of the farmers are of limited value since adoption will be hampered by lack of resources. Therefore, these perceived high cost and labor requirement in a peak-season labor period could really delay adoption of improved wooden granary by farmers with modest financial resources and limited family labor. For example, in a study by Udoh et al. (2000) in Nigeria, farmers reported that the crib, storage method recommended by FAO, is not cost effective to store maize and therefore not willing to use it. The farmers also believed that they would incur additional expenses in terms of purchase of pesticides if they adopted this new technology. To mitigate the effects of high costs on adoption, the extension program of the project provided to farmers credit and granary building materials.

The most wanted characteristics for conservation measures were the length of conservation, the effectiveness against pests, and the ease of the application (Table 3.2). But only the length of conservation and the effectiveness against pests are better provided by Sofagrain® than by indigenous measures. These two characteristics meet therefore the desires of the maize producers.

Table 3. 2 Farmers' perceptions of conservation measures

Variable	Demand index	Supply index	Attainment index
Length of conservation	0.921	0.839	0.780
Effectiveness against pest	0.900	0.771	0.716
Ease of use	0.801	0.526	0.465
Product availability	0.717	-0.155	-0.093
Labor need	0.615	0.419	0.307
Purchase price	0.593	-0.242	-0.126
Intoxication risks	0.526	0.157	0.153

The attainment indices are low for the ease to use Sofagrain® and negative for the availability of this product. This means that the farmers are not satisfied with the method of application and the availability of Sofagrain®. The application of Sofagrain® requires additional labor in dehusking the maize and shelling the cobs into grains, which are not commonly used storage practices for southern Beninois farmers. A low purchase price is the fifth characteristic that the producers appreciate in a conservation method. Sofagrain® scored lowest on this point for the attainment index. However, the high cost of Sofagrain® can limit its adoption by poor-resources farmers. According to Hell et al. (2000) farmers in Benin were still using indigenous conservation measures or cotton insecticides to protect their stored grains because they have no access to or cannot afford recommended storage insecticides such as Sofagrain®.

Based on the results of this section, the causal effect of participation in the project on the perceptions that farmers have on the quality provided by the new storage technologies of the three most important characteristics that affect their technological choice decision is next studied.

3.3 Project participation effects on farmers' perceptions on storage innovations characteristics

This section presents the second part of the study dealing with the assessment of impact of farmers' participation in the project on their perceptions of the quality of characteristics provided by the storage innovations. The section is laid out as follows. Sub-section 3.3.1 describes the modeling framework. Motivations of the variables included in the model are presented in sub-section 3.3.2. Next, the survey data and the characteristics of the samples are discussed. Estimation results and discussions follow in the last sub-section.

3.3.1 The modeling framework

This sub-section describes the estimation method used to evaluate the impact that the participation in the project had on farmers' perceptions of the quality of the characteristics provided by the improved wooden granary and the use of Sofagrain®.

The counterfactual framework is used to estimate the average causal effect of the participation of the farmers in the extension program on their perceptions of the quality of the characteristics provided by the improved wooden granary and Sofagrain®. To take into account one of the shortcomings of impact evaluation studies it is assumed that the impact of farmers' participation in the project on their perceptions is heterogeneous (Blundell and Dias, 2002). Following this framework, the conditional mean of a probit response model (y_1) is specified as follows:

$$E[y_1 \mid x_1, y_2, x_1 y_2, z_1] = \Phi(x_1\beta_1 + y_2\beta_2 + (x_1 - \bar{x}_1)y_2\beta_3) + E[e \mid x_1, z_1] \qquad (4)$$

where y_1 is the observed perception of the quality of a characteristic provided by a storage innovation for farmers who either participate in the project or do not, $\Phi(\cdot)$ is the standard normal distribution function, x_1 is a vector of other observed relevant characteristics that affect the farmers' formation of their perceptions on a characteristic of a storage innovation, $\bar{x}_1$ is the sample average of x_1, y_2 is an indicator of farmer's participation in the project ($y_2 = 1$ if participated in the project; $y_2 = 0$ otherwise) and e is a vector of omitted and unobserved variables that affect the perceptions of storage innovations characteristics. Interaction terms of demeaned explanatory variables $(x_1 - \bar{x}_1)$ with variable y_2 take heterogeneity of the impact into account (Wooldridge, 2002: 67-70). The vector z_1 is a vector of instruments and E is the expectation operator. The parameters β_1, β_2 and β_3 are unknown regression coefficients to be estimated. The parameter β_2 measures the average impact on a randomly selected farmer of his participation in the project. Demeaning some covariates x_1 before interacting them with y_2 makes sure that the parameter β_2 is the average treatment effect (Wooldridge, 2007b). The probit model corresponding to (4) is:

$$y_1 = \mathrm{I}[x_1\beta_1 + y_2\beta_2 + (x_1 - \bar{x}_1)y_2\beta_3 + e \geq 0] \qquad (5)$$

where e is the random error such as $E[e \mid x_1, z_1] = 0$ and $\mathrm{I}[A]$ is the indicator function that equals 1 when A is true and 0 otherwise.

Studies that assessed the impact of agricultural extension projects on individual farmers often argue that better-off, better-endowed and more innovative farmers select themselves into these projects, because they seek knowledge about innovations and are also likely to adopt innovations. Similarly, agents working for the agricultural extension projects may prefer to interact with better-off, better-endowed and more innovative farmers, who are likely to exhibit better performance in agricultural production (Birkhaeuser et al., 1991; Owens et al., 2003; Diagne, 2006). In addition, if the better-off farmers have some distinctive unobservable characteristics that affect their perceptions of the attributes of the storage innovation, the participation in the project variable y_2 is endogenous as it is correlated with the disturbance term e of the outcome equation y_1. Accordingly the error term e in equation (4), conditional on the participation into the project (y_2) has a nonzero expected value. Hence, the estimate β_2 of the impact of farmers' participation in the project on the formation of their perceptions on the characteristics of the storage innovations is likely to be biased.

To provide a means for dealing with the endogeneity bias in estimating the probit response model (5), the existence of a control variable is generally assumed. In other words we assume that e and y_2 are independent conditional on some (unobserved) random vector v. This random vector can be written as an identified function of y_2 and some vector of exogenous instruments z which comprises z_1 and some of the exogenous components of x_1 as:

$$e \perp y_2 \mid v \text{ for some } v = v_0(y_2, z) \qquad (6)$$

The leading case in which such a control variable will typically be available is when the binary endogenous regressors are generated through a reduced form equation specified here as a probit model:

$$y_2 = \mathrm{I}[z\delta + v \geq 0], \qquad E(v \mid z) = 0 \qquad (7)$$

where δ are the column vector of unknown parameters and $\mathrm{I}[A]$ is the indicator function that equals 1 when A is true and 0 otherwise. The vector of explanatory variables in the Eq (7) comprises the exogenous variables in the vector x_1 of the equation y_1 and the vector of instruments z that satisfy the restrictions of exogeneity and exclusion. The size of z is at least equal to the size of the endogenous variables in the equation y_1 including the interaction terms. Because y_1 and y_2 are binary dependent variables, consistent and asymptotically efficient parameter estimates of equation (5) are obtained by maximum likelihood estimation of the bivariate probit model (Wooldridge, 2007a). To achieve this we assume that the disturbance terms of the perceptions of storage innovations' characteristics and the project participation equations are correlated with ρ representing the correlation coefficient. Moreover we assume that these disturbance terms are distributed as bivariate normal and independent of the explanatory variables (Wooldridge, 2002: 570). Under these assumptions and following Greene (2008: 896), the log-likelihood function is defined as:

$$\begin{aligned}\ln L = &\sum_{y_{i1}=1,\, y_{i2}=1} \ln \Phi_2\left[x_{i1}\beta_1,\, \left(x_{i1}-\bar{x}_1\right)y_2\beta_3, z_i\delta,\, \rho\right] \\ &+ \sum_{y_{i1}=0,\, y_{i2}=1} \ln \Phi_2\left[-x_{i1}\beta_1,\, -\left(x_{i1}-\bar{x}_1\right)y_2\beta_3,\, z_i\delta,\, -\rho\right] \\ &+ \sum_{y_{i2}=0} \ln\left[1-\Phi\left[z_i\delta\right]\right]\end{aligned} \qquad (8)$$

where Φ_2 denotes a bivariate normal cumulative distribution function and Φ is the univariate normal cumulative distribution function. The maximum likelihood estimates of parameters β_1, β_2, β_3, δ and ρ are obtained by maximizing in one step the log-likelihood function in equation (8), which rests on the definition of conditional probability. A Wald test or Likelihood ratio test is used to the null hypothesis that ρ equals zero. The rejection of the null hypothesis implies that the participation in the project y_2 is endogenous in the outcome equation for y_1. Following Bartus (2005), the total marginal effect of participation in the project is obtained in two steps. The first step is the separate estimation of marginal effects of the variable participation in the project and each interaction term. The total marginal effect is computed in the second step by doing the sum of the marginal effects time their respective derivative with respect to participation in the project.

3.3.2 Description of variables included in the model

This sub-section motivates the variables included in the outcome equation y_1 and the reduced equation of the endogenous variable y_2.

The dependent variable in the outcome equation y_1 is generated by a binary response model with three types of covariates, of which one, the variable y_2 is endogenous and the other ones are the exogenous variables and the interaction of some demeaned exogenous variables with the endogenous variable. For each storage innovation, three models of impact of project participation were separately estimated. The dependent variables are the perceptions of the quality provided by each storage innovation for the three perceived characteristics which were ranked by farmers as the most important in their adoption decisions. Drawing from the results in section 3.2.3, the following characteristics were selected: effectiveness against insects, effectiveness against rodents and the length of the storage for the improved wooden granary and length of storage, effectiveness against pests and ease of the application of Sofagrain®. Because of the complexity of the improved wooden granary, the exogenous variables included in its outcome equations y_1 are different from those in Sofagrain® outcome equations. On the other hand, for each storage innovation, the same exogenous variables are used in the three perceptions outcome equations. Drawing from the literature on the factors that influence the participation of farmers in agricultural extension services in developing countries (Bindlish and Evenson, 1997; Nambiro et al., 2006), the following exogenous instruments z are hypothesized to influence the decision of the farmers to participate in the project:

- *Membership in a farmers' co-operative or association*. In order to make an efficient use of the limited resources, agricultural extension programs use farmer groups assuming that messages will spread from group members to other farmers. In addition several studies found that groups encourage their members to change their attitudes. Therefore, farmer groups are the main contact points for extension agents (Bindlish and Evenson, 1997; Guerin, 1999). It is assumed that the variable membership in a farmers' co-operative has a positive influence on the probability to participate in the storage innovations program.
- *Distance of farmer's village to the main city*. Several studies show that the closer the farmer is to the source of agricultural extension, the more likely he is to seek its services. Similarly, the extension's agents have to spend more time and fuel to visit farmers who

are located farther away from the town center (Umali-Deininger, 1997; Nambiro et al., 2006). It is therefore expected that the distance of the farmer to the main city decreases the probability of participating in the storage innovation extension program.

- *Distance from the village to the main market.* Farmers living closer to markets are likely to take advantage from this position and produce more for markets. They will therefore seek information on new post-harvest technologies so that their product satisfies consumers' needs. Hence, it is hypothesized that farmers located nearer to the markets are more likely to participate in events of extension services.
- *Off-farm income of the household*. Non-farm income is important in sub-Saharan Africa for diversifying income sources and increasing total income (Reardon et al. 2006). In other respects, contact farmers for extension services tend to be the wealthier and more powerful in their community (Hoang et al. 2006). Hence, it is assumed that the likelihood of participating in the extension program increases as off-farm income of the household increases. The coefficient of the variable off-farm income of the household is expected to be positive.
- *Access to credit*. Farmers with access to credit are mostly those who have contact with agricultural extension services. It is therefore assumed that farmers who have access to credit are more likely to participate in the extension program.
- *Quantity of maize produced.* Farm size is an indicator of wealth and perhaps a proxy for social status and influence within a community. In addition larger producers are usually better able to bear possible costs of information collection and may have better contacts with agricultural extension services. High quantity of maize is expected to be positively associated with the decision to participate in the extension program.
- *Severity of storage problems*. Farmers with severe storage problems have more to gain from the new technologies and they will therefore increase their search efforts for new technologies. They are then more likely to seek contact with extension services. A positive sign is expected for the coefficient of the variable severity of storage problems.
- *Experience of the household head with maize production*. More experienced farmers are more aware of the constraints in their farming systems and need specialized knowledge. They tend to seek contact with agricultural extension services on their storage problems. Therefore a positive relationship is expected between the variable experience of the household head and the decision to participate in the storage innovations program. The logarithm of the variable experience with maize production is used in this study.

- *Education level of the household head*. Farmers with higher levels of schooling have a greater appreciation for extension advice and expect to benefit from it. They have therefore a higher probability of participating in an agricultural extension program (Bindlish and Evenson, 1997; Hoang et al., 2006; Nambiro et al., 2006). Thus, it is assumed that the variable education level of the household head has a positive effect on the probability of participating in the storage innovations extension program.
- *Sex of household head*. According to Bindlish and Evenson (1997), female farmers are more likely to seek contact with agricultural extension services than male farmers, because they want to compensate their limited access to credit and other inputs by using more advice from extension programs. However, Nambiro et al. (2006) found in Kenya that the male headed households are likely to receive an extension visit. In this study, it is expected that the variable sex of household head will be negatively related to the probability of participating in the extension program on storage innovations.
- *Access to the village throughout the year (road condition)*. Extension contacts are constrained by infrastructure. In the same way, underdeveloped road and transport facilities add to the cost and difficulty of the extension agents to reach farmers (Bindlish and Evenson, 1997; Rahman, 2003; Anderson and Gershon, 2004). Thus, it is assumed that the variable access to the village has a positive effect on the probability of participating in the storage innovations extension program.
- *Availability of family labor*. Better-off farmers have larger farms and use more family workers. They are farmers who usually have contact with extension services. Availability of family labor and its square are included in the models. It is hypothesized that availability of family labor will have a positive but declining effects on participation in extension, respectively.
- *Age of the household head.* Young farmers are likely to seek direct contact with extension services and are more involved in extension events (Bindlish and Evenson, 1997; Hoang et al. 2006). Moreover it is hypothesized that the effect of age on participation in extension is increasing at a decreasing rate. Hence, age of household head and age of household head squared are included in the models. It is assumed that age of household head and age of household head squared will have negative and positive effects on participation in extension, respectively.
- *Share of stored maize intended to use for sale.* Market oriented farmers have more to gain from new technologies and may be inclined to seek out extension contact. It is therefore

hypothesized that higher share of maize intended to use for sale will be associated with participation in extension.

Studies on the factors that influence the formation of the perceptions indicate that they are determined by various factors, such as socio-economic and demographic variables and the information available to the decision-maker (Kulshreshtha and Brown, 1993; Guerin, 1999; Negatu and Parikh, 1999; Valli and Traill, 2005). Therefore, it is assumed in this study that the formation of perceptions on the quality of characteristics provided by the improved wooden granary and Sofagrain® depends on the following variables:

- *Membership of farmers' co-operative or association*. Membership of farmers' groups gives opportunities to the farmers to have accurate knowledge about the storage innovations. Therefore, farmers who are members of co-operative or associations are likely to have positive perceptions of characteristics of storage innovations. The coefficients of membership of farmers' co-operative are expected to be positive.
- *Distance of farmer's village to a town*. Negatu and Parikh (1999) found that farmers who are nearer to town are more likely to have a positive perception for the marketability of their crops than those who are far away from the city. Accordingly it is hypothesized that farmers located nearer to a town are more likely to have a positive perception of the characteristics of storage innovations. A negative sign is therefore expected for the variable distance of farmer's village to a town.
- *Off-farm income of the household.* Off-farm income variable indicates the potential investment of the household in the storage innovations. Negatu and Parikh (1999) for example found that farmers with higher incomes are more likely to have a positive perception for marketability of a new wheat variety than low income farmers. Higher income farmers are able to use the storage innovations as recommended or modify them to increase its efficacy. Therefore, it is hypothesized that maize producers with higher income are likely to have positive perceptions of the characteristics of the storage innovations. Thus, a positive sign is expected for the coefficient of the variable off-farm income of the household.
- *Access to credit*. Farmers who have access to credit can relax their financial constraints and use the storage innovations as recommended. It is therefore expected that access to credit increases the probability of having positive perceptions on the quality of the characteristics provided by the storage innovations.

- *Quantity of maize produced.* Several studies indicate that many resource-poor producers do not use conventional insecticides to protect their products in storage because they cannot afford them (Hell et al., 2000; Adegbola and Gardebroek, 2007). For this reason when the quantity of maize to store increases, they combine Sofagrain® with indigenous protection methods or use it under the recommended doses. Under these conditions application of Sofagrain® can fail to fully protect against pest attacks and farmers will perceive it as ineffective. Similarly, the improved wooden granary is modified when the quantity of maize to store increases. In other words, storage with the improved wooden and Sofagrain® requires additional work for farmers compared to storage with traditional granaries and protection measures. Therefore it is assumed that farmers with large quantity of maize will have a negative perception of the effectiveness of the storage innovations against pests' attacks, the possibility to store for a long period with them and the ease of use of Sofagrain®. Accordingly negative signs are expected for the coefficients of the variable quantity of maize produced.
- *Severity of storage problem*. The perceptions of the effectiveness of the storage innovations against pests and the length of storage depend on the severity of the storage problem encountered by the farmers. The more severe the storage problem, the less the improved wooden granary is effective against attacks by insects and the length of storage. Effective pest damage control and long period of storage could be achieved only when the improved wooden granary is combined with application of a protection method (Adegbola and Gardebroek, 2007). It is hypothesized that farmers with severe storage problems are likely to have negative perceptions on the effectiveness of the storage innovations against pest attacks and the possibility to store for a long period of time using them. Thus, the expected signs of the coefficients of the perception on effectiveness against pests and the storage length are negative. However the sign of the perception of ease of use of Sofagrain® cannot be predicted.
- *Education level of the household head*. Education gives farmers the ability to perceive and interpret the innovations in a dynamic environment (Rahman, 2003). The level of education often influences the point of view of the farmers (Chianu et al., 2006). Better educated farmers are expected to have positive perceptions of quality of the characteristics provided by the storage innovations. The anticipated signs of the coefficients of education level of the household head are positive.

The interactions of the participation in extension program variable with the demeaning of quantity of maize produced and severity of storage problem are included in the three models of improved wooden granaries. On the other hand, in addition to the interactions of the participation with the demeaned values of quantity of maize produced and severity of storage problem, interaction of participation with the demeaned values of access to credit, severity of storage problem and distance of farmer's village to the main city are included in the three outcomes perceptions y_1 of Sofagrain®.

3.3.3 Data

The data used to evaluate the causal effect of farmers' extension participation on their perceptions are collected from the same survey used in analyzing the perceptions as discussed in section 3.2. In addition to the perceptions data, the survey provided detailed information on the farmer's socio-economic and demographic variables and adoption status of each storage innovation. The dataset also included the village characteristics such as road conditions, distance to a market, distance to the main city. The definitions, the sample means and the standard deviations of the explanatory variables included in the project participation model are presented in Table 3.3. Data used in the perception equations are summarized in Table 3.4. The two-tailed t-test results in table 3.4 show that except for the perception of length of conservation for Sofagrain®, on average farmers who participated in the project more often had positive perceptions on the quality of the characteristics provided by the storage innovations. In addition, participants and non-participants in the project are different in some of their socio-economic characteristics and the distance of their village to the main city (Table 3.4). Furthermore, results of the two-tailed t-tests on the differences in means of the independent variables indicate that compared to the non-participants in the project, the participants were usually members of a farmers' group, were closer to the main cities, earned less off-farm income and had often access to credit. These results show that the two groups of participants and non-participants in the project are systematically different. Moreover, the participation in the project can also be influenced by unobservable characteristics of the farmers**.** As was discussed earlier in the method sub-section, these differences between the two groups of farmers may manifest themselves in positive perceptions of the farmers on the quality of characteristics provided by the storage innovations and could be confounded with the differences due to the participation in the project. Therefore the endogeneity problem is assumed and taken into account in the estimation model.

Table 3. 3 Variables used in equations of participation in the project.

Description	Unit	Mean	Standard deviation
Membership of farmers' cooperative or association	1 if the farmer is a member of farmers cooperative; 0 otherwise	0.678	0.467
Distance of farmer's village to the main city	Km	0.172	0.377
Off-farm income share in total income of the household	Share	4.712	2.098
Quantity of maize produced	Kg	2019.124	2132.678
Severity of storage problem	1 for severe maize storage's problem; 0 otherwise	0.686	0.464
Experience of the household head in maize production	Years	20.321	11.953
Availability of family labor	Man-equivalent	2.947	2.947
Sex of the household head	1 for male household headed; 0 otherwise	0.851	0.356
Age of the household head	Years	44.214	43.777
Share of maize intended to use for sale in the total of stored maize	Share	5.573	1.933
Education level of the household head	1 for formal education; 0 otherwise	0.357	0.479
Access to credit	1 if the farmer had an access to credit; 0 otherwise	0.485	0.485
Distance of farmer's village to the market	Km	3.340	1.080
Access to the village throughout the year (road condition)	3 for a paved road, 2 for graded road, 1 for ungraded road and 0 for footpath	0.631	0.483
Number of observations	523		

Table 3. 4 Variables used in equations of causal effect of project participation on farmers' perceptions (standard deviations in parentheses).

Description	Unit	No contact with Extension program $(y_2 = 0)$	Contact with Extension program $(y_2 = 1)$	T-test statistic
Perception of effectiveness of improved wooden granary against insects	1 if improved wooden granary is more effective against insects than the farmer's technology; 0 otherwise	0.325 (0.470)	0.925 (0.263)	18.214***
Perception of effectiveness of granary against rodents	1 if improved wooden granary is more effective against rodents than the farmer's technology; 0 otherwise	0.948 (0.222)	0.976 (0.150)	1.666*
Perception of storage length when storing in improved wooden granary	1 if improved wooden granary makes storage possible for a long period of time than the farmer's technology; 0 otherwise	0.925 (0.262)	0.925 (0.263)	0.025
Perception of length of conservation with Sofagrain®	1 if Sofagrain® makes storage possible for a long period of time than the farmer's technology; 0 otherwise	0.918 (0.274)	0.822 (0.382)	-2.692***
Perception of effectiveness of Sofagrain® against pest	1 if Sofagrain® is more effective against pest than the farmer's technology; 0 otherwise	0.592 (0.493)	0.721 (0.448)	2.804***
Perception of Sofagrain® ease of use	1 if Sofagrain® is more easier to use than the farmer's technology; 0 otherwise	0.459 (0.500)	0.590 (0.492)	2.650***
Membership in farmers' co-operative or association	1 if the farmer is a member of farmers cooperative; 0 otherwise	0.422 (0.495)	0.768 (0.422)	7.819***
Distance of farmer's village to the main city	Km	0.266 (0.443)	0.139 (0.346)	-3.411***
Off-farm income share in total income of the household	Share	5.033 (2.098)	4.600 (2.090)	2.070**
Quantity of maize produced	Kg	2273.926 (2201.49)	1930.468 (2103.871)	1.614
Severity of storage problem	1 for severe maize storage's problem; 0 otherwise	0.666 (0.473)	0.693 (0.461)	0.573
Education level of the household head	1 for formal education; 0 otherwise	0.325 (0.470)	0.368 (0.483)	0.889
Access to credit	1 if the farmer had an access to credit; 0 otherwise	0.259 (0.439)	0.422 (0.494)	3.399***
Participation the project * Quantity of maize		0	-0.025 (0.399)	0.736
Participation in the project * Severity of storage problem		0	0.006 (0.461)	0.172
Participation in the project*Access to credit		0	0.042 (0.494)	0.990
Participation in the project * Distance to city		0	-0.032 (0.346)	1.102
Number of observations		135	388	

Notes: Off-farm income of the household are in 2003 FCFA (FCFA 1= US$ 0.002 in 2003). T-test statistic is for equality of the two means. *=P < 0.1, **=P < 0.05, and ***=P < 0.01.

3.3.4 Results of impact assessment of farmers' participation in extension program

This sub-section presents the results of the analysis of the causal effect of farmers' extension participation on the perceptions of the quality provided by the storage innovations of the three characteristics ranked by farmers as the most important in their adoption decisions. First, goodness-of-fit measures of the seemingly unrelated bivariate models are presented as well as the estimates of the models of participation in extension program and their implications for the consistency of the estimates of the impact models discussed. Next, the results of the models of impact of farmers' participation in extension program on the quality of characteristics provided by each storage innovation are presented and discussed.

Goodness-of-fit of the bivariate probit estimations and participation in extension program

The goodness-of-fit measures of the bivariate probit estimations and the estimates of the participation into the storage innovations extension program are presented in Table 3.5 for the improved wooden granary and in Table 3.6 for Sofagrain®. The results in Tables 3.5 and 3.6 deserve special attention because it is assumed that the consistency of the bivariate probit model used to estimate the impact on farmers' perceptions hinges on the model of participation in the extension program being correctly specified (Heckman et al. 2006; Wooldridge, 2007a).

The Wald tests statistic results presented at the bottom of Tables 3.5 and 3.6 indicate that the null hypothesis that all slope coefficients are zero in each of the six seemingly unrelated bivariate probit is rejected at the 1% significance level. Accordingly, the variables in each model of participation in project and each impact model of perception contribute significantly as a group to explain the decisions to participate or not in the project and the formation of the perception on each technological characteristic, respectively. In other respects, the three correlation coefficients ρ between the equation of participation in the project and the equation of characteristic perception are all significantly different from zero at the 10% critical level for improved wooden granary. In contrast, the correlation coefficient ρ is significantly different from zero at the 10% critical level only for the length of conservation model in Sofagrain®. This implies that the variable y_2 of participation in the project is endogenous in four of the six estimated outcome equations y_1 of characteristic perception. This indicates that the seemingly unrelated bivariate probit model is appropriate to estimate consistently the causal effect of the participation in the project in these four estimated outcome equations y_1 of characteristic perception. The univariate probit model is enough to estimate the remaining two models of perceptions of the technological characteristics.

Compared to the base line of approximately 74%, the Count R^2 of the three models of participation in extension program of Sofagrain® are higher than those of the three models for the improved wooden granary (Tables 3.5 and 3.6). For Sofagrain®, the three models of participation in extension correctly predict the participation for approximately 86% of the sample. In contrast, the participation is correctly predicted for 81% or 82% of the sample for the three models of improved wooden granary. Moreover, all the exclusion restrictions are significantly different from zero at least at 10% critical level. These results indicate that the models of participation in extension are well specified and in addition to the use of bivariate probit model, consistent estimates of the impact models can be expected. Irrespective of the storage innovation, 10 of the 13 estimated coefficients of the variables in each of the model of participation in extension are significantly different from zero at the 10% critical level at least. However, the level of significance of each variable varies slightly through the six models. In addition, six and nine of the significant parameters have the expected signs in the participation models of improved wooden granary and Sofagrain®, respectively. Being a member of farmers' co-operative and increasing age were associated with a higher likelihood of participating in extension for the two storage innovations. In contrast, higher off-farm income, facing severe storage problems and living in villages with easy access were associated with a higher likelihood of participating in extension only for Sofagrain®. The variable severity of storage problems has the expected positive sign but is not statistically significant in participation in extension models of improved wooden granary. This result indicates that when farmers are experiencing severe storage problems, they seek contact with extension personnel for advice on the use of Sofagrain® which they possibly think more effective than improved granary against pest damage. On the other hand, having more experience in maize production was associated with a higher likelihood of participating in extension for the improved wooden granary. In other respects, farmers living far from the main city or a market have a lower likelihood of participating in storage innovations program. The variables quantity of maize produced, access to credit and percentage of stored maize intended to use for sale have the expected positive signs but are not statistically significant in participation in extension models of Sofagrain®. These results are consistent with the initial hypotheses on these variables as given in sub-section 3.3.2. Moreover, the anticipated positive signs of membership of farmers' association and off-farm income for Sofagrain® are consistent with the extension approach of the program which focused on farmers' associations and agricultural products processing activities for the female farmers. The unexpected positive sign of sex of the household head for improved wooden granary also agrees with the project approach which targeted male farmers for the dissemination of the improved wooden granaries.

Table 3. 5 Estimation results for the bivariate probit models on project participation and perceptions of characteristics of improved wooden granary (standard errors in parentheses)

	Perception variable		
	Effectiveness against insect	Effectiveness against rodents	Storage length
Participation in project models			
Constant	-5.831 (4.022)	-9.735 (3.450)***	-9.753 (3.128)***
Membership in farmers' co-operative or association	1.025 (0.135)***	1.011 (0.143)***	0.994 (0.144)***
Distance of farmer's village to the main city	-0.496 (0.170)***	-0.552 (0.163)***	-0.499 (0.176)***
Off farm income of household	-0.607 (0.342)*	-0.669 (0.357)*	-0.490 (0.365)
Quantity of maize produced[1]	-0.194 (0.195)	-0.200 (0.210)	-0.220 (0.196)
Severity of storage problem	0.176 (0.153)	0.136 (0.151)	0.115 (0.146)
Experience of the household head in maize production[1]	1.340 (0.487)**	1.591 (0.570)***	1.870 (0.577)***
Squared experience of the household head in maize production[1]	-0.215 (0.102)**	-0.275 (0.117)**	-0.312 (0.112)***
Availability of family labor[1]	-3.106 (0.757)***	-2.825 (0.883)***	-2.582 (0.820)***
Squared availability of family labor[1]	0.597 (0.202)***	0.476 (0.241)**	0.423 (0.211)**
Sex of the household head	0.374 (0.207)*	0.367 (0.220)*	0.507 (0.225)**
Age of the household head[1]	3.523 (1.792)**	4.984 (1.508)***	4.681 (1.432)***
Squared age of the household head[1]	-0.385 (0.182)**	-0.528 (0.156)***	-0.496 (0.148)***
Share of stored maize intended to use for sale	0.020 (0.036)	0.061 (0.0393)	0.055 (0.032)*
Count R^2 (%)	80.88	81.64	81.07
Base line (%) based on model with constant	74.18	74.18	74.18
Perception models			
Constant	-2.494 (0.826)***	4.826 (1.493)**	0.497 (1.506)
Participation in project	2.740 (0.320)***	0.918 (0.538)*	1.218 (0.601)**
Membership in farmers' co-operative or association	0.421 (0.214)**	0.003 (0.295)	-0.257 (0.244)
Distance of farmer's village to the main city	0.340 (0.230)	0.426 (0.391)	0.190 (0.281)
Off farm income of household/10	0.407 (0.342)	1.028 (0.529)*	0.898 (0.384)**
Quantity of maize produced[1]	0.197 (0.239)	-1.318 (0.433)***	-0.231 (0.425)
Severity of storage problem	0.292 (0.242)	0.007 (0.381)	0.508 (0.309)*
Participation* demean quantity of maize produced	-0.544 (0.332)*	1.089 (0.428)***	0.228 (0.459)
Participation* demean severity of storage problem	-0.265 (0.308)	0.147 (0.462)	-0.690 (0.353)**
Total marginal effect of perception variable	0.818 (0.063)	0.090 (0.092)	0.291 (0.211)
Wald chi2(df) test for joint significance of coefficients of the interacted terms: (all interaction terms=0)	3.56(2)	6.68(2)**	3.83(2)
Log pseudolikelihood	-395.073	-290.453	-357.974
Wald chi2(df)	461.11 (21)***	136.67 (21)***	181.33 (21)***
Rho	-0.764(0.243)*	-0.533 (0.236)*	-0.829 (0.213)*
Number of observations	523	523	523

Note: Robust standard errors in parentheses. *=P < 0.1, **=P < 0.05, and ***=P < 0.01.

Table 3. 6 Estimation results for the bivariate probit models on project participation and perceptions of characteristics of Sofagrain® (standard errors in parentheses)

	Perception variable		
	Length of conservation	Effectiveness of against pests	Ease of use
Participation in project models			
Constant	-5.761 (3.022)*	-6.521(3.048)**	-6.071 (3.166)*
Membership in farmers' co-operative or association	1.017 (0.158)***	0.995 (0.158)***	1.013 (0.158)***
Education level of the household head	0.029 (0.160)	0.035 (0.157)	0.027 (0.159)
Quantity of maize produced[1]	0.117 (0.220)	0.075 (0.219)	0.095 (0.220)
Access to credit	0.242 (0.167)	0.251 (0.166)	0.242 (0.168)
Severity of storage problem	0.298 (0.162)*	0.291 (0.162)*	0.303 (0.162)*
Distance of farmer's village to the main city	-1.513 (0.234)***	-1.480 (0.232)***	-1.496 (0.233)***
Distance from village to the main market	-0.588 (0.087)***	-0.573 (0.088)***	-0.574 (0.088)***
Availability of family labor[1]	-1.082 (0.185)***	-1.021 (0.189)***	-1.055 (0.189)***
Access to the village throughout the year	1.313 (0.172)***	1.351 (0.168)***	1.343 (0.170)***
Age of the household head[1]	3.701 (1.438)***	3.921 (1.457)***	3.759 (1.501)**
Squared age of the household head[1]	-0.404 (0.174)**	-0.419 (0.177)**	-0.405 (0.182)**
Off-farm income of the household[1]	1.017 (0.546)*	1.179 (0.526)**	1.147 (0.557)**
Squared Off-farm income of the household[1]	-0.460 (0.201)**	-0.512 (0.195)***	-0.508 (0.209)**
Count R^2 (%)	86.04	86.42	85.85
Base line (%)	74.18	74.18	74.18
Perception models			
Constant	-0.401 (1.262)	2.846 (1.179)**	-0.080 (0.991)
Participation in project	-0.861 (0.3051***)	0.675 (0.254)***	0.449 (0.264)*
Membership in farmers' co-operative or association	-0.152 (0.180)	-0.356 (0.151)**	-0.072 (0.145)
Education level of the household head	0.240 (0.152)	0.263 (0.128)**	0.194 (0.119)*
Quantity of maize produced[1]	0.793 (0.419)*	-0.692 (0.352)**	0.100 (0.305)
Access to credit	0.257(0.407)	-0.397 (0.260)	-0.489 (0.266)*
Severity of storage problem	-0.572 (0.443)	-0.516 (0.267)*	-0.522 (0.257)**
Distance of farmer's village to the main city	-0.312 (0.386)	-0.102 (0.282)	0.345 (0.279)
Participation* Quantity of maize produced	-1.583 (0.470)***	0.181 (0.394)	-0.413 (0.347)
Participation*demean access to credit	0.300 (0.437)	0.876 (0.297)***	0.615 (0.295)**
Participation* demean severity of storage problem	0.733 (0.471)	0.283 (0.307)	0.755 (0.292)***
Participation* demean distance of farmer's village to the main city	0.367 (0.445)	-0.124 (0.337)	-0.428 (0.334)
Total marginal effect of perception variable	-0.152 (0.044)	0.25 (0.097)	0.177 (0.102)
Wald chi2(df) test for joint significance of coefficients of the interacted terms: (all interaction terms=0)	12.45(4)**	10.16(4)**	12.23(4)**
Log likelihood	-385.904	-479.326	-528.675
Wald chi2(df)	199.61 (24)***	218.21 (24)***	174.08 (24)***
Rho	0.344 (0.191)*	-0.256 (0.175)	0.004 (0.181)
Number of observations	523	523	523

Note: the variables with superscript (1) are in logarithm forms. Standard errors are in parentheses. *=P < 0.1, **=P < 0.05, and ***=P < 0.01.

Results of impact models estimation

The estimation results on the impact of farmers' participation in project on their perceptions of the technological characteristics are presented in the lower parts of Tables 3.5 and 3.6. The marginal effects are also presented in these Tables and indicate the average partial effect of each variable in each model.

The results in Table 3.5 and Table 3.6 indicate that, except for the perception of length of conservation for Sofagrain®, participation in the project has positive causal effects on farmers' perceptions of the quality of five characteristics provided by the storage innovations. In other words, participation in the project raises the number of farmers who have positive perceptions of these characteristics of the improved wooden granary. The values of these parameter estimates are all significant at least at the 10% critical level. The total marginal effects results show that the highest total marginal effects of participation in extension on perceptions are obtained for effectiveness against insects or pest damage for the two storage innovations. Indeed, the total marginal effects of participation in the project on the quality of effectiveness against insects or pest damage provided by improved wooden granary and Sofagrain® are 0.818 and 0.25, respectively. In other words, farmers' participation in the storage extension program increases the probability of having a positive perception on the quality of effectiveness against insects or pest damage provided by improved wooden granary and Sofagrain® by 81.8% and 25%, respectively. This result is not surprising because the storage innovations are designed to address the ineffectiveness of the existing technologies against pest damage. Farmers reported during exploratory surveys that pests and rodents attacks are their major storage constraints (Table 3.7). Effectiveness of granary and protection method against pest damage becomes therefore the key criterion of development of new technologies. In order to increase the degree of effectiveness and rate of adoption of new technologies, scientists decided to improve the most effective indigenous granary selected by the farmers. In addition the best method for protecting grain against insect attack during storage is to apply synthetic organophosphate insecticides such as Sofagrain® (Stathers et al., 2002). The second highest values of total marginal effects of participation in extension are obtained for the perceptions of quality of storage length provided by improved wooden granary (0.291) and the perceptions of quality of ease of use provided by Sofagrain® (0.177). These positive impacts can be the result of on-farm trials in which several farmers have been involved. Although application of Sofagrain® requires dehusking the maize and shelling the grains, participants in on-farm trials better understand the process and find it finally easy to undertake. The most surprising result is the significant and negative effect of participation in the project on the quality of length of conservation provided by Sofagrain® (-0.152). The negative value of this parameter may be explained by the lack of knowledge on the application of Sofagrain® from some participants in the project.

Table 3. 7 Major storage problems and applied solutions

Reason for changing adoption status	Improved wooden granary	Sofagrain®
LATE ADOPTER		
Effectiveness of storage innovations against pests	47	43
High length of conservation	26	57
Good quality of stored product	16	-
Have a thorough knowledge on improved wooden construction technique	8	-
DISADOPTER		
High construction cost of improved wooden granary /Purchase price of Sofagrain®	49	19
Do not have a thorough knowledge on improved wooden construction technique	19	-
Low quantity of harvested maize	18	3
High labor need	9	12
Non-availability of granaries' building materials and Sofagrain®	4	61
Bad quality of "akassa"	-	6

() = Rank

Results of Wald test in Table 3.5 show that the null hypothesis that all interaction terms are jointly equal to zero, is rejected only for the effectiveness against rodents at 5% critical level. In other words the average partial effect of participation varies only for the effectiveness against rodents. The total marginal effect of participation in the project on the quality of effectiveness against rodents provided by the improved wooden granary varied with the quantity of maize produced. In contrast to the results of improved wooden granary, the results in Table 3.6 show that the total marginal effects of participation in the project on the perceptions of the quality of the three characteristics provided by Sofagrain® vary among the maize producers. The null hypothesis that all interaction terms are jointly equal to zero, is rejected at 5% critical level for the three models. Total marginal effect of participation in the project varies with severity of storage problem and access to credit for ease of use, while variation is caused by access to credit only for the effectiveness against pests.

3.4 Conclusions and Implications

This study measures the extent to which the storage innovations provide characteristics that are consistent with the needs of the maize producers, and examines the impact of farmers' participation in extension program on their perceptions of the quality of the characteristics provided by each storage innovation. Focus group interviews were first organized to generate the eight granary characteristics and seven conservation measure characteristics that farmers most frequently regarded as important. Next, data were collected from 523 individual adopters and non-adopters of the storage innovations in southern Benin. An index approach proposed by Reed et al. (1991) is used to rate the desired characteristics of the granaries and conservation measures for maize storage and assess their quality in the improved wooden granary and Sofagrain®. Next, bivariate probit models are used to control for the endogeneity of participation in extension and estimate its average partial effect on farmers' perceptions of the quality of the three most important characteristics provided by each storage innovation. Results from the index approach show that the effectiveness against insects and rodents, and the storage length are the most important characteristics that farmers consider for a granary. The improved wooden granaries meet the demand of the maize producers for these three most important characteristics. Although the labor requirement and cost of implementation are perceived as less important, the improved wooden granary provides these characteristics badly. The most important characteristics for Sofagrain® were the length of conservation, the effectiveness against pest damage, and the ease of application. The first two characteristics are well provided by Sofagrain®, while the ease of application is not. In addition, the availability and the price of the conservation measure are also not well provided by Sofagrain®. These results can be attributed to the participatory approach as it was implemented in the project. The project focused on the causes of the ineffectiveness of indigenous maize storage technologies. To develop an effective granary, scientists improved the best effective indigenous granary and introduced Sofagrain®, one of the best synthetic organophosphate insecticides for protecting grain against insect attack during storage. However, implementation of the participation approach did not address other long term constraints to adoption of these new technologies such as high costs, high labor requirement in labor pick-season and availability of product. These constraints can prevent poor-resource farmers and those with limited family labor from taking advantage of effectiveness of the storage innovations against pests' attacks. The high rates of adoption observed can be explained by the incentives provided by the project to mitigate the effects of these constraints. Therefore in the long term abandonment of these new technologies can occur if these constraints are not addressed. These results imply that during a participatory development process of new technologies in addition to the needs of farmers, attention should also be paid to their most important constraints to adoption. Therefore the participatory approach should not be restricted to the technical aspects only. Thus, the process should be conducted with a multidisciplinary team in order to take into account others aspects with the final objective of acceptance of new technologies.

The use of the bivariate probit model is appropriate in four out of six perceptions impact models to control for the endogeneity of the participation in extension. Except for the perception of length of conservation for Sofagrain®, participation in extension has positive causal effects on farmers' perceptions of the quality of five characteristics provided by the storage innovations. The highest total marginal effects of participation in extension on perceptions are obtained for effectiveness against insects or pest damage for the two storage innovations. This result is consistent with the objective and approach of the program which focused on the development of effective storage innovations against pests. The total marginal effects of participation in extension on the perceptions of the quality of the characteristics provided by storage innovation are heterogeneous for the three characteristics of Sofagrain®. The overall results of this study reinforce the potential payoff from interaction between farmers, researchers and extension staff. They also provide some direction for the storage innovations programs for future research and suggestions for implementation of participatory approach in new technology development processes. For instance, future work may be oriented to developing granaries that are easily affordable by resource-poor farmers and which take into account the female farmers. Finally, the access of the farmers to credit, alternative synthetic organophosphate insecticides and building materials could boost the adoption of the improved wooden granary and appropriate protecting insecticide.

Appendix 3A

Table 3A. 1 Demand and supply weights used for the robustness evaluation

Weight	Wooden granaries			
Supply	s^A(15 10 -1)	s^B(5 2 -2)	s^C(2 1 -1)	s^D(4 1 -3)
Demand	d^A(40 39 38 37 36 7 6 5)	d^B(20 17 15 13 11 10 9 7)	d^C(26 25 20 19 17 16 15 14)	d^D(28 27 21 19 18 16 14 13)
	Conservation measures			
Supply	s^A(3 1 -1)	s^B(5 2 -2)	s^C(2 1 -2)	s^D(4 1 -3)
Demand	d^A(15 14 13 12 11 10 1)	d^B(17 10 7 6 5 2 1)	d^C(20 17 15 13 12 5 3)	d^D(19 17 14 12 9 7 1)

Table 3A. 2 Correlations between Attainment scores given by different weighting formulae for granaries

Characteristic	Supply and demand weights combination				
		W^{AA}	*W^{BB}*	*W^{CC}*	*W^{DD}*
Loss rates due to insects	W^{AA}		*0.990*	*0.988*	*0.983*
	W^{BB}	0.993		*1.000*	*0.998*
	W^{CC}	0.993	0.999		*0.998*
	W^{DD}	0.990	0.998	1.000	
Loss rates due to rodents	W^{AA}		*0.990*	*0.990*	*0.988*
	W^{BB}	0.987		*1.000*	*0.999*
	W^{CC}	0.990	0.999		*0.999*
	W^{DD}	0.988	0.999	1.000	
Storage length	W^{AA}		*0.987*	*0.986*	*0.986*
	W^{BB}	0.985		*0.998*	*0.999*
	W^{CC}	0.989	0.998		*1.000*
	W^{DD}	0.986	0.998	1.000	
Loss rates due to rottenness	W^{AA}		*0.983*	*0.983*	*0.979*
	W^{BB}	0.981		*0.998*	*0.997*
	W^{CC}	0.985	0.997		*0.997*
	W^{DD}	0.982	0.997	0.999	
Quality of stored product	W^{AA}		*0.973*	*0.964*	*0.966*
	W^{BB}	0.968		*0.997*	*0.997*
	W^{CC}	0.969	0.998		*0.997*
	W^{DD}	0.971	0.998	0.999	
Construction cost	W^{AA}		0.848	0.827	0.844
	W^{BB}	0.736		0.986	0.984
	W^{CC}	0.643	0.984		0.978
	W^{DD}	0.624	0.978	0.994	
Construction period	W^{AA}		*0.879*	*0.876*	*0.824*
	W^{BB}	0.783		*0.997*	*0.980*
	W^{CC}	0.753	0.982		*0.975*
	W^{DD}	0.641	0.942	0.913	
Labor need for construction	W^{AA}		*0.945*	*0.931*	*0.935*
	W^{BB}	0.649		*0.991*	*0.999*
	W^{CC}	0.636	0.998		0.990
	W^{DD}	0.561	0.988	0.990	

Notes: The weight combination given by s^A and d^B is referred to as W^{AB}, and so on. Pearson correlations in roman, Spearman rank correlations in italics. *** Correlation is significant at the 1% critical level.

Table 3A. 3 Correlations between Attainment scores given by different weighting formulae for conservation measures

Characteristic	Supply and demand weights combination				
		W^{AA}	*W^{BB}*	*W^{CC}*	*W^{DD}*
Length of conservation	W^{AA}		*0.984*	*0.987*	*0.997*
	W^{BB}	0.963		*0.997*	*0.991*
	W^{CC}	0.996	0.974		*0.992*
	W^{DD}	0.998	0.972	0.999	
Effectiveness against pest	W^{AA}		*0.965*	*0.960*	*0.982*
	W^{BB}	0.979		*0.997*	*0.990*
	W^{CC}	0.997	0.985		*0.984*
	W^{DD}	0.999	0.983	0.999	
Ease of use	W^{AA}		*0.984*	*0.995*	*0.999*
	W^{BB}	0.938		*0.992*	*0.988*
	W^{CC}	0.979	0.937		*0.997*
	W^{DD}	0.991	0.960	0.988	
Product availability	W^{AA}		*0.960*	*0.981*	*0.986*
	W^{BB}	0.912		*0.977*	*0.982*
	W^{CC}	0.935	0.968		*0.978*
	W^{DD}	0.979	0.948	0.974	
Labor need	W^{AA}		0.977	0.981	0.994
	W^{BB}	0.965		0.991	0.984
	W^{CC}	0.966	0.959		0.981
	W^{DD}	0.990	0.977	0.977	
Purchase price	W^{AA}		*0.961*	*0.982*	*0.992*
	W^{BB}	0.813		*0.975*	*0.974*
	W^{CC}	0.899	0.935		*0.980*
	W^{DD}	0.974	0.898	0.952	
Intoxication risks	W^{AA}		*0.975*	*0.981*	*0.992*
	W^{BB}	0.947		*0.993*	*0.985*
	W^{CC}	0.904	0.923		*0.986*
	W^{DD}	0.970	0.953	0.950	

Notes: The weight combination given by s^A and d^B is referred to as W^{AB}, and so on. Pearson correlations in roman, Spearman rank correlations in italics. *** Correlation is significant at the 1% critical level.

CHAPTER 4

THE EFFECT OF INFORMATION SOURCES ON TECHNOLOGY ADOPTION AND MODIFICATION DECISIONS[1]

Abstract

This chapter focuses on adoption and modification decisions on improved maize storage technologies in southern Benin. Modification implies changing a technology to adapt to farmers' circumstances. A sample selection framework is used to account for selectivity bias as some farmers were not aware of the new technologies. Using this framework, the study investigates the effect of alternative information sources on adoption and modification decisions. Farmers are either informed by extension agents or by other farmers. The empirical results show that there are differences in adoption and modification decisions between these two groups.
JEL classification: C35, O33
Keywords: Maize; Storage; Information sources; Adoption and modification; Sample selection bias; Southern Benin.

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4.1 Introduction

In Benin, maize is a staple food and an important source of income for farmers. However, storage of maize is a major problem, resulting in substantial quantity losses. Estimated quantity losses after six months of storage range from 17% to 40% of the total maize production (Kossou and Aho, 1993; Affognon et al. 2000). Storage losses reduce food availability but may also have a negative impact on farmers' incomes if the losses in quantity are insufficiently compensated by a price increase due to lower overall maize supply. A second major problem in maize storage is loss of quality. Individual farmers mainly use traditional storage systems that are not very effective in protecting the maize from insects and changing weather conditions, reducing maize quality considerably. Moreover, the stored maize may also be contaminated by pathogenic agents due to rodents that feed on maize. This can have severe impact on public health.

To reduce storage losses and improve maize quality, new storage systems have been developed and disseminated in Benin since 1992. These new systems are improved wooden- and clay- made granaries, combined with application of Sofagrain®, a commercial pesticide, specific for stored grains. Although the effectiveness of improved granaries is documented, little is known about the determinants of farmers' adoption and the effectiveness of extension and research services in promoting the new technology. Such information is however essential to researchers and to national extension services in assessing the persistence of the adoption process of these technologies.

Many studies on individual farmers' technology adoption compared of expected utilities or profits of alternative technologies, leading to a limited dependent variable model (e.g. logit, probit or tobit). More recent work extended this framework by recognizing that people that are not aware of a new technology cannot adopt it (Saha et al., 1994; Dimara and Skuras, 2003). In these models, adoption decisions are conditional upon being aware of the new technology. What is often not recognized in these studies is that it matters how potential adopters became aware of an innovation. There is a difference between having close contacts with extension agents and being informed by them, and being informed by another farmer who has already adopted the new technology. Not only are the information source and the information process different, but the information content may also differ. Farmers who have used a particular technology may stress their particular experience with (certain aspects of) it in communication with other farmers. Moreover, they may be less able to elucidate technical aspects. So, the perception of non-users of a new technology is influenced by the source of information. An example is the promotion of Sofagrain® in southern Benin. Farmers who came to know Sofagrain® via other farmers who were using it already, often considered it to be a chemical product that is dangerous to public health. Farmers who were informed by extension agents obtained more objective information on the usage of Sofagrain®.

The role of early adopters in information dissemination on new technologies is recognized in the literature on copying behavior in technology diffusion. Bevan et al. (1989: 109-122) included two variables in their logit models to account for the effect of copying: the number of previous adopters in the same cluster and the percentage of current adopters. Pomp and Burger (1995) included in individual adoption equations the ratio of farmers who adopted a new technology to the total number of farmers in the village. A drawback of studies like these is that it is not explicitly known whether farmers adopted after contacts with extension agents or whether they copied adoption decisions from others. This makes it difficult to assess the role of copying in the diffusion of innovations. Another neglected aspect in these studies is that copying may involve modifications of the technology. Farmers who imitate their neighbors in adopting a certain technology may have various reasons to modify it according to their needs: credit constraints, negative experiences with certain aspects of the technology, availability of materials, local culture etc.

In this chapter, we investigate whether adoption and modification decisions differ because of alternative information sources (i.e. extension agents or other farmers). In this sense, the chapter bridges the literature on “information conditional adoption” (e.g. Saha et al., 1994) and the literature on “copying of adoption decisions” (e.g. Bevan et al., 1989: 109-122; Pomp and Burger, 1995). The empirical analysis of this chapter is based on a farm survey in southern Benin, where data were collected on adoption and modification decisions on improved maize storage systems.

The chapter is organized as follows: Section 2 briefly describes the improved maize storage systems in southern Benin and Section 3 discusses the conceptual model. The survey data are outlined in Section 4, and Section 5 presents the empirical results. Section 6 ends the chapter with conclusions and implications.

4.2 Maize storage and conservation systems

A maize storage and conservation system consists of two elements that can be adopted separately: a storage structure (granary) and a conservation technique used to protect stocks against pests' attacks. In southern Benin, there are two types of traditional granaries called "Ago" and "Ava" in local languages. The conical roofing of "Ago" is made of straw and the body is made of palm tree branches. The body is generally circular but can also be rectangular. The "Ava" granaries have only one specific structure with a cylindrical body and straw roofing. Besides these traditional granaries, two types of improved granaries were introduced: one made of wood and another of clay. The wooden granary investigated in this study was introduced in southern Benin in 1992. It is an improvement of the traditional "Ago" granary. The roof is made of straw in which an opening is allowed for loading. At the bottom, another opening can be created for unloading. The body is made of bamboo (*Bambusa spp*) or mallotus (*Mallotus oppositifolius*). The platform rests on stakes around which anti-rat devices made of small-galvanized iron are wrapped to prevent rodents from accessing the granary. As for maize conservation methods, the most common traditional products used in southern Benin are ash, kerosene, diesel oil, water from palm wine distillations, and neem (*Azadirachta indica*) leaves. Improved conservation techniques are Sofagrain® (1.5% *pirimiphos-methyl* and 0.5% *deltamethrin*) and Actellic® (2% *pirimiphos-methyl*).

4.3 A model for analyzing adoption and modification decisions

In this section, a framework for analyzing adoption and modification decisions on maize storage systems by individual farmers is presented. The adoption decision is modeled following Saha et al. (1994) and Dimara and Skuras (2003) who stated that farmers can only adopt a technology if they are aware of it. Once an information threshold is crossed the adoption decision becomes relevant. Not accounting for awareness leads to selection bias in the estimation of adoption decisions. After having decided to adopt an innovation or not, adopters also decide whether to modify the innovation or not. In this section also, reasons for modification are discussed. The section ends with some estimation issues.

Farmers obtain information on improved storage granaries and conservation techniques from extension agents, farmer organizations, farmer colleagues or other sources. These contacts as well as the amount of information obtained vary among farmers. A farmer is considered to be aware of a conservation technology component (storage structure or conservation method) when his information level on the component exceeds a threshold level (Saha et al., 1994). A latent variable Y_i^{I*} can be defined that indicates the degree of being aware of conservation component *i*:

$$Y_i^{I*} \equiv I_i^*\left(X_i^I\right) - \overline{I}_i, \tag{4.1}$$

where $I_i^*(.)$ is the amount of information obtained, X_i^I is a vector of variables that affect the amount of information obtained, and $\overline{I}_i$ is the information threshold level. Assuming a linear specification for the latent variable Y_i^{I*}, the issue whether a farmer is aware ($Y_i^I = 1$) or not ($Y_i^I = 0$) of conservation technology component *i* is defined as:

$$Y_i^I = \begin{cases} 1 \quad if \quad Y_i^{I*} = X_i^I\alpha_i + \varepsilon^I \geq 0 & \Leftrightarrow \quad X_i^I\alpha_i \geq -\varepsilon^I \\ 0 \quad if \quad Y_i^{I*} = X_i^I\alpha_i + \varepsilon^I < 0 & \Leftrightarrow \quad X_i^I\alpha_i < -\varepsilon^I \end{cases}, \tag{4.2}$$

where α_i represents the vector of parameters to be estimated and ε^I a vector of error terms.

The following variables are assumed to explain the amount of information obtained and thereby the awareness of improved maize storage and conservation measures:

- *Contact with extension and/or research agents (CONT)*. Contact with extension agents and/or researchers at a given time, is an indicator of exposure to information on the improved maize storage technologies. Such contacts may engender a positive attitude among maize growers towards the improved storage technologies (Thangata and Alavalapati, 2003). Therefore, we expect that the variable CONT is positively related to the probability of awareness.
- *Membership of farmers' co-operative or association (MECAS)*. This variable indicates the intensity of contacts with other farmers. Farmers who do not have contacts with extension agents may still be informed about new technologies by their colleagues. Membership is

therefore hypothesized to be positively associated with the awareness of improved maize technologies.

- *Quantity of maize produced (PROMA)*. Larger farmers are expected to look for improved technologies since they are expected to benefit more from them and usually experience fewer constraints in adoption (Feder et al., 1985). Furthermore, larger producers may have better contacts with maize traders who could also spread information on storage technologies. Larger producers are usually also better able to bear possible costs of information collection.
- *Severity of storage problem (PROST)*. It is hypothesized that the more farmers are confronted with storage problems, the more they will look for information on improved storage technologies.
- *Education level of the farmer (NINST)*. Farmers who are able to read are more likely to have been exposed to information on improved maize storage technologies. Furthermore, educated farmers are better able to process information and search for the appropriate technologies to alleviate potential storage problems. Therefore, it is assumed that the variable NINST has a positive effect on the probability of being aware of the improved maize storage technologies.

Farmers who are aware of a certain technology component decide whether to adopt it or not by evaluating the gain in expected profits of the component, taking into account the initial investment and related variable costs. If this expected gain is positive then the technology component (either the improved storage structure or the conservation means) is adopted. In determining this gain, the perception of the storage problem and the attributes of the technology component are expected to be important variables. Assuming that the expected difference in profits is a linear function of its determinants leads to the following equation:

$$E\left[\Pi_i^A - \Pi_i^0\right] = X_i^A \beta_i + \varepsilon^A , \qquad (4.3)$$

where E is the expectation operator, Π_i^A is the stream of profits when the storage technology component i is adopted, Π_i^0 is the stream of profits without adoption, X_i^A is a vector of variables that influence the expected difference in profits and β_i represents a vector of parameters to be estimated. Note that there are variables that have a direct impact on profits (e.g. severity of storage problem, cost of granary construction, etc.) but also variables that have an impact on how expectations are formed (e.g. age, education level). The adoption decision can now be specified as:

$$Y_i^A = \begin{cases} 1 \quad if \quad E\left[\Pi_i^A - \Pi_i^0\right] \geq 0 \quad \Leftrightarrow \quad X_i^A \beta_i \geq -\varepsilon^A \\ 0 \quad if \quad E\left[\Pi_i^A - \Pi_i^0\right] < 0 \quad \Leftrightarrow \quad X_i^A \beta_i < -\varepsilon^A \end{cases} \tag{4.4}$$

In the empirical analysis, separate models are estimated for adoption of improved wooden granaries and Sofagrain®. These models are based on a number of hypotheses. It was hypothesized that a farmer's decision to adopt or reject a component of improved maize storage technologies is influenced by the combined effects of a number of factors. Studies on the effect of certain factors on adoption are extensive and numerous (see e.g., Feder et al., 1985, for an overview). The following variables were hypothesized to influence the probability of adopting (a component of) the improved maize storage technologies:

- *Access to the village throughout the year (road condition) (ACCES)*. Farmers located in villages with good access throughout the year have good market access and can sell their maize stock more easily. Therefore, they will store their maize as long as the profitability is ensured. Besides, access to markets is an indicator of risk preference among farmers with different locations (Feder et al., 1985). Farmers with easier access to the market may require a high risk premium for uncertain future profit compared to farmers with difficult access to markets. The former may use a higher discount rate for the future cash flow, leading to a low expected future profit. So, this variable is expected to have a negative impact on the probability of adoption via the expectation operator in Eq. (4).
- *Maize quantity produced by the farmer (PROMA)*. The improved wooden granary is a lumpy technology that requires a certain scale of production to be profitable. A minimum threshold quantity of maize is therefore necessary for adoption. So, the difference in expected profits between adoption and non-adoption is larger for large farmer than for small farmers. In addition, large producers are expected to be less constrained by credit than small producers. Small producers may be able to borrow money for investment, but

at higher interest rates, lowering expected profit from adoption. The chemical conservation product, Sofagrain® also requires a setup cost in term of learning, training and operating cost. The higher the fixed and operating costs required for adoption, the lower the adoption of the technology by small farms (Feder et al., 1985). Therefore, the probability of adoption of improved storage technologies is expected to increase with the quantity of maize produced. The logarithm of this variable is used in the different equations where it appears.

- *Severity of storage problems felt by the producer (PROST).* The degree to which an innovation meets a need felt by potential adopters affects its adoption positively (Rogers, 2003). So, farmers with severe storage problems will expect a substantial increase in maize profits ($E\left[\Pi_i^A\right]$ in Eq. (4)) from adopting the improved storage technologies. So, it is hypothesized that the probability to adopt the improved maize storage technologies increases with the severity of storage problems encountered.
- *Age of farmer (AGE).* The relationship between age and adoption is often unclear. Old farmers may adopt technologies more easily than young farmers because old farmers might have accumulated capital or have preferential access to credit due to their age, availability of land, or family size (Sall et al., 2000). In contrast, young farmers might have a longer planning horizon and might be more willing to take risk (Zegeye et al., 2001), which would affect the way expectations are formed in Eq. (4). Thus, this variable could have either a positive or negative effect on farmers' decisions to adopt a specific storage system. The logarithm of age is used in this study.
- *Education level of the farmer (NINST).* Education may enhance farmer's abilities to efficiently allocate inputs across competing uses, and to select the "best" technology mix (Polson and Spencer, 1991). In addition, educated producers are assumed to be more efficient in their acquisition and processing of technical knowledge and are therefore better able to assess expected profits of adoption appearing in Eq. (4). Therefore, a positive sign for this parameter is expected.
- *Access to credit (ACRED).* Farmers can invest in new technologies either using previously accumulated capital or through borrowing. The lack of sufficient accumulated savings by smallholder farmers prevents them from owing the required capital for investing in new technologies. Maximizing expected profits of adoption subject to a severe credit constraint results in low or zero expected profit of adoption in Eq. (4). Farmers who have access to

credit can relax their financial constraints. Other studies have shown that credit is an important determinant for adoption of improved technologies (Adesina, 1996; Hassan et al., 1998). It is therefore expected that access to credit increases the probability of adopting improved maize storage technologies.

- *Availability of family labor (FTRAV).* Constructing an improved granary is labor intensive. It requires twice the labor needed for constructing a traditional granary. In addition, granary construction coincides with the harvesting period and land preparation activities for the second rainy season. Peak-season labor scarcity is found to be an operative constraint in African farming systems and can explain the rejection of labor-using technologies (Feder et al. 1985). So, farmers with limited family labor are less expected to adopt the improved granary since they would have to hire labor for construction, reducing expected profits of adoption. Therefore, a positive relationship is expected between adoption and availability of family labor. The logarithm of available labor is used in this study.

An issue often ignored in adoption studies is how farmers perceive the potential improvements provided by a new technology. Previous work has shown that farmers' perceptions of technology attributes are important in adoption decisions (Adesina and Zinnah, 1993). Three perception variables that indicate how farmers perceive the contribution of a new technology on a number of issues are considered in this study. In the theoretical model, and particularly in Eq. (4.4), these perception variables affect the expectations that farmers have.

- *Perception of efficiency against pests (EFPE).* Insect pest damage is the first of three major constraints associated with traditional storage systems. In addition, results from qualitative surveys indicate that the efficiency against pest damage is ranked by farmers as the most important attribute of a storage technology. Farmers prefer a storage technology that results in a low maize loss rate. It is assumed that if improved technologies are perceived to lower the maize loss rate, they will be adopted. Thus, a positive coefficient is expected for EFPE.
- *Perception of investment cost (COST).* Initial investment costs are also an important attribute that affects adoption decisions, especially for resource-poor farmers (Rogers, 2003; Hintze et al., 2003). Improved storage systems require an initial investment. Thus, it

is expected to be lower than it is for traditional ones, which positively contributes to the expected difference in profits between both technologies.

- *Perception of easiness of utilization of the conservation product (FACULT).* Like in any innovation, the perceived ease of utilization of the conservation product is expected to increase the probability of its adoption (Rogers, 2003). Easy utilization reduces operational cost of the innovation raising expected profits.

For the adoption of improved maize storage technologies, there may be an additional step, that is, the decision to modify the innovation. Farmers will tend to modify (a component) of the maize storage technology to adapt it more closely to their individual conditions. The decision whether to modify or not any storage technology component can be specified as:

$$Y_i^M = \begin{cases} 1 \quad if \quad E\left[\Pi_i^M - \Pi_i^A\right] \geq 0 & \Leftrightarrow \quad X_i^M \beta_i \geq -\varepsilon^M \\ 0 \quad if \quad E\left[\Pi_i^M - \Pi_i^A\right] < 0 & \Leftrightarrow \quad X_i^M \beta_i < -\varepsilon^M \end{cases} \tag{4.5}$$

where again E is the expectation operator, Π_i^M is the stream of profits from an adopted and modified storage technology component i, Π_i^A is the stream of profits without modification, X_i^M is a vector of variables that influence the expected difference in profits, and β_i represents a vector of parameters. There can be negative and positive reasons to modify the improved maize storage technologies. Negative reasons are: low effectiveness of the technology, financial constraints, unavailability of required building materials or protection method, lack of detailed knowledge about the innovation and ignorance or inadequate learning. A positive reason for modification may be learning from experiences of earlier adopters that led to improvements of the innovation. It is assumed in this study that the variables below have an impact on modification decisions. The working hypotheses used in formation of the modification models are mainly drawn from the results of an exploratory survey conducted at the beginning of this study.

- *Severity of storage problems felt by the producer (PROST).* Farmers in southern Benin are confronted with substantial losses of farm-stored maize, which have increased since the introduction of the large grain borer (*Prostephanus truncatus*). To address the severity of this pest damage, adopters of the improved storage technologies may modify them to increase their effectiveness again pests. This affects the expected profit of modification in Eq. (4.5). A positive relation is therefore expected between the variable PROST and the decision to modify.

- *Access to credit (ACRED).* Farmers who adopt the improved wooden granary without access to credit may substitute the anti-rat devices and the recommended granary building materials by cheaper solutions. This suggests a negative relation between access to credit and modification. Other farmers may improve the standard technology even further requiring more financial means, suggesting a positive relationship. In both cases expected profits of modification are higher than expected profits of the standard technology components.
- *Availability of family labor (FTRAV).* Building an improved maize granary is labor intensive. Farmers with limited family labor available may modify it in such a way that less labor is required, which makes expected profit from the modified technology higher than expected profit from the standard technology since for the latter labor needs to be hired. So, it is expected that availability of labor is negatively related to modification.
- *Perception of efficiency against pests (EFPE).* Because of the severity of pest damages in southern Benin, farmers who doubt the effectiveness of the improved maize technologies will tend to modify them in such a way that they believe them to be more effective. Again this leads to a difference in expected profits between the modified and original technologies. So, a negative relation between perceived effectiveness and the decision to modify is expected.
- *Perception of investment cost (COST).* Perceived high initial investment cost of the original technologies may induce maize producers who are likely to adopt a component of improved storage technologies to modify them. They modify in such a way that investment costs are reduced, increasing the profitability of stored maize. Since the variable COST is defined as measuring lower perceived cost for the improved technology a negative relation is expected.
- *Availability of the conservation product (DISPOS).* Availability of the conservation product in the village is hypothesized to have a negative relation with the probability of modification.
- *Perception of easiness of utilization of the conservation product (FACULT).* The perceived ease of utilization of the conservation product is expected to decrease the probability of its modification.

- *Maize's quantity produced by the farmer (PROMA).* During an exploratory survey farmers suggested to strengthen the granary's solidity when the quantity of stored maize is high. In that case quantity of maize would be positively related to the probability of modification of improved wooden granaries.

In the empirical analysis, probit specifications are used to estimate equations for being aware of the technology (Eq. (4.2)), for adoption decisions (Eq. (4.4)), and for modification decisions (Eq. (4.5)). The probit specifications for adoption and modification are corrected for sample selection bias as the adoption decision is only relevant for those who are aware of the innovation component (Saha et al., 1994). This leads to a conditional probability of adoption:

$$prob(Y_i^A = 1 \middle| Y_i^I = 1) = E\left(Y_i^A \middle| Y_i^{I*} > 0\right) = \Phi\left(X_i^A \beta_i^A\right) + \sigma_{\varepsilon^A \varepsilon^I} \cdot \frac{\phi\left(X_i^I \alpha_i\right)}{\Phi\left(X_i^I \alpha_i\right)} \tag{4.6}$$

where Φ and ϕ are the cumulative distribution function (cdf) and probability density function (pdf) of a univariate normal distribution respectively, and where the last term is an inverse Mills ratio obtained from the parameter estimates of the probit regression of Eq. (4.2). A similar sample selection correction is introduced in the probit equation for modification. So, estimation consists of two steps. In the first step, the probability of being aware of each component of improved maize storage technologies is estimated (Eq. (4.2)) and the inverse Mills ratio is computed from the fitted values. In the second step, using only the observations of farmers who are aware of the component of technology considered, the adoption Eq. (4.4) and the modification Eq. (4.5) that include the inverse Mills ratios as regressors are estimated.

One pooled awareness Eq. (4.2) is estimated for both farmers aware from extension agents and those aware from other farmers. This is because for being aware of new storage technologies it does not matter whether farmers are informed by extension or by other farmers. It only matters whether a farmer is aware or not. Moreover, the same pooled awareness equation is specified for improved wooden granaries and protection methods because these technologies are disseminated together. The adoption Eq. (4.4) and the modification Eq. (4.5) are estimated separately for the improved wooden granary and Sofagrain® because adoption and modification rates differ for both technology components.

To investigate the effect of different information sources on adoption and modification decisions, Eqs. (4.4) and (4.5) are estimated separately for maize producers informed by extension and research services, and for producers informed by their colleagues. So, both Eqs. (4.4) and (4.5) are estimated four times.

For each equation, an LR test is performed to test the null hypothesis that all slope parameters are equal to zero. For adoption and modification decisions, LR tests are performed to test for group differences between farmers who are aware of the improved technologies from extension agents and those who are aware from other farmers. This is done for improved wooden granaries and for Sofagrain®. If the null hypothesis no group differences in parameters is rejected, one can conclude that the source of information has an impact on adoption and modification behavior[2]. For some of the models, different variables are included for the separate groups. The restrictive pooled model that is used in the test contains all variables that appear in any of the subgroup models. This implies that testing the subgroup model against the pooled model also includes testing for zero coefficients in the subgroup model. To separate this effect from testing for group differences, it was first tested whether the parameters of the variables that were not included in an equation for a group are zero or not.

4.4 Data

The data used for this study were collected between March and May 2002. A random sample of 743 maize producers was drawn from farmers in 30 villages located in rural provinces of southern Benin. The selected villages were among those involved in on-farm experiments of improved maize storage technology projects. In addition, the sample villages also included neighboring villages that were not included in these projects. The data set contains information on socio-economic characteristics of farmers, farmers' perception on improved maize storage technologies, farmers' perceptions about the severity of maize storage problem, and village characteristics. Units and descriptive statistics of the variables included in the empirical models are given in Table 4.1.

[2] An anonymous reviewer suggested estimating one model with both groups combined and a dummy variable for information source. However, note that such a model only allows for variable intercepts and not for differences in slope parameters. We want to investigate whether different information sources also lead to different slope parameters in adoption and modification.

Of the 743 observations that are used in estimating the awareness Eq. (4.2), 523 are from farmers who were aware of improved maize storage technologies, and 220 are from farmers who were not. In the first group, 427 farmers were aware of the technology from extension or research services, while 96 were aware from previous adopters. For both groups the adoption Eq. (4.4) is estimated for improved granaries and for Sofagrain®. Of the total 523 aware farmers, 205 adopted the improved granary and 229 adopted Sofagrain®. Of the 205 improved granary adopters, 175 were aware of the technology from extension and 30 from other farmers. Of the 229 Sofagrain® adopters, 200 were aware of the technology from extension and 29 by other farmers. This gives the sizes of the subsamples used in estimating the modification Eq. (4.5). Of the 205 farmers who adopted the improved granary, 45 (22%) decided to modify the granary. Eighty-seven (38%) producers modified the use of Sofagrain®. These data show that modification is a serious issue in adoption of improved maize storage systems.

Before specifying and estimating each model, partial correlation coefficients of explanatory variables were checked to see if there was a potential multicollinearity problem. The correlation matrix showed that none of the partial correlation coefficients is high for any variable included in the models. Therefore, we expect no multicollinearity problems in estimation.

Table 4. 1 Summary of sample means of model variables (standard deviation in parentheses)

Explanatory variables	Unit	Information equation	Adoption equation		Modification equation	
			Informed by extension	Informed by others farmers	Informed by extension	Informed by others farmers
CONT	1 for contact with extension agents, 0 otherwise.	0.71 (0.45)				
MECAS	1 for a member of farmers cooperative, 0 otherwise.	0.61 (0.49)				
PROMA	Kilograms	3.10 (0.39)	3.15 (0.40)	3.08 (0.39)	3.14^{G} (0.34)	3.00^{G} (0.54)
PROST	1 for severe maize storage problem, 0 if not.	0.68 (0.47)	0.67 (0.47)	0.75^{G} (0.44)	0.61^{G} (0.48) 0.72^{S} (0.45)	0.67^{G} (0.48)/ 0.76^{S} (0.44)
NINST	1 for formal education, 0 otherwise	0.34 (0.47)	0.36 (0.48)	0.36 (0.48)		
AGE	Years		3.75^{G} (0.33)	3.63^{G} (0.29)		
ACCES	3 for a paved road, 2 for graded road, 1 for ungraded road and 0 for footpath.		1.53 (1.28)	1.78 (1.24)		
ACRED	1 for access to credit, 0 otherwise.		0.40^{G} (0.49)	0.28^{G} (0.45)	0.42^{G} (0.49) 0.44^{S} (0.50)	0.10^{G} (0.31) 0.31^{S} (0.47)
FTRAV	Man-equivalent		1.62^{G} (0.49)	1.51^{G} (0.44)	1.62^{G} (0.47)	1.42^{G} (0.40)
DISPOS	1 if Sofagrain® is available in the village, 0 otherwise.				0.14^{S} (0.35)	0.14^{S} (0.35)
EFPE	1 if farmer thinks that improved system is better than local system, 0 otherwise.		0.93^{G} (0.25)/ 0.73^{S} (0.44)	0.88^{G} (0.33)/ 0.85^{S} (0.35)	0.91^{G} (0.28) 0.65^{S} (0.49)	0.80^{G} (0.41)/ 0.86^{S} (0.35)
COST	1 if farmer thinks that initial cost of improved system is lower than local system, 0 otherwise		0.11^{G} (0.32)/ 0.06^{S} (0.23)	0.11^{G} (0.32)/ 0.04^{S} (0.20)	0.12^{G} (0.33)	0.17^{G} (0.38)
FACULT	1 if farmer perceives utilization of Sofagrain® easier than local product, 0 otherwise.		0.56^{S} (0.50)	0.55^{S} (0.50)	0.62^{S} (0.49)	
Number of observations	--	743	427	96	175^{G}/ 200^{S}	30^{G}/ 29^{S}

^{G} for granary, ^{S} for Sofagrain®. No indication when the variable is included in equations of both technologies.

4.5 Empirical results and discussion

In this section, estimation results for awareness (Eq. (4.2)), adoption (Eq. (4.4)), and modification (Eq. (4.5)) are presented. Parameters estimates and t-statistics for the different models are presented in Tables 4.2 and 4.3 for the improved wooden granary and protection method, respectively.

4.5.1 Awareness of improved maize storage technologies

In the estimated pooled awareness equation, three of the five estimated slope parameters are significantly different from zero at the 1% critical level. In addition, these parameters had a positive sign, suggesting that maize producers who have contact with extension and/or research agents, members of a co-operative or farmers' association or those who produce a considerable quantity of maize have a higher probability of being aware of improved storage technologies. These results are in accordance with the initial hypotheses on these variables formulated in section 4.3. Public agricultural extension and research services are the major sources of information in the study area, and farmers who have contact with them have easy access to information on improved storage technologies. Farmers without contacts to extension services get their information in meetings of cooperatives or farmers' associations. It is interesting to see that education level and severity of the storage problem do not contribute to awareness of improved maize technologies, but quantity of maize produced does. As hypothesized in Section 3, the latter effect may be attributed to better contacts with traders who disseminate information, more need for information, and better options to collect it.

Table 4. 2 Estimation results for information, adoption and modification of improved granaries (t-statistics in parentheses)

Variables	Information	Adoption		Modification	
		Informed by extension	Informed by others farmers	Informed by extension	Informed by others farmers
Constant	-1.84 (-4.41)***	1.19 (3.20)***	0.98 (0.92)	-0.43 (-1.25)	0.12 (0.22)
CONT	0.70 (6.28)***				
MECAS	0.33 (3.13)***				
PROST	0.08 (0.75)	-0.13 (-2.53)**	-0.18 (-1.37)	0.13 (1.98)**	0.10 (0.63)
NINST	0.12 (1.06)	0.07 (1.26)	-0.03 (0.12)		
PROMA	0.53 (3.97)***	-0.18 (-2.37)**	-0.29 (-1.73)*	0.25 (2.63)***	0.14 (0.94)
ACCES		-0.12 (-6.69)***	-0.09 (-2.64)***		
ACRED		0.02 (0.27)	-0.28 (-2.80)***	-0.15 (-2.37)**	-0.07 (-0.27)
FTRAV		-0.01 (-0.15)	-0.29 (-2.74)***	0.02 (0.35)	-0.19 (-0.96)
AGE		0.02 (0.25)	0.49 (3.19)***		
$EFPE^G$		0.22 (3.45)***	-0.14 (-1.11)	-0.13 (-1.06)	-0.64 (-2.94)***
$COST^G$		0.04 (0.62)	0.02 (0.11)	-0.18 (-1.97)**	0.27 (1.23)
Inverse Mills Ratio		-0.45 (-4.11)***	-0.56 (-1.68)*	-0.06 (-0.59)	0.42 (2.11)**
Number of observations	743	427	96	175	30
χ^2 (df)	91.35 (5)***	67.98 (10)***	31.96 (10)***	23.01 (7)***	14.16 (7)**
LR test on group differences		40.04 (11)***		22.00 (8)***	

* $p<0.1$, ** $p<0.05$ and *** $p<0.01$.

4.5.2 Adoption decisions and the effect of different information sources

For all four estimated adoption equations the null hypothesis that all slope parameters are zero is rejected. For both the improved wooden granary and Sofagrain® the estimated coefficients associated with the Inverse Mills ratio are significantly different from zero at the 5% level for farmers informed by extension agents. For producers informed by their colleagues, this parameter is different from zero at the 10% significance level only for the improved granary model. This indicates that in three of the four estimated equations it is important to condition the adoption model on awareness of the technology to avoid selection bias in parameter estimates.

There are differences in adoption behavior between farmers informed by extension agents and those informed by colleagues as reflected in the LR test outcomes for group differences. For adoption of the improved wooden granary, the LR test statistic is 40.04, which exceeds the critical $\chi^2_{11;0.95}$ value of 19.7. Therefore, the null hypothesis that all parameters equal for both groups in improved granary adoption equations is rejected. For Sofagrain® a similar result is found. The LR test statistic is 28.58 exceeds the critical $\chi^2_{9;0.95}$ value of 16.9, again rejecting the null hypothesis of equal parameters for both groups of farmers[3]. Detailed examination of the estimation results indicates that there are differences in slopes of particular variables, indicating differences in marginal effects but also in the variables that explain adoption of granaries and Sofagrain®.

Looking at adoption of improved granaries (Table 4.3) a number of interesting differences are found. First, severity of storage problems felt by the producers is significant only in the model of farmers informed by extension, but with an unexpected negative sign. According to some earlier adopters, with very severe storage problems the improved wooden granary is also not effective against attacks by insects, which might explain this negative sign. Effective insect control could be achieved only when the improved wooden granary is combined with application of a protection method. With severe storage problems, the improved wooden granary also may have been modified to increase its effectiveness against insects' attack, which is confirmed by the finding on this variable for modification of granaries. For farmers informed by colleagues, severity of the storage problem is not a reason

[3] Here it was first tested whether the variable "Severity of storage problems felt by the producer" was correctly left out from the equation for farmers informed by other farmers. Test results confirmed this decision.

to adopt but also not a reason to abstain from adoption given the insignificant parameter for this group.

Second, access to credit, availability of labor, and age of farmer are significant only in the model for farmers informed by other farmers. However, the negative signs of access to credit and availability of labor are opposite to the effects hypothesized in Section 4.3. The unexpected negative sign for access to credit is difficult to explain. It could be that farmers with good access to credit may be less involved in maize production and have other activities (e.g., off-farm labor), which might explain non adoption, but this cannot be derived from this analysis. For the negative sign of labor availability an explanation could be that although the improved wooden granary initially requires labor for its construction, it may also save labor after its construction. With respect to age, we can conclude that older maize producers who are informed by colleagues tend to adopt improved granaries, whereas young farmers do not. Apparently, for older farmers without extension agent contacts, accumulated capital or availability of land play a role in adopting improved granaries, whereas for older farmers informed by extension agents this does not play a role.

Perception of effectiveness against pests and perceived costs of the improved granary did not play a role in adoption decisions of farmers informed by other farmers, but for farmers informed by extension the perceived effectiveness against pests has a positive effect that is significant at 1% critical level. This result is in concordance with the initial hypothesis on this variable as given in Section 4.3. However, estimation results for this group show that perceived investment costs do not affect adoption decisions. So, our results only partly confirm the hypothesis that farmers have subjective preferences for technology characteristics that play a major role in technology adoption as argued by Adesina and Zinnah (1993) and Sall et al. (2000).

The adoption decisions of both groups are affected by quantity of maize produced and access to the village throughout the year. Both variables were significantly different from zero in the two models. However, contrary to our expectations, maize production was negatively correlated with the adoption of an improved wooden granary. Large maize producers may sell their maize directly to traders in which case they do not need to store it. So, there could be a lower limit above which adoption becomes attractive as hypothesized in Section 4.3 based on the literature (Feder et. al., 1985), but in this case an upper limit for maize might exist above which farmers do not store their maize. Access to the village throughout the year had a negative sign, as expected. This means that farmers located in villages with easy access throughout the year, receive higher prices for their products and consequently they may decide not to store their product as argued in Section 4.3. This also confirms the finding by Maboudou et al. (2004) who concluded that the safest option for small scale farmers with low incomes is to quickly sell the portion intended for the market due to the uncertainty of the disorganized maize market in Benin.

Next, we consider differences in adoption of the conservation method Sofagrain® (see Table 4.3). Estimation results suggest that differences between the two groups of farmers are related to three variables: education level, access to the village throughout the year, and perception of investment cost. Education only has a significant effect in the equation for Sofagrain® adopters who were informed by their colleagues. However, the sign is negative, contradicting the often-stated hypothesis that is also raised in Section 4.3 that educated farmers tend to adopt new technologies. Educated farmers aware of Sofagrain® from other farmers may perceive this product to be toxic and therefore decide not to adopt it. Educated farmers informed by extension agents may have better information on this product so that they do not consider this. However, for both groups, we did not find a positive effect for education. Also note that this insecticide is not a knowledge-intensive innovation in which management ability is required for its successful adaptation and adoption (Lee, 2005). Village access throughout the year and perception of investment costs were only significant in the equation for farmers informed by extension agents, and had the expected signs and are thus consistent with the hypotheses presented in Section 4.3. For both groups, perceived ease of utilization has the expected positive effect on adoption of Sofagrain®.

Table 4. 3 Estimation results for information, adoption and modification of Sofagrain® (t-statistics in parentheses)

Variables	Information	Adoption		Modification	
		Informed by extension	Informed by others farmers	Informed by extension	Informed by others farmers
Constant	-1.84 (-4.41)***	0.35 (1.28)	0.84 (0.92)	0.49 (3.24)***	0.26 (0.50)
CONT	0.70 (6.28)***				
MECAS	0.33 (3.13)***				
PROST	0.08 (0.75)	0.07 (1.36)		0.02 (0.21)	0.06 (0.32)
NINST	0.12 (1.06)	0.02 (0.35)	-0.21 (-1.71)*		
PROMA	0.53 (3.97)***	0.05 (0.73)	-0.13 (-0.72)		
ACCES		-0.06 (-3.00)***	0.04 (1.12)		
ACRED				-0.11 (-1.62)	0.24 (1.29)
$EFPE^S$		0.07 (1.23)	0.05 (0.40)	-0.16 (-2.23)**	-0.78 (-2.75)***
$COST^S$		0.31 (3.03)***	0.18 (0.74)		
FACULT		0.11 (2.19)**	0.16 (1.70)*		
DISPOS				-0.28 (-2.86)***	0.03 (0.12)
Inverse Mills Ratio		-0.27 (-2.41)**	-0.27 (-0.72)	0.09 (0.71)	0.62 (1.75)*
Number of observations	743	427	96	200	29
χ^2 (df)	91.35 (5)***	37.54 (8)***	19.42 (7)***	22.61 (5)***	10.25 (5)*
LR test	--	28.58 (9)***		19.24 (6)***	

* p<0.1, ** p<0.05 and *** p<0.01.

4.5.3 Modification of improved maize storage technologies

Empirical results for modification are also presented in Tables 4.2 and 4.3 for improved wooden granary and protection method, respectively. The coefficient of the inverse Mills ratio was significant only in the equations for farmers informed by other farmers. The null hypothesis that all slope parameters are zero was rejected for all four equations, by only at the 10% significance level for the Sofagrain® equation for farmers informed by peers.

Testing for group differences between farmers informed by extension agents and those informed by other farmers revealed significant results. For improved granaries, the LR test statistic of 22.00 exceeds the critical $\chi^2_{8;0.95}$ value of 15.5, and for Sofagrain® the LR test statistic of 19.24 exceeds the critical $\chi^2_{6;0.95}$ value of 12.6.

Looking in more detail at the differences in modification decisions, we first concentrate on modification of improved granaries. For farmers informed by extension services, modification decisions depend significantly upon severity of storage problems (positive sign), the quantity of maize produced (positive sign), access to credit (negative sign) and perception of investment cost (negative sign). These results are consistent with the hypotheses formulated for these variables in Section 4.3. They also connect to the results found for adoption. There we found that large quantities of maize and severe storage problems have a negative effect on adoption. The results on modification indicate that farmers with these characteristics may adopt but then modify the improved granary to their needs. For farmers informed by other farmers, the only variable that is significantly related to modification decisions is the perceived effectiveness against pest. If this group of farmers perceives this effectiveness to be low, they tend to modify the granary, as expected. Other variables included in the model apparently do not play a role in their modification decisions. Note that perceived effectiveness against pests is not a significant determinant of modification decisions for farmers informed by extension.

The empirical results considering modification in the use of Sofagrain® (Table 4.3) are less striking. For both groups of farmers, the perceived efficiency against pests has a significant and expected negative effect on modification decisions. The groups differ in one respect, that is, availability of the conservation product. Farmers who are informed by extension agents tend to modify the use of Sofagrain® if the product is not available in their village (although they could obtain it from somewhere else). This finding is in line with complaints by farmers about the non availability of the protection method, which apparently stimulates them to modify the use of Sofagrain®. Note that this does not seem to play a role for farmers informed by colleagues.

4.6 Conclusion and implications

Recent studies recognized that the assumption of full information on available technologies does not always hold when modeling adoption decisions. A sample selection framework is then used to account for selectivity bias when it can be expected that some farmers are not aware of the new technologies studied. In this chapter, we went beyond this model and investigated the effect of alternative information sources, that is, extension agents versus other farmers, on adoption decisions. Moreover, we investigated a step that may follow adoption, that is, modification of a new technology to adapt it to the farmer's circumstances. The focus in this study is on the adoption and modification of improved maize storage technologies in Benin. Survey results show that modification is a serious issue for maize producers in southern Benin.

The empirical results mostly confirm that failure to control for selectivity bias yields inconsistent coefficients in estimation of improved maize storage technologies adoption and modification equations. Modeling awareness should precede analysis of decisions to adopt the improved maize storage technologies. The results from the estimated awareness equation reveal the importance of contact with extension agents and membership of a cooperative as major sources of information on improved maize storage technologies in southern Benin. Therefore, it can be concluded that greater emphasis on exposing farmers to improved storage technologies is needed as a first step in increasing the adoption rates of these new technologies.

The estimation results also reveal that adoption and modification decisions on improved storage technologies in southern Benin are different for farmers with alternative sources of information. Different factors play a role in adoption and modification decisions of the two technology components considered, that is, improved wooden granaries and the conservation method Sofagrain®. The fact that different variables influence the adoption decisions made by each group indicates that the information spread by extension services differ from that spread by farmers to colleagues. This has implications for further diffusion of these technologies. Adoption after being informed by extension is a different process from adoption based on information from other farmers.

With respect to adoption of improved wooden granaries, it turns out that farmers informed by extension agents and producing large quantities of maize and/or having severe storage problems may adopt these granaries but modify them to their situation. Perceived effectiveness against pest is an important determinant in adoption of improved granaries for this group, but it is not for farmers informed by others. This reveals that extension services have succeeded in convincing farmers on the benefits of improved granaries in reducing pest damage. Apparently, their colleagues who were not informed by extension agents were less convinced. For them a low perceived effectiveness against pest is an important determinant of modification.

In the adoption models for the protection method Sofagrain®, besides access to the village, perceptions on costs and ease of use are important determinants of adoption by farmers informed by extension agents. Ease of use is also a factor that affects adoption of Sofagrain® by farmers informed by peers. The only other factor that has an impact on Sofagrain® adoption for this group is education level, but with an unexpected negative sign. It could be that these educated farmers informed by peers are more concerned about the toxicity of Sofagrain®, but this requires further investigation. Throughout this study we did not find any effect of education on adoption or modification decisions. Modification decisions with respect to the use of Sofagrain® are not much different for both groups.

Overall we conclude that besides some common effects that vary from case to case, there are also differences in the factors that determine adoption and modification of improved wooden granary and Sofagrain® adoption between the two groups of farmers. Most of the coefficients of the variables that appear to affect these decisions have signs that are in line with the hypotheses presented in the literature and stated in this chapter. Nevertheless, further research on the effects of different information sources on adoption and modification decisions is necessary to improve understanding of technology diffusion and the role of information therein. More research on modification would also be fruitful, as our results on modification decisions for farmers informed by peers are obtained using relatively small subsamples.

CHAPTER 5

IMPACT OF MAIZE STORAGE INNOVATIONS ADOPTION ON SCHOOLING EXPENDITURE IN SOUTHERN BENIN[1]

Abstract

Since the declaration of Millennium Development Goals, policy makers and donors have increased their interest in the impact of agricultural innovations on the wellbeing of poor people. This chapter examines whether adoption of maize storage innovations has a causal impact on schooling expenditure for children in southern Benin. Impact on schooling expenditure is computed using a correction function approach. Estimation results reveal that average schooling expenditure raises with adoption of maize storage innovations. Constraints to widespread diffusion of storage innovations such as high costs, high labor requirement and availability of protection measure and granary building materials must be addressed to sustain the impact of adoption.

JEL classification: I22; O33; R22

Key words: Maize, storage innovations, heterogeneous impact, schooling expenditure, counterfactual framework, correction function approach, Benin.

[1] Paper by Patrice Ygue Adegbola, resubmitted after revision for publication in *Agricultural Economics*.

5.1 Introduction

Recent works show that pest damage during maize storage is a serious constraint to food security and agricultural income of households in southern Benin. To control pest damage in stored maize, a package of complementary innovations of improved wooden granary and Sofagrain®[2] was designed and introduced in 1992. On-farm trials have indicated that after six months of storage, the losses were reduced from 30% to only 5%[3] for maize which is treated with Sofagrain® and stored in an improved wooden granary (PADSA, 2000). Despite important efforts to improve maize storage systems, few studies have dealt with their economic impact. Studies have focused mostly on factors that determine the probability of storage innovation adoption (Maboudou et al., 2004; Adegbola and Gardebroek, 2007). Previous impact studies have mainly focused on return from agricultural research investment and cost-benefit analysis of agricultural production innovations (Marasas et al., 2003; Mather et al. 2003). Since the declaration of the Millennium Development Goals in 2002, policy makers and donors have increased their interest in the impact of agricultural innovations on the livelihood of poor people in sub-Saharan Africa. Indeed, agriculture in sub-Saharan Africa countries employs a large share of labor force and contributes large fractions of national income. In many of these countries, however, agricultural productivity is extremely low. Therefore, increasing agricultural productivity is critical to economic growth, overall development and improved rural welfare (Gollin et al., 2002). A productivity increase in key export crops and livestock products ensures the profitability of these products for producers, resulting in an increase in their income (Huffman and Orazem, 2007, p. 2335). The rising incomes of small farmers and agro-processors are typically spent on locally provided goods and services. Beyond the direct effect on poor producers in the form of higher farm incomes, there are other slower but powerful indirect effects: lower food prices, higher wages in the agricultural sector and increasing employment and income opportunities in the non-farm sector (Huffman and Orazem, 2007, p. 2335). One important and most used way to increase agricultural productivity is through the introduction of improved agricultural technologies and management systems (Alwang and Siegel, 2003). However, human capital is another important determinant and increasing this could also raise agricultural productivity thereby triggering economic growth. Furthermore, Huffman and Orazem (2007, p. 2307) raise the

[2] The symbol ® stands for 'Registered trade mark'. Sofagrain is an insecticide protectant constituted of 0.2% Delmethrin and 1.5% Pyrimiphos-Methyl. It's used to control pests in stored grains, notably cereals and leguminous.
[3] The count and weigh (also known as gravimetric) method is used to assess the maize storage losses (Pantenius, 1988).

need in developing countries to implement a policy framework that emphasizes universal completion of primary education. Schooling expenditure is an effective means to enhance ability to make good decisions on information acquisition and technology adoption (Groot and Maassen van den Brink, 2007; Huffman and Orazem, 2007, p. 2291; Orazem and King, 2008, p. 3478). More educated farmers can make better decisions regarding resource reallocation in a market economy where rules-of-thumb are no longer appropriate. More educated farmers have the potential for contributing to agricultural production and are mostly the first to adopt technological innovations (Huffman and Orazem, 2007, p. 2333; Orazem and King, 2008, p. 3495). Studies show that the return to schooling in rural areas depends on the adoption rate of agricultural innovation and human capital is complementary with adoption of new technologies (Foster and Rosenzweig, 1996; Orazem and King, 2008, p. 3495).

This chapter provides an ex post impact assessment of storage innovation adoption on primary schooling expenditures. Farmers have reported during an exploratory study that profits derived from adoption of storage innovations are spent on family health, children's schooling, purchasing of food, investment in farm and off-farm activities, etc. Most parents in Benin are aware of the schooling benefits and enroll their children in school.

Regression-based methods have been increasingly used to assess the economic impact of adopting agricultural innovations. The target response indicator is regressed upon the adoption status variable and a set of socio-economic characteristics and environmental covariates. More recent works recognize causality issues and refine the regression methods to correct for self-selection or simultaneity biases (Fernandez-Cornejo et al., 2002; Bravo-Ureta et al. 2006). The two-stage approach is often applied to correct for self-selection and simultaneity, using predicted probabilities of adoption as instruments for the adoption decisions variable in the response equation. Some studies on the other hand included inverse Mills' ratios estimated from Heckman's two stage method, together with predicted probabilities of adoption, to control for simultaneity and self-selectivity biases (McBride and El-Osta, 2002). These studies assume inappropriately that adoption has the same effect for all adopters (Blundell and Dias, 2002). As farmers are heterogeneous in socio-economic characteristics, it is appropriate to assume that the impact magnitude of adopting agricultural innovations will vary among them. Exceptions are the studies by Adekambi et al. (2009) and Agboh-Noameshie et al. (2007) which estimate the impact of NERICA adoption on income and expenditure, respectively using the local average treatment effect (LATE) to correct for the endogeneity of the adoption variable and take into account the heterogeneity of the impact. Impact studies of new technologies adoption that correct for endogeneity of the adoption variable ignore that this variable could interact with unobserved heterogeneity which is in consequence generally correlated with it (Wooldridge, 2007b). Because producers self-select into adoption status based on their own unobserved gain from storage innovation adoption and in addition this gain is correlated with the adoption variable, the standard instrumental variable approach becomes inappropriate to estimate the impact of adoption (Heckman et al. 2006; Wooldridge, 2007b).

Control function and LATE approaches are commonly used to estimate binary treatment models, where responses are heterogeneous and individuals self-select into treatment based on their own unobserved gain (Imbens and Angrist, 1994; Vella and Verbeek, 1999; Wooldridge, 2002: 625-633; Wooldridge, 2007b). A control function approach leads to a sample selection model, when it is used to compute an average adoption impact of schooling expenditure on adopters (Wooldridge, 2002, p. 630). Moreover, LATE estimates average adoption impact of potential adopters which is an unidentified subpopulation and depends greatly on the instruments used (Wooldridge, 2002, p. 605).

This chapter uses a correction function approach applied to a binary treatment effect model (Wooldridge, 2007b) to investigate the (heterogeneous) effect of improved storage technologies on schooling expenditures. It is assumed that impacts of storage innovations adoption on schooling expenditure vary and adopters are self-selected based on the unobserved schooling expenditure gain they expected from the adoption. Accordingly, this chapter fills an important gap in the literature on impact assessment of agricultural innovation adoption in using the treatment effect framework and allowing for the heterogeneity of the impacts of adoption. This chapter therefore adds to the literature by providing an empirical analysis of the causal effect of storage innovations adoption on household schooling expenditures. The correction function approach developed by Wooldridge (2007b) is used to compute the average relative impact of maize storage innovation adoption on schooling expenditure of adopters. In the literature on treatment effects analysis the link to economic theory is often obscure (Heckman and Vytlacil, 2005). The selection of covariates for the expenditures model is therefore partly based on the economic framework of demand for schooling under imperfect capital markets as developed by Arleen Leibowit (Haveman and

Wolfe, 1995). The estimation model is based on a cross-section survey of maize producers in southern Benin. Data on schooling expenditure, socio-economic characteristics of households and schooling supply-factors were collected. Results show that, when determinants of demand for schooling are controlled for, adopters of storage innovations spend on average more on their children's schooling than non-adopters did. The treatment effect model applied ensures that this is a causal effect.

The chapter is laid out as follows: The next section provides an overview of the development and promotion of storage innovations in southern Benin (see also Adegbola and Gardebroek, 2007). The primary schooling system in Benin is described in section 3. Section 4 presents the conceptual framework and econometric models, whereas the estimation method is described in section 5. The survey data and the characteristics of the sample are outlined in section 6. Section 7 presents and discusses the estimation results. Conclusions and implications are given in the last section.

5.2 Development and promotion of storage innovations in southern Benin

Research and dissemination of improved wooden granaries and Sofagrain® started in Benin in 1992 with a project funded by the Food and Agricultural Organization (FAO). Research has concentrated on the improvement of the local maize granary that farmers considered to be the most effective against pests. Hence, the improved wooden granary made from bamboo or mallotus has been designed and promoted. The project also recommended a combination of Actellic with K-othrine or Sofagrain® as chemical control of pest damage during maize storage in the improved wooden granary. Since control using Sofagrain® is easiest, this has been largely disseminated. The construction cost of the improved wooden depends on its capacity and the type of building materials. Moreover, irrespective of the capacity of the granary, the construction costs of improved wooden granaries are higher than those of traditional granaries. For example, building an improved wooden granary of a capacity of 3700 Kg costs US$73.32[4] while the building of a traditional granary of the same capacity costs US$ 63.71 (Arouna, 2002, p. 69). In other respects, application of Sofagrain® to protect stored maize costs US$ 6 to US$ 9 per ton of maize. Using Sofagrain® to protect stored maize costs about 4 to 6 times than protecting stored maize with farmer's methods. Despite the high

[4] US$ value of 2003

construction costs of the improved wooden granary and the high application costs of Sofagrain®, it is more profitable to store maize with the storage innovations than the traditional storage technologies. For example, storing maize in the improved wooden granary of a capacity of 3700 kg and protect it with Sofagrain® yields a net profit of US$60.06 per ton while the profit from the use of traditional wooden granary of the same capacity and application of traditional protection method is only US$34.36 per ton (Arouna, 2002, p. 90).

As a follow up of the FAO's project a second post-harvest project started in 1997 within the Agricultural Development Program (PADSA) supported by the Danish International Development Agency (DANIDA). Field demonstrations and trials were conducted to improve the visibility of the storage innovations. Moreover an extension component was included in the projects to increase the effectiveness of the post-harvest research. These projects have been implemented within the governmental agricultural research and extension services. Furthermore some Non Government Organizations (NGOs) have been involved in promotion of the storage innovations. Table 5.1 reports for each year the adoption rates among farmers who are aware of improved wooden granaries and Sofagrain® from 1992 to 2001.

Table 5. 1 Evolution of percent of users of storage innovations within farmers who are aware of these innovations

	Year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Improved wooden granary and Sofagrain®	0.33	0.66	1.32	1.66	6.95	8.28	14.90	24.50	33.44	38.41
Improved wooden granary	1.02	1.02	1.84	2.45	7.14	9.59	15.92	27.55	37.35	44.49
Sofagrain®	8.22	10.53	12.17	13.16	16.78	21.71	30.26	36.51	44.74	48.03

5.3 General features of primary schooling system

Since this study assesses the impact of adoption of improved storage systems on household schooling expenditures, this section provides some background on general developments in the primary schooling system of Benin. The government adopted in 1998 an educational policy framework which emphasized universal completion of primary education and improvements in quality. On average 6.82% of pupils attend the private primary schools against 93.18% for the public primary schools in Benin. The sizes of primary schools vary from 255 to 307 for the public schools and from 145 to 224 for the private schools in southern Benin. The average pupil/teacher ratios for the whole country were 65.4 and 33.6 for the public and the private primary schools, respectively in 2002. Enrollment rates in primary school in rural areas were 86 % for boys and 64 % for girls. But only 39% of boys and 14% of girls completed primary school education in rural areas (DSRP, 2002). Primary school fees were initially abolished for rural girls for the 1993-94 school year and then for all in 2000. These decisions resulted in an expansion of public education that created an under-provision of education. School facilities were inadequately staffed, lacking funds, and suffered from poor infrastructure. Consequently, in addition to the direct costs of schooling generally consisting of tuition, books, uniforms, and transportation costs, households contribute to the financing of primary education by paying for community teachers and building classrooms (World Bank, 2004, p. 35). The estimated share of the household budget devoted to the education of the children varies from 0.86% to 7.1% in southern Benin (MDR, 2000). Because of the ineffectiveness of previous measures, the new government again announced in 2006, free primary education with a view to establishing “universal primary education” and meeting the Millennium Development Goals target of universal access by 2015. However, the implementation of the plan is hampered by limited resources (lack of funds, substantial proportion of unqualified teachers, lack of classrooms etc.). Public investment does not rise sufficiently fast to cover the additional expenditures caused by the sudden increase of enrolment rates in public primary education. In 2003 when the data used in this chapter were collected, schooling expenditure consisted generally of tuition, books, uniforms, and transportation costs.

5.4 Conceptual framework

This section presents the theoretical framework used to assess the impact of adopting maize storage innovations. The appropriate method to evaluate the impact of adopting improved storage innovations is to compare expenditures on schooling by adopters with their counterfactuals in the absence of adoption. Several methods are developed to assess counterfactuals, drawing on the impact evaluation literature.[5] The framework used in this

[5] More comprehensive and detailed surveys can be found in Blundell and Costa Dias (2000), Wooldridge (2002) and Lee (2005).

study is based on the "potential outcomes framework", which was first developed by Rubin (1974).

To outline the "potential outcomes framework", in more formal terms, let Y_i be the observed expenditure in children's schooling for a maize producer i, who either does or does not adopt a storage innovation. In addition, let A_i be the observed adoption decision of storage innovations and define $A_i = 1$ if a farmer adopted any storage innovation and $A_i = 0$ if he did not. Furthermore, assuming that the intercept of the schooling expenditure equation depends on observed and unobserved factors, and using the conventional regression notation, the schooling expenditure Y_i, can be written as

$$Y_i = \lambda + \gamma x_i + \beta A_i + \varepsilon_i \qquad E\left(\varepsilon_i \middle| \lambda, \gamma, \beta, x_i, A_i\right) = 0 \tag{1}$$

where λ, γ and β are unknown parameters to be estimated, x_i are explanatory variables and ε_i is error term. β is the average causal impact of A on Y across all observational units (ATE).

Drawing from the literature on the determinants of demand for schooling, expenditures on children's schooling is a function of household income, a set of household specific characteristics and school-supply factors (Haveman and Wolfe, 1995; Tansel, 1997; Holmes, 2003). Many of these factors also influence the adoption of storage innovations (Adegbola and Gardebroek, 2007). The common factors must be controlled for otherwise we may wrongly conclude that there is a causal relation between the adoption of storage innovations and expenditures on schooling. Some unobservable factors, such as time preference, individual or childhood household characteristics, ability, motivation etc. may influence the adoption of storage innovations as well as expenditures on schooling. In such cases, the effects of adoption of storage innovations on primary schooling expenditures cannot be interpreted causally. For instance, an individual's unobserved preferences for the future can affect the likelihood of both adopting an improved wooden granary and schooling of children with current costs and benefits that are harvested in the future. Individuals with higher preferences for the future are more likely to adopt and to spend on children's schooling, since parents traditionally expect children to provide for them in old age through remittances, which is one of their reasons for being concerned about their children's wealth or income (Glick and

Sahn, 2000; Holmes, 2003). Therefore, with unobserved preferences for the future, we might observe that adopters of improved wooden granary spent more on their children's schooling and vice versa, even if adoption of storage innovations did not play any direct role in children schooling expenditures. Similarly some farmers have an inherent ability to be more likely to adopt storage innovations as well as to invest more in their children schooling**.** This ability might be neither specifically reported in the data nor proxied by any of the reported variables. This may arise if the data do not reflect unobserved farmer skills, or initial beliefs of investing in storage innovation and children schooling. The adoption and schooling expenditure decisions are then both partially determined by the unobserved ability. Consequently due to unobserved ability, high schooling expenditure can be observed with adopters of storage innovations and vice versa even when adoption of storage innovations did not have any direct effect with children schooling expenditures. These examples of effect of unobserved factors indicate the potential endogeneity of the adoption decisions variable in the schooling expenditure equation which causes biases in all the estimated coefficients. The consistent estimation of equation (1) requires A_i to be instrumented such that unobserved heterogeneity is mean independent from the instruments once the observed factors are controlled for.

In this study, we also assume that the impact of adoption of storage innovations on schooling expenditure is heterogeneous. To take this hypothesis into account some interaction terms of a subset of demeaned explanatory variables x with the dummy adoption variable A_i are included in the model. The impact of adopting storage innovations on schooling expenditure (β) in Eq. (1) is accordingly written in equation (2) as a function of the demeaned explanatory variables x and unobserved heterogeneity (v).

$$\beta = \alpha + (x_i - \bar{x})\delta + v_i \qquad E(v_i \mid x_i) = 0 \qquad (2)$$

where $\bar{x}$ is a vector of sample means of x.

Substituting the value of β given by equation (2) into equation (1) yields the specification of the estimation model as

$$Y_i = \lambda + x_i \ \gamma + \alpha \ A_i + A_i \left(x_i - \bar{x}\right) \delta + A_i \ v_i + \ \varepsilon_i \qquad (3)$$

In addition, specifying equation (3) with the interactions of A_i with the demeaned covariates x instead of x ensures that the coefficient α is the unconditional average estimate of the population adoption effect on the schooling investment. The parameter vector δ measures the respective partial effects of the covariates x on the schooling investment holding adoption constant. Consequently, in addition to estimating α, one can estimate the average adoption effect for any value of x in the elements of δ because the average adoption effect on the schooling investment conditional on x is

$$E(\beta \mid x) = \alpha + (x_i - \bar{x})\delta \qquad (4)$$

Identification of the impact of adopting storage innovations on schooling expenditure, using a standard instrumental variable estimation strategy, hinges on the presence of $A_i v_i$ in the composite error $\left(A_i v_i + \varepsilon_i\right)$ of equation (3). A farmer's decision to adopt a storage innovation is determined by the positive net expected utility resulting from the difference between expected utilities of adopting and rejecting (Dimara and Skuras, 2003). In other words, based on their own unobserved gain v_i, the exogenous variables x, farmers 'select' themselves to adopt the storage innovations, resulting in correlation between $A_i v_i$ and z. The conditional expected value of $A_i v_i$ given (x, z) can be written as follows.

$$E\left(A_i v_i | x_i z\right) = E\left(v_i | A_i = 1, z\right) \Pr\left(A_i = 1 | z\right) \neq 0 \qquad (5)$$

The first term in equation (5) is not zero since farmers adopt storage innovations based on own unobserved gains v_i (Heckman et al. 2006). Therefore the expected value of $A_i v_i$ given (x, z) is not zero.

Because farmers 'select' themselves to adopt the storage innovations, based on their own unobserved gain, a standard instrumental variable approach cannot identify the impact parameter. However, assuming the restrictions of exogeneity and exclusion of the vector x and vector z in the school expenditures equation and using a standard probit model to estimate the probability of adoption, Wooldridge (2007b) showed that

$$E\left(A_i v_i \mid x_i z_i\right) = \phi_i\left(\theta_0 + x_i\,\theta_1 + z_i\,\theta_2\right) \tag{6}$$

where $\phi_i(\cdot)$ is the standard probability density function and the correction function.

Equation (3) can therefore be rewritten as

$$Y_i = \lambda + x_i\,\gamma + \alpha\,A_i + A_i\left(x_i - \bar{x}\right)\delta + \rho\phi_i\left(\hat{\theta}_0 + x_i\hat{\theta}_1 + z_i\hat{\theta}_2\right) + \varepsilon_i \tag{7}$$

Adding the correction function to the estimating equation does not produce an estimating equation in which A_i and $A_i\left(x_i - \bar{x}\right)$ are exogenous. Instrumental variables are still needed for the terms involving A_i in equation (7) to correct for the omitted variable bias that plagues the usual IV estimator. A consistent estimate of α, the unconditional average causal impact of A on Y (ATE) is therefore obtained using the standard instrumental approach to estimate equation (7). Following Wooldridge (2007b), the natural instrumental variables are

$$\left[1, x_i, z_i, x_{i1}x_i, \ldots, x_{ik}x_i, z_{i1}x_i, \ldots, z_{iL}x_i, \hat{\phi}_i\right]$$

or the smaller set

$$\left[1, x_i, \hat{\Phi}_i, \hat{\Phi}_i \cdot \left(x_i - \bar{x}\right), \hat{\phi}_i\right] \tag{8}$$

where $\hat{\Phi}_i$ is the predicted probabilities of the probit estimation of A_i on $(1, x_i, z_i)$ and the $\hat{\phi}_i$ the estimated standard probability density function or correction function. A drawback to the latter set of instruments is that it just identifies the parameters of equation (7), and so there are no overidentifying restrictions to test. Typically, using the former set of variables would generate testable overidentifying restrictions. Plus, recent work by Hahn et al. (2003) suggests that estimators from just identified equations can behave poorly if the instruments are weak. The statistical significance level of $\hat{\phi}_i$ allows ones to determine whether individual farmer based their adoption decision on unobserved expenditure in schooling gain and whether this unobserved heterogeneity interacts with the adoption variable. According to Heckman et al. (2006), statistical dependence of v_i and A_i cannot be settled a priori and one must assume for such dependence in model estimation.

5.5 Model estimation

Based on the conceptual model, this section describes the implementation of the empirical strategy used in this chapter to assess the impact of adopting storage innovations on households' schooling expenditure.

Following Wooldridge (2007b), the model of the heterogeneous impact of storage innovation adoption on schooling expenditure, specified in (7) is estimated in two stages. The first stage consists of estimating a probit model of factors that influence the likelihood of adopting a storage innovation upon exogenous covariates x and z. The exogenous variables x are common for adoption and expenditures equations while the exogenous covariates z belong solely to the adoption equation. These exclusion and exogeneity restrictions of the variables z are determinant for the estimation of schooling expenditures model to be convincing. The first stage yields the correction function which is here the standard normal density $\phi(\cdot)$ and also suggests a set of instruments for A_i in the expenditure model. Then in the second stage the standard normal density $\phi(\cdot)$ and the suggested instruments from the first stage are used to estimate the schooling expenditure model. The specification of the first stage model and details on the explanatory variables included are presented in Adegbola and Gardebroek (2007). The intensity of an individual's attitude towards an innovation is a major determinant of his anticipated adoption behavior (Lemon, 1973). The attitude of a decision-maker towards an innovation depends on his valuations of the set of characteristics of that innovation (Wossink et al. 1997). Studies show that in addition to farmers' socio-economic characteristics and institutional factors, farmers' perception of attributes of technologies play an important role in explaining whether and how they adopt the technology (Adesina and Zinnah, 1993; Negatu and Parikh, 1999; Batz et al. 2003; Llewellyn et al. 2004). Therefore, farmers' perceptions of characteristics of the storage innovation are potential instrumental variables z that satisfy the restrictions of exogeneity and exclusion which can be included in the adoption equation along with other exogenous variables x. Prior to this study, farmers were asked to evaluate the storage innovations during an adoption study of storage innovations. Exposure to storage innovations provided the sample farmers with opportunities to evaluate the improved wooden granary and Sofagrain®. In the survey questionnaire of adoption, separate lists of granary and conservation measure characteristics derived from focus group meetings were presented to all respondents. They were asked to compare for each characteristic, the storage innovations with their current storage technologies. Consequently, each perception variable relating to technology characteristics was defined as a dummy variable that equals 1 if the farmer perceived the storage technological innovations as better than the current technologies and 0 otherwise. The technology characteristics included in the estimation model of adoption as instruments in addition to exogenous variables are as follows: farmers' own perceptions of the storage innovations of the ease of use, investment costs and efficiency against pests. Probability density functions derived from the first stage estimation provide the input for estimation of the second stage (Eq. 7). In other respects, a large literature on child labor argues that schooling and child labor decisions are jointly determined (Huffman and Orazem, 2007: 2329-2330; Edmonds, 2008, p. 3640). So, the same observed and unobserved factors simultaneously influence both schooling expenditures and child work decisions. Hence, child labor is an endogenous variable in the schooling expenditure equation. To insure the independence between the error term of the schooling expenditure equation and the child labor, this variable should be instrumented. Hence a probit model is estimated to determine factors that influence the likelihood of children to work on farms. Hypotheses on the effects of the variables in the child labor equation can be formulated on the basis of the literature. Studies show that correlation between land and child labor could be either negative or positive (Bhalotra and Heady, 2003; Beegle et al., 2006). Beegle et al. (2006) find a positive and significant relationship between the level of household assets and the use of child labor. Higher permanent income level and higher parental education are associated with less child labor (Kruger, 2007, p. 409, 461). Edmonds (2008: 3698) argues that credit constraints force families to make child labor decisions without fully considering future returns to education. Hence, access to credit might reduce the extent of child labor (Beegle et al., 2006). Participation in child labor is instrumented by using the value of household asset holdings, encompassing houses, motorbikes, bicycles and radios.

Next, the impact model of adopting maize storage innovation was estimated using the generalized method of moments (GMM), where an efficient weighting matrix accounts for heteroskedasticity of unknown form. Schooling expenditure in Equation (7) is represented by its logarithmic value. In addition to the adoption decisions variable included in the model, other explanatory variables incorporated in the estimation model were selected on the basis of literature on determinants of demand for schooling and on the specification of covariates required to ensure the identification of causal effects in an impact assessment framework (e.g. Lee, 2005, p. 31; White and Chalack, 2006). It was hypothesized that expenditure for schooling by a given household depended on family-background characteristics and on school-supply factors at the community level. Studies on the influence of these factors on expenditure for schooling are numerous (see e.g. Haverman and Wolf, 1995 for an overview). The variables included in the model to control for variation in expenditure for schooling between adopters and non adopters caused by variation in family-background characteristics, farmer's village characteristics and school-supply factors are as follows. A variable relative to children's participation in household farm activities was included to account for its effect on schooling expenditure. Indeed, Ray (2003) observes that an increase of one hour in the weekly wage work for children in Ghana, leads to more than one year less completed educational attainment. Nankhuni and Findeis (2004) report that time for collection wood for fuel in Malawi is associated with reduced schooling participation. Kruger (2007, p. 461) argues that boys who live in rural areas are more likely to work and less likely to attend school than urban counterparts. However, Ravallion and Wodon (2000) argue that child labor and schooling are not mutually exclusive outcomes. Hence, in a context of modest agricultural demand for child labor, the time spent in school may not be affected. But if agricultural employment opportunities improve and child wages or returns to child time in agriculture increase, then children will likely work more and attend school less (Huffman and Orazem, 2007: 2329-2330). In other respects, since changes in labor earnings have income and substitution effects, it is difficult to predict the direction of the correlation between child labor and schooling (Kruger, 2007, p. 409). It could be either negative (due to the substitution of time away from school activities to labor) or positive due to the additional income derived from work and that make schooling affordable (especially in poor families).

Household consumption increases over the life cycle of the head of a household. Schooling expenditure is also expected to follow the same pattern, reaching its highest level around upper-middle age of the household head. It is therefore expected that schooling expenditure will increase with the age of household head (Kim and Lee, 2001), hence it is assumed to have a positive effect on schooling expenditure.

It is often stated that females care more about children and males more about consumption and investment in goods. E.g. Pillon (1995) finds that female headed households spend more on schooling for their children than male headed households. Male headed households are therefore assumed to spend less on schooling than female headed households. Thus the dummy variable for gender of household head (1 for male and 0 for female) is expected to have a negative sign.

Parents can spend on their children's schooling from current income, savings, selling assets or through borrowing. Poor households may not be able to afford the costs of schooling and do not have easy access to credit to cover the costs. Studies show that parental income is an important direct positive determinant of expenditures for children's schooling, especially when capital markets are inefficient (Haverman and Wolf, 1995; Glick and Sahn, 2000; Tansel and Bircan, 2006). Therefore, children's schooling expenditure is assumed to increase with household level of income per adult equivalent.

Human capital literature emphasizes that per capita human expenditures decline as household size increases (Haveman and Wolfe, 1995). In addition, in every developing country household size has been found to be an important determinant of youth enrollment in school (Connelly and Zheng, 2003). Tansel and Bircan (2006) find that an increase in the number of children in the household reduced the private tutoring expenditures. In contrast it is assumed in this chapter that an increase in number of school aged children will raise the schooling expenditures. Therefore, the variable household size is expected to have a positive influence on schooling expenditure.

Literature on school demand argues that parents' education is a predictor of household potential market earnings. Moreover, male household heads devoted more resources to children human capital than they would do when their wives were not educated (Holmes, 2003). Studies find that children schooling attendance and the amount of schooling expenditure depend on the education level of the household heads and their spouse (Mabika and Dimbuene, 2002; Tansel and Bircan, 2006). The education level of the household heads is therefore assumed to be positively associated with the schooling expenditure.

The variable average distance to schools is included in the model to approximate the price of schooling. Time and transportation costs associated with attending school rise with the distance to school and increase the expenditures for schooling (Holmes, 2003; Connelly and Zheng, 2003).

Kruger (2007, p. 461) shows that children who live in remote areas with lower accessibility are less likely to attend school. Hence, access to the village throughout the year is assumed to have a negative effect on the schooling expenditures.

The variable distance from village to communal county town is included in the model to capture the effects of migration opportunities expected in an urban center and modernizing effects on demand for schooling (Orazem and King, 2008: 3495). Tansel (2002) finds that the distances to cities have negative and statistically significant effects on schooling decisions. In other hand, Fafchamps and Wahba (2006) argue that children are more likely to attend school as household specialization increases with urban proximity. Thus, this variable could have either a positive or negative effect on children schooling expenditures.

Godoy et al. (2005) report that the returns to education in rural Bolivia are higher among households who live close to market towns due to off-farm opportunities. Thus, it is assumed that the expenditures for schooling will decrease as the distance from village to the main market rises.

Brown and Park (2002) have shown that, children in rural families with severe credit constraints are less likely to be enrolled in schools. Edmonds (2008, p. 3679) finds that, the pension income given to elder males in South Africa declines their hours worked and increases school attendance to nearly 100 percent for rural boys. Moreover, he argues that, inability to afford schooling is the primary reason why children are not in school prior to receipt of anticipated income. He concludes that credit constraints for elder men reduce school enrollment in South Africa. The variable access to credit is included to account for the constraint of credit and its coefficient is assumed to be positive.

Problems may arise in estimation if some explanatory variables are highly correlated. Consequently, partial correlation coefficients were checked for all variables included in the model. The highest partial correlation coefficients were found between children's participation in household farm activities and distance from village to the main market (0.509) and between household size and household level of income (-0.384). In addition the variables distance from village to the main market and access to the village throughout the year those were expected to have some correlation only have a partial correlation coefficient of -0.042. Similarly the variables average distance to schools and access to the village throughout the year have a partial correlation coefficient of 0.141. Based on these partial correlation coefficients it is assumed that there is no multicollinearity problem in estimation.

In order to test the assumption that the impact of innovations adoption on schooling expenditure is heterogeneous within the sample farmers, demeaned values of some of the above variables interact with the adoption of storage innovations dummy variable. Heterogeneity of impact is evaluated through a Wald-test used to test the null hypothesis that all interaction terms are jointly equal to zero. Coefficients for interaction variables measure to what extent the impact of storage innovations adoption on schooling expenditure differs among adopters. Differences among farmers for average distance to schools, access to credit and age of household head are too substantial to rely on their shift parameters alone. Interaction terms of demeaned variables with the adoption variable were included in the model. The impact of adopting storage innovations on schooling expenditure is assumed to be larger for the adopters who live closer to a primary school and experience credit constraints than those who do not. In other respects the impact of adopting storage innovations on schooling expenditure is hypothesized to be smaller for the younger adopters than the older.

Finally to consistently estimate the schooling expenditure Eq. (7), the adoption decisions variable, the three interaction terms and the variable relative to participation of children in farm activities are instrumented. The vector of instruments is chosen to generate testable overidentifying restrictions and to avoid a possible poorly behavior of the estimators resulting from weakness of instruments in just identified equations (Hahn et al. 2003). For these reasons and based on the first set of instruments in Eq. (8) suggested by Wooldridge (2007b), the following vector of instruments are used in the GMM estimation of Eq. (7). First, the vectors of the three characteristics of perceptions, z_i along with interactions of z_i with the demeaned covariates x_i are used as instruments. Secondly, the covariates x_i and interaction of x_i with one another are also included as instrumental variables. Finally the probability density functions estimated from the adoption-decision models $\hat{\phi}_i$ and 1 are used as instruments in the schooling expenditure model. To avoid multicollinearity problems in estimation, partial correlation coefficients were checked for these instrumental variables. Those with highest partial correlation coefficients were dropped from the model.

Under self-selection, adopters will benefit more from storage innovations than would a randomly selected individual who appears at first sight to have the same characteristics (Maddala, 1983, p. 261). Accordingly, the impact of adopting the storage innovations on schooling expenditure of adopters is calculated in this study (Blundell and Dias, 2002). Moreover, because β in Eq. (2) is a function of an unobserved heterogeneity**,** the impact of adopting the storage innovations cannot be estimated for any particular adopter. Therefore the average impact of adopting the storage innovations on the schooling expenditure of adopters $\left(ATE_1\right)$ is estimated. Estimated parameters $\hat{\alpha}$ and $\hat{\delta}$ along with the demeaned covariates x_i which interact with the adoption variable are used to estimate the conditional average adoption impact on schooling expenditure $ATE\left(x\right)$ over the data set. Averaging $ATE\left(x\right)$ over observations with $A_i = 1$ gives a consistent estimation of ATE_1.

5.6 Data

The data were obtained from surveys conducted since 2001 on the socio-economic evaluation of post-harvest innovations in Benin within the framework of the Agricultural Development Program (PADSA). Data used for this study were collected between March and May 2003 in 26 villages located in rural provinces of southern Benin where maize storage innovations were introduced since 1992. Selected villages were either involved in maize storage innovations on-farms trials or were surrounding them. Data were obtained using a two-phase process. In the first stage, data collection dealt with farmers' perceptions of impact of adopting maize storage innovations. Next, structured questionnaires were designed and administered to individual maize producers to collect detailed farm-level data. A random sample of 306 maize producers was surveyed in this second step. All observations with missing or incomplete data were excluded from the analysis. In addition, we discarded households who did not have children in schooling ages at the time of the interviews. Thus the final data set for the analysis of impact encompassed a total of 267 observations and contained 95 non-adopters of maize storage innovations and 172 who adopted between 1997 and 2001 at least one of these innovations. The estimation model consists of two dependent variables: adoption and schooling expenditure. The adoption variable indicated whether the farmer adopted or rejected at least one maize storage innovation. Schooling expenditure measured the total amount of money which the household devoted to children's primary schooling during the survey year. As stated in section 5.3, children's schooling expenditures include generally tuition, books, uniforms, and transportation costs. Definition, sample means and standard deviations for the dependent and explanatory variables of the schooling expenditure equation are computed for adopters and non-adopters of storage innovations and reported in Table 5.2.

Table 5. 1 Definition and sample means for model variables of schooling expenditure equation (standard deviation in parentheses).

Description	Unit	Non adoption $(A_i=0)$	Adoption $(A_i=1)$	T-test statistic
Primary schooling expenditure	Fcfa by household	20243.43 (22438.75)	37223.26 (52511.96)	-3.002***
Children's participation in household farm activities	1 if children participate in the household farm activities; 0 otherwise	0.916 (0.279)	0.733 (0.444)	3.643***
Age of the household head	Years	41.084 (13.243)	41.366 (11.156)	-0.185
Sex of the household head	1 for male household headed; 0 otherwise	0.895 (0.308)	0.785 (0.412)	2.270**
Household income per adult equivalent	Fcfa per adult eq.	126995.3 (117206.2)	155901 (216062.2)	-1.208
Household size	Adult-equivalent	7.874 (5.153)	7.669 (5.111)	0.313
Education level of the household head	1 if the farmer received a formal education; 0 otherwise	0.242 (0.430)	0.314 (0.465)	-1.240
Average distance to schools	Km	2.789 (3.716)	1.982 (2.707)	2.035**
Access to the village throughout the year	1 if the village is accessible throughout the year; 0 otherwise	0.547 (0.5)	0.465 (0.5)	1.286
Distance from village to communal county town	Km	10.03 (5.33)	10.085 (6.269)	-0.073
Distance from village to the main market	Km	4.631 (2.973)	3.587 (3.141)	2.650***
Access to credit	1 if household head has access to credit; 0 otherwise	0.358 (0.482)	0.343 (0.476)	0.243
Adoption*Average distance across schools available	-	0	-0.076 (0.713)	1.044
Adoption*Access to credit	-	0	0.011 (0.425)	-0.252
Adoption* Age of the household head	-	0	0.814 (10.184)	-0.778
Number of observations		95	172	

Note: Primary schooling expenditure is in 2003 FCFA (FCFA 1= US$ 0.002 in 2003). T-test statistic is for equality of the two means, except for the variable Primary schooling expenditure for which the one-tailed test is performed. *=P < 0.1, **=P < 0.05, and ***=P < 0.01.

Descriptive statistics show that farmers who adopted storage innovations spent on average more on their children's schooling than did non-adopters (p-value = 0.003). Furthermore, the two-tailed tests on the differences in means of the explanatory variables for adopters and non-adopters showed that adopters of storage innovations in this sample were more often females (p = 0.024), on average are closer both to primary schools (p = 0.043) and markets (p = 0.008) than non-adopters and used on average less child labor in household farm activities than non-adopters (p = 0.000). Therefore it can be suspected that differences in schooling expenditure reflect at least partly the farmers' sex, distances to primary schools and markets, and the use of child labor in the household farm activities. To correct for these differences, the impact of adoption on schooling expenditure is controlled for by the household head's sex, distances to both primary schools and markets and the use of child labor in the household farm activities, and other possible determinants of schooling expenditure. Definition and descriptive statistics of the explanatory variables included in the model of the adoption of storage innovations is presented in Table 5A. 1 of Appendix 5A.

5.7 Estimation results and discussion

This section reports and discusses the results of the GMM model for the impact of adopting storage innovations on schooling expenditures of adopters (Eq. (7)). Because the first stage regression, the reduced probit model of maize storage innovations adoption, is estimated to yield the correction function and getting instrument variables for the schooling expenditure model, its results are presented only in Table 5.1 of the appendix and are not discussed in the chapter. This section is laid out as follows. Next, the reliability of the results is discussed as well as the factors that influence schooling expenditure. Then the estimated impact of adoption of storage innovation on schooling expenditure of adopters is presented and discussed.

5.7.1 Goodness-of-fit of the GMM model and determinants of schooling expenditures

Estimates and test statistics of the GMM estimation model are presented in Table 5.3. An interesting result was that the correction term coefficient, in other words the probability density function coefficient was significant (p=0.062). This indicates that, in this study, the adoption variable and farmers' own unobserved schooling expenditure gains from adopting the storage innovations are not statistically independent and hence correlated. However the endogeneity of the adoption dummy variable or the self-selection of farmers to the status of adopters is still to be corrected. This result implies that the standard instrumental variable approach was not appropriate to control for the self-selection bias in estimation of the causal effect of adopting the storage innovations on schooling expenditure of adopters. But this could not be anticipated. The variables used to instrument the adoption variable and its interaction terms are based on the first set of variables in Eq. 8. The use of this set of instruments and the exclusion of some of them because of the problem of multicollinearity lead to 25 excluded instruments. Moreover, the variable children participation in farm activities is instrumented with household assets. Consequently, 26 excluded instruments are used to instrument five endogenous variables. Tests on relevance and validity of the instruments used to correct for self-selection bias are next provided. First, the relevance of the instruments was tested using the canonical correlation test. The canonical correlation likelihood ratio statistic was 54.752, which exceeded the 1% critical value of 40.289 for a Chi-Squared distribution with 22 degrees of freedom. This implies that the null hypothesis that the instruments are irrelevant to identify the schooling expenditure equation should be rejected. Next, the statistical independence of the instruments from the error term was tested by the Hansen overidentification test. The Hansen J statistic value, at a significance level of 1% and 21 degrees of freedom was 20.575, which is smaller than the critical Chi-square level of 35.479. This indicates that we cannot reject the null hypothesis that the instruments are uncorrelated with the error term. The model is then correctly specified. In addition, the C-statistic was used to test whether the three perception variables (ease of use, required investment costs and efficiency against pests) and the value of household assets are valid instruments in the schooling expenditure model. The test statistic value at a significance level of 1% and 4 degrees of freedom was 5.638. The critical value of the C-statistic test at a 1% significance level and 4 degrees of freedom was 13.277. The data are therefore consistent with the joint validity of 4 moment conditions. These statistical tests results imply that the correlation between adoption of storage innovations and schooling expenditures is a causal relationship. By correcting for self-selection bias, this study is consistent with some recent works on impact of adoption of new agricultural technologies (Fernandez-Cornejo et al., 2002; McBride and El-Osta, 2002; Bravo-Ureta et al., 2006).

Table 5. 3 Estimation results for the GMM model of average effect on children schooling expenditure of improved maize storage innovations adoption.

Parameter	Estimate	Robust S. Error	
CONSTANT	-25.115***	7.549	
Adoption of improved wooden granary or Sofagrain®	2.189**	1.086	
Children's participation in household farm activities	-3.026***	1.083	
Age of the household head[1]	7.658***	2.181	
Sex of the household head	0.494	0.896	
Household income per adult equivalent	0.375	0.265	
Household size	0.102*	0.058	
Education level of the household head	0.17	0.764	
Average distance to schools[1]	0.454	0.585	
Access to the village throughout the year	0.103	0.679	
Distance from village to communal county town[1]	-1.53***	0.533	
Distance from village to the main market[1]	0.977*	0.547	
Access to credit	-4.186**	1.482	
Adoption*Average distance to schools	-2.244	1.428	
Adoption* Age of the household head	-0.335***	0.1	
Adoption*Access to credit	7.386***	2.492	
Correction function (Probability density function)	5.229*	2.803	
Average adoption effect on a random farmer (ATE)	1.819 (0.273)***		
Average adoption effect on adopters (ATE1)	1.874 (0.336)***		
T-test for equality of ATE and ATE1	-1.904*		
F-statistic (slopes=0)	F(16, 249)=7.21		
Wald test for joint significance of coefficients of the interacted terms: (all interaction terms=0)	25.72	$\chi 2$ (3)	P-value=0.000
No. of observations	266		
Anderson canon. Corr. LR statistic	54.752	$\chi 2$ (22)	P-value=0.000
Hansen overidentification test	20.575	$\chi 2$ (21)	P-value=0.485
C statistic	5.638	$\chi 2$ (4)	P-value=0.228

Note: The dependent variable is (log) children schooling expenditure. In addition, the variables with superscript ([1]) are in logarithm form. *=P < 0.1, **=P < 0.05, and ***=P < 0.01. Value in parentheses for ATE1 is standard error.

Estimation results showed that the coefficients of ten out of sixteen variables included in the model were significantly different from zero at 10% critical level at least. This indicates that the inclusion of these variables in the model was correctly justified in explaining the schooling expenditures and strongly supports the hypotheses stated in section 5.5. Moreover an F test was performed to test whether all the parameters were jointly equal to zero. At a significance level of 1%, this hypothesis was rejected. The uncentered R^2 for the model was 0.527, indicating that the variables in the model explain satisfactorily the schooling expenditures. However the estimated parameters of some variables such as distance from village to the main market and access to credit had the unexpected signs. The estimated parameters for the variables dealing respectively with the income per adult and the average distance to schools had the expected signs but were not statistically significant. The insignificance of income was surprising because the cost of schooling remains a major barrier to school attendance in Benin, especially for the poorest that live to a large extent in rural areas (World Bank, 2003, p. 73). In other respects, findings from Core Welfare Indicators Questionnaire (CWIQ) surveys in Benin show that just 2 percent of children do not attend school because of distance (World Bank, 2003, p. 138). This might explain the insignificance of the average distance across schools available to the household in the model. As expected, the estimated coefficient of age of household head is positive and significantly different from zero at the 1% critical level. The estimated coefficients of distance from village to communal county town and children's participation in household farm activities have negative signs and are both significantly different from zero at the 1% critical level. The negative sign of distance from village to communal county is similar to the results of Tansel (2002). Proximity of a communal county town provides migration opportunities to children and affects negatively the demand for schooling. The negative sign of children participation in farm activities shows a substitution effect of child time away from school activities to labor in farms and suggests that the returns to child time in agriculture in the study area are high (Huffman and Orazem 2007, p. 2329). Participation of children in farm activities is often reported in rural areas of Benin as the most common reason for children to not attending school (World Bank, 2003, p. 76).

5.7.2 Results of GMM estimation for the storage adoption impact on schooling expenditures

Two implications can be drawn from the estimation results presented above. First, there are direct effects on schooling expenditure of some common family background characteristics and schooling supply-factors. This means that the observed impact of adopting storage innovations can be wrongly ascribed to confounding family characteristics and schooling supply factors that affect the schooling expenditure. This evidence supports the assumption in section 5.3, that relation between adoption of storage innovations and schooling expenditure will not be a causal one if we do not control for these common factors. Second, after controlling for family background and village characteristics, and schooling supply factors, the adoption of storage innovations variable is related to schooling expenditure (p=0.044).

The unconditional average impact of adopting storage innovations on schooling expenditure of a randomly selected farmer was 2.189 and significantly different from zero at 5% critical level (Table 5.3). In other words for a randomly selected adopter of a storage innovation in the sample, the relative expected schooling expenditure differential is approximately 219%. Two of the interaction terms are significantly different from zero at 1% critical level (Table 5.3). A Wald test for joint insignificance of the 3 interaction terms was performed to test whether the impact of adopting storage innovations on schooling expenditure did not vary among maize producers. At the 1% critical level, this hypothesis was firmly rejected. The variables distance to primary school, access to credit and age of household head determined together the variation in impact of adopting storage innovations on schooling expenditure. The impact of adopting storage innovations is lower by 224.39% for the farmers who are located farther to their children schools than farmers who are living nearer to the schools. Similarly the impact value is higher for the young household heads than the older by approximately 33.55%. The highest difference of impact is between farmers with and without access to credit. The expected estimated average adoption effect of storage innovations on the schooling expenditure of a randomly selected farmer, conditional on these three variables was 181.88% and significantly different from zero at 1% critical level (Table 5.3). In other hand, the average impact of adopting storage innovations on schooling expenditures of adopting households was 187.46% and significantly different from zero at 1% critical level. In other words, compared with the non-adopters of the storage innovations, schooling expenditure of adopters increases by about 187.46%. In other respects, the average impact on schooling expenditure of adopters (187.46%) are slightly higher than the average impact on a randomly selected farmer (181.88%) and significantly different from zero at 10% critical level (Table 5.3). This implies that farmers self-selected in adoption status based on the gain or utility they expected from the adoption of a storage innovation. These results confirm the descriptive statistics in Table 2 which indicate that schooling expenditure for adopters increases on average by 84% compared to the non adopters without controlling for the confounding factors. The magnitudes of impact may not be seen too high because the difference in average schooling expenditure between adopters and no adopters were already 84% and the amounts of money spent for primary schooling of children are relatively small. The results are consistent with the findings of our farmer participatory impact assessment of storage innovations. Farmers reported during focus group discussions, that schooling expenditure constitutes one of the uses of extra income derived from adopting storage innovations. This result was not surprising. Parents are aware of future benefits from investments in children's schooling and accordingly pay for the direct costs of schooling from the available resources. In addition, although the primary school fees were abolished for all in 2000, parents have to contribute to the financing of primary education by paying for study materials, community teachers and building classrooms. Maize is the main source of income for 50% of the farmers in the sample and represented 40% of their household income; hence an increase in maize income through adoption of storage innovations affects agricultural household consumptions. The findings are also consistent with those of Adekambi et al. (2009) who estimate a local average treatment effect (LATE) and show that adoption of NERICA, a new variety of rice has significantly improved household expenditure.

5.8 Conclusions

Since the Millennium Development Goals were declared, policy makers and donors have increased their interest in the impact of agricultural innovations on poor people's wellbeing. This chapter provides an ex post assessment of the impact of adopting storage innovations on schooling expenditure. The challenge in this study was to show whether changes in expenditure for schooling can be attributed to the adoption of storage innovations. A counterfactual framework was applied to deal with this attribution problem. Moreover, unlike the previous studies, self-selection of producers into adoption status and statistical dependence between the adoption variable and unobserved gain from adoption storage innovation were assumed in this study. In addition, heterogeneity of impact of adoption storage innovation was hypothesized. A correction function approach was therefore used to compute the relative average impact of adopting maize storage innovations on schooling expenditure of the adopters. The results of this study depart from recent works on adoption impact of new agricultural technologies by the use of the correction function approach to assess the impact of adoption on a welfare outcome taking into account the heterogeneity of the effect. Hence, it fills important gaps in the literature on impact assessment of agricultural innovation adoption. Findings show that children participation in farming activities affects schooling expenditure negatively and this result is consistent with previous studies. Surprisingly, neither household income nor distance to school is significant but have the positive expected signs. Estimation results show that the coefficient of the correction function is not statistically different from zero. Hence, the adoption variable is not correlated with the unobserved gain of adoption of storage innovations and the standard IV approach could be appropriately used to estimate the causal effect of adoption on schooling expenditure. However the independence between adoption variable and unobserved gain from adoption could not be anticipated. Statistical tests indicate also that the instruments used in the model of schooling expenditure are relevant and independent from the error term. The causal effect of adoption of storage innovations on schooling expenditure is approximately 219% for a randomly selected farmer. However the causal effect of adoption varies among sample maize farmers. This variation is related to the distance to schooling, age of the household head and access to credit of sample farmers. Conditional on these three variables, the estimated causal effect of adoption of storage innovation is approximately 182% while the impact of adoption of storage innovations on schooling expenditure of adopters is about 187%. This latter magnitude of impact is not much higher than the average difference of 84% resulting from the comparison of the means of schooling expenditure of adopters and non adopters of storage innovations. This finding suggests that the correction function estimates of the effect of adoption on schooling expenditure produce a satisfactorily association between adoption and schooling expenditure compare to correlation contained in the raw data. The difference in magnitude may be attributed to the control of confounding factors. Moreover, because the conditional impact of adoption on schooling expenditure of adopters are higher than that of randomly selected farmers, confirms that farmers self-selected in adoption status based on the expected gain from adoption. These results are consistent with farmers' own declarations during focus group discussions on how they used the extra income derived from adopting storage innovations and on the share of income derived from maize sales in the total annual income of the agricultural household. Regardless of how they are interpreted, our results do demonstrate that adopters of storage innovations increase their schooling expenditures compared to non-adopters. Therefore policies that address constraints of adoption of storage innovations such as access to credit and availability of Sofagrain® might be developed. There are several important avenues for future research. Firstly, more studies that use the potential outcome framework and correct for self-selection in adoption status and potential statistical correlation between unobserved gain and adoption variable are needed. Different approaches of treatment effects estimators such as matching methods, control function, local average treatment effect (LATE) and the marginal treatment effect (MTE) could also be used and the results of different approaches compared. Secondly, because impact of adopting agricultural innovations on farmer welfare is a major concern to policy-makers and donors, studies may go beyond the usual effect on income and focus on the poverty indicators such as schooling and health expenditures, food security and nutrition status. This will give a precise contribution of agriculture to the fulfillment of the Millennium Development Goals. Thirdly, treatment effect estimators may be extended to panel data using for example the model of the composite causal effect for time-varying treatments.

Appendix 5A

Table 5A. 1 Definition and sample means for model variables of adoption of maize storage innovations equation (standard deviation in parentheses).

Description	Unit	Non adoption $(A_i = 0)$	Adoption $(A_i = 1)$	T-test statistic
Children's participation in household farm activities	1 if children participate in the household farm activities; 0 otherwise	0.925 (0.264)	0.740 (0.440)	3.943***
Age of the household head	Years	39.745 (13.362)	41.186 (11.174)	-0.976
Sex of the household head	1 for male household headed; 0 otherwise	0.897 (0.305)	0.791 (0.408)	2.329**
Household income per adult equivalent	Fcfa per adult eq.	137354.1 (123093.1)	155662.7 (213440.2)	-0.809
Household size	Adult-equivalent	7.327 (5.111)	7.565 (5.079)	-0.381
Education level of the household head	1 if the farmer received a formal education; 0 otherwise	0.271 (0.446)	0.316 (0.466)	-0.807
Average distance to schools	Km	2.832 (3.651)	2 (2.697)	2.198**
Access to the village throughout the year	1 if the village is accessible throughout the year; 0 otherwise	0.533 (0.501)	0.469 (0.5)	1.040
Distance from village to communal county town	Km	9.817 (5.339)	10.077 (6.225)	-0.359
Distance from village to the main market	Km	4.757 (3.288)	3.698 (3.373)	2.589***
Access to credit	1 if household head has access to credit; 0 otherwise	0.327 (0.471)	0.350 (0.478)	-0.398
Contact with extension and/or research agents	1 if the farmer had contact with extension or research agents; 0 otherwise	0.720 (0.451)	0.915 (0.279)	-4.514***
Membership in farmers' co-operative or association	1 if the farmer is a member of farmers cooperative; 0 otherwise.	0.542 (0.5)	0.763 (0.427)	-3.953***
Quantity of maize produced	Kilograms	2043.766 (1481.397)	1992.09 (1561.225)	0.275
Availability of family labor	Man-equivalent	5.344 (3.425)	4.78 (2.88)	1.487
Availability of the conservation product or granaries' building materials	1 if Sofagrain®/ granaries' building materials are available in the village; 0 otherwise	0.112 (0.317)	0.158 (0.366)	-1.079
Perception of investment cost of storage technologies	1 if the investment cost of a storage innovation is lower than that of the farmer's technology; 0 otherwise	0.103 (0.305)	0.198 (0.427)	-2.01**
Perception of effectiveness of storage technologies against pests	1 if a storage innovation is more effective than the farmer's; 0 otherwise	0.71 (0.456)	0.93 (0.252)	-5.281***
Perception of ease of use of storage technologies	1 if storage innovation is easier to use than the farmer's technology; 0 otherwise	0.383 (0.488)	0.644 (0.48)	-4.408***
Number of observations		107	177	

*=P < 0.1, **=P < 0.05, and ***=P < 0.01.

Table 5A. 2 Estimation results for the reduced probit model of maize storage innovations adoption.

Parameter	Estimate	Robust St. Error
CONSTANT	-4.782***	1.842
Children's participation in household farm activities	-0.444	0.319
Age of the household head[1]	0.372	0.35
Sex of the household head	0.555*	0.3
Household income per adult equivalent	0.11	0.082
Household size	0.029	0.025
Education level of the household head	0.095	0.209
Average distance to schools[1]	0.07	0.112
Access to the village throughout the year	-0.343*	0.185
Distance from village to communal county town[1]	0.02	0.123
Distance from village to the main market[1]	-0.346**	0.166
Access to credit	-0.152	0.207
Contact with extension and/or research agents	1.332***	0.257
Membership in farmers' co-operative or association	0.672***	0.206
Quantity of maize produced[1]	0.203*	0.119
Availability of family labor	-0.079*	0.041
Availability of the conservation product or granaries' building materials	0.597*	0.317
Perception of investment cost of storage technologies (COSTT)	0.461*	0.248
Perception of effectiveness of storage technologies against pests (EFPE)	0.747***	0.264
Perception of ease of use of storage technologies (FACULT)	0.578***	0.188
Pseudo -R^2 0.282		
Logpseudolikelihood -134.992	Wald $\chi 2$ (19)=78.56	P-value = 0.000
Number of observations 284		
Correct predictions	Overall: 76.76% Adopters: 85.31% Non-adopters: 62.62%	
Wald test for joint insignificance of coefficients of the instruments: (COSTT=EFPE=FACULT=0)	Wald $\chi 2$ (3)=22.54	P-value = 0.000

Note: The variables with superscript ([1]) are in logarithm forms. *=P < 0.1, **=P < 0.05, and ***=P < 0.01.

CHAPTER 6

ONE STEP FORWARD, ONE STEP BACK? WHAT DROVE ABANDONMENT OF MAIZE STORAGE INNOVATIONS IN SOUTHERN BENIN?[1]

Abstract

This study uses a conditional maximum likelihood fixed effects logit model and two-period panel data for the years 2002 and 2008 to understand the dynamics of adoption of maize storage innovations in southern Benin. Adoption of maize storage innovations plays a critically important role in food security and household income in this region. However high proportions of earlier adopters of the improved storage systems abandoned their use by 2008. High initial costs were reported by most of farmers as one of the major reasons to abandon the storage innovations. Major results are that farmers who live in villages with improved access throughout the year, and who have less family labor available are likely to abandon the use of the storage innovations. Moreover, for the two storage innovations, different factors are found to be important in explaining adoption and abandonment.

JEL classification: C 35, D99, O33; Q16
Key words: Maize; Storage Innovations; Abandonment; Southern Benin.

[1] Paper by Patrice Ygue Adegbola and Cornelis Gardebroek submitted to *World Development*.

6.1 Introduction

Adoption of new and better technologies is considered to be an important driver of economic growth. In developing countries poor rural households often can improve their livelihoods by adopting promising new or improved farm technologies such as improved seeds, small water saving systems, better food storage facilities or simply better quality farm tools. This is also reflected in the numerous efforts by agricultural research centers, non-governmental organizations (NGOs) and government agencies to develop new agricultural technologies and to stimulate farmers to adopt them. The multitude of programs promoting new technologies also led to a large number of economic studies trying to find the determining factors behind farmers' technology adoption. See Feder et al. (1985) for an early review and Doss (2006) for a recent critical assessment of decades of adoption studies. A typical adoption study uses cross-sectional data on adopters and non-adopters to estimate a binary choice equation with adoption as the dependent (binary) variable and a set of socio-economic characteristics such as age, education level, access to credit, etc., as explanatory variables (see e.g. Adegbola and Gardebroek, 2007). Use of cross-sectional data implies that these adoption studies are of a static nature. As a consequence, it often cannot be investigated whether adoption sustains in the long run or whether recent adopters abandon the new technologies again after some time. It is therefore not surprising that abandonment of recently introduced technologies is hardly addressed in the (economic) literature[2]. Another explanation for the lack of focus on this issue could be that researchers rather prefer to explain successes (of adoption) instead of failures (abandonment of adoption). Nevertheless, in order to address the impact of adopting new technologies on household livelihoods it is crucial to know whether these technologies remain to be used and, if not so, why technologies that brought a promise of progress are abandoned.

Although abandonment of recently introduced technologies by individual households seems to be a failure, this is not necessarily the case. Indeed farmers may stop using a new technology because it turned out that it does not meet their needs, because operational costs are too high, because they have negative experience with the technology, or because incentives to adopt provided by extension programs have disappeared. But abandonment of a technology after some years may also be natural given a change in circumstances of

[2] This chapter focuses explicitly on abandonment of recently introduced new technologies that at the time of abandonment by some farmers are still adopted by others. We realise that all technologies at a certain point become outdated and are replaced by a new and better alternatives. However, those are not considered in this chapter.

households. For example, households may have changed their production plan so that particular improved seeds or a storage technology for a specific crop are not necessary anymore. In other words, there is a variety of reasons for discontinuing the use of recently introduced technologies. Section two gives a detailed overview of reasons for abandoning recently adopted technologies based on a review of previous studies on technology abandonment.

In this chapter we focus on adoption and abandonment of maize storage technologies in southern Benin. Maize is staple food in southern Benin and the harvested maize is usually stored for later consumption or sale. However, in the humid tropical climate in this region, stored maize is prone to decay and pest attacks, leading to substantial losses. According to Helbig (1995), with the introduction of the larger grain borer, 7 to 30% of maize harvested is destroyed by pests after 6 to 8 months of storage indicating that pest damage is a serious constraint for food security and household income. To reduce storage problems, improved storage structures (granaries) and chemical conservation products (e.g. Sofagrain®[3]) introduced in the region since 1992 have been proven to be effective in reducing pest damage in stored maize. In recent years many farmers have adopted these innovations and factors that influence adoption and modifications decisions have been studied (Maboudou et al., 2004; Adegbola and Gardebroek, 2007)**.** However, in a follow up survey performed for this study it was found that about 56% of the farmers who had adopted the improved wooden granary in 2002 and that were surveyed again in 2008 had abandoned it by 2008. Similarly for Sofagrain® even 73% out of the 212 adopters in 2002 had abandoned it by 2008. That these high rates of abandonment are not due to replacement of these technologies by newer variant is reflected by the fact that in 2008 there were still new adopters of both technologies. Adegbola and Gardebroek (2007) have indicated that lack of access to specific credit and limited availability of Sofagrain® constrain adoption of these storage innovations and these factors may as well cause abandonment after initial adoption. Moreover, also for these technologies the initial promotion projects provided additional incentives for adoption to farmers. Removal of these incentives could also be a reason for abandonment.

The objective of this study is to investigate the changes in the adoption of improved maize storage systems in southern Benin. This includes changes from non-adoption to

[3] The symbol ® stands for 'Registered trade mark'. Sofagrain is an insecticide protectant constituted of 0.2% Delmethrin and 1.5% Pyrimiphos-Methyl. It's used to control pests in stored grains, notably cereals and leguminous.

adoption, but also changes from adoption to abandonment. It is analyzed which *changes* in key variables lead to changes in adoption status, identifying which kind of maize producers are likely to discontinue the use of the storage innovations in southern Benin.

To achieve this objective a panel data set with observations in 2002 and 2008 is analyzed using a conditional maximum likelihood (CML) fixed effects logit model. The advantage of this approach is that unobserved farmer heterogeneity is controlled for and that changes in adoption status instead of observed adoption status quos are analyzed. Focusing explicitly on this issue the chapter differs from previous research on dynamics of adoption of agricultural innovations using panel data (e.g. Cameron, 1999; Barham et al., 2004). Major results are that farmers who live in villages with improved access throughout the year, and who have less family labor available are likely to abandon the use of the storage innovations. Moreover, for the two storage innovations, different factors are found to be important in explaining adoption and abandonment.

The remainder of this chapter is organized as follows. The next section gives a literature review of previous studies that focused on technology abandonment and based on this a conceptual framework for analyzing determinants of changes in adoption status is developed in the third section. In the fourth section, the empirical model used to analyze the dynamics of adoption behavior is specified. The panel data used and some of its descriptive statistics are presented in the fifth section. The estimation results are presented and discussed in section six and the chapter ends with some concluding remarks.

6.2 Reasons for technology abandonment: a review of existing literature

Since many technology adoption studies use the classic work of Rogers as a reference, it is good to start our review of literature on technology abandonment with this source. Rogers (2003:190-192) reviews some early literature on abandonment, some showing substantial rates of abandonment next to adoption at the same time, and he gives two reasons for abandonment: replacement and disenchantment. Replacement is due to the arrival of a new and better technology. Disenchantment may be due to inappropriateness of the innovation for the individual, not perceiving its benefits, misuse, or lack of financial means to further maintain the innovation. Interestingly, Rogers (2003:190-191) also cites literature that shows that late adopters abandon innovations more often than early adopters. High rates of abandonment are characterized by less formal education, lower socioeconomic status, and less contact with extension agents.

Whereas Rogers pays some limited attention to technology abandonment, the often cited review chapter on technology adoption in developing countries by Feder et al. (1985) is silent on this issue. Nevertheless, there are a few other studies that explicitly analyzed technology abandonment.

Dinar and Yaron (1992) investigate adoption and abandonment of irrigation technologies in Israel. They estimate aggregate diffusion curves, where diffusion of innovations can also decrease due to abandonment. These authors assume that abandonment happens because new and better technologies are introduced that replaced the 'old' technologies they investigated. Boys et al. (2007) also consider abandonment at an aggregate level by analyzing S-curves of adoption of improved cowpea varieties and cowpea storage technologies in Senegal.

Neill and Lee (2001) model adoption and abandonment of sustainable maize production practices in Honduras using a bivariate probit model. Their survey carried out in 1997 indicated that 45% of the respondents had abandoned the sustainable practices that used to be considered as a success story. From their regression analysis they find that low quantity of maize produced, quality of infrastructure and having an off-farm job led to abandonment of the sustainable maize production practices. Although they model both adoption and abandonment simultaneously, a drawback of their study is that it is based on cross-sectional data that does not enable to investigate why a specific farmer that adopted before, abandons later. In other words their study gives insight in characteristics of disadopters, but does not indicate which changes in key variables induced abandonment of the technology at a certain point in time.

A study related to the one by Neill and Lee (2001) is by Moser and Barrett (2006) who investigate adoption, expanded use and disadoption of a high-yielding low input rice production method in Madagascar. On average 40% of the respondents abandoned the technology at some point in time. They also use cross-sectional data, combined with recall questions in order to construct a so-called quasi-panel (Besley and Case, 1993). Following Neill and Lee they analyze abandonment by a simple probit model, so without taking any farm specific effects into account and not considering *changes* in key variables. They find that abandonment of the investigated technologies is related to lack of available labor, experience with the technology, having off-farm income, small areas planted with rice and observed abandonment by other farmers.

A study that uses panel data is by Barham et al. (2004) who analyze adoption and abandonment of the 'politicized' (Barham, 1996) technology rBST, a genetically engineered milk production enhancing growth hormone. Their study is not only interesting because of the controversial nature of the technology investigated, which suggests that farmers' attitudes and perceptions should play a big role in adoption decisions, but also because of the methodology used. Besides a multinomial model to analyze behavior of different groups of farmers, the study also uses a random effects panel logit model to investigate adoption and non-adoption. This model uses both within and between variation of the data to explain observed adoption status in different years. A drawback of this model, which is also realized by the authors, is that the model is easily prone to endogeneity bias. Nevertheless, they find that herd size, use of a complementary technology and antibiotech attitude are important explanations for (non-) adoption of this technology. Abandonment is rather low in their data, with less than 10% of the farmers who previously adopted, abandoning in some later years.

6.3 Conceptual framework

The literature review in the previous section showed that there are a number of factors that seem to be universal in explaining technology abandonment: production level or output quantity, experiences with the technology that might change perceptions or attitudes towards the technology, presence of infrastructure, use of a complementary technology, replacement by a new technology, and having off-farm income. The last factor basically has two effects. A farmer working off-farm may have less labor available to be used with the technology. But having an off-farm job he may also be less interested in obtaining a good farm income.

These findings from the literature are in line with the adoption–perception paradigm. At a given point in time producers will select an innovation that is consistent with their needs, socio-economic status and attitudes toward it (Guerin, 1999). A change in the attitudes of producers toward an innovation is a prerequisite for behavioral change (Guerin, 1999). Therefore if farmers perceive a storage innovation to be inferior to their traditional storage technology in terms of one or several characteristics, they are unlikely to adopt or to continue using such a storage innovation. Furthermore, the technological characteristics that are relevant at a time to farmers may not be so in the future (Kshirsagar et al., 2002). For instance, Oladele (2005) finds that attitude towards improved cowpea varieties significantly affects farmers' discontinuance of using them. Moreover farmers can adjust their perceptions of storage innovations attributes based on learning by doing, observation from neighbors or a process of cognitive dissonance (Llewellyn et al., 2004). This is also reflected in the following equation:

$$E_{it}\left[FI_{it}^{1}(x_{it})-FI_{it}^{0}(x_{it})\mid\Omega_{it}\right] \quad (1)$$

where E_{it} indicates that at time t farmer i forms expectations on the difference between individual farm income with the technology (FI_{it}^{1}) and the farm income without the new technology (FI_{it}^{0}). Individual farm income can be a function of a number of variables x, e.g. available labor and other inputs, presence of infrastructure and markets nearby, prices, etc. Very important in forming expectations is the information farmer i has at time t, summarized by Ω_{it}. This may be information from extension agents, colleagues, but also information the farmer may have collected while using the new technology already. This information is updated over time, just as the socio-economic circumstances of the farmer, leading to a renewed assessment on the need for the innovation. For example, Oladele (2005) finds that the lack of extension visits to farmers who have adopted improved varieties of maize lead to the discontinuance of these new technologies. What is important in this framework is that farmers vary in observed characteristics, but that they also differ in unobserved characteristics. The latter will be explicitly taken into account in specifying the empirical model and choice of the estimation method.

6.4 Empirical framework

The conceptual framework described in the previous section is naturally translated into a binary choice framework, just like many previous studies on adoption and abandonment. Note however that in our framework we explicitly pay attention to unobserved farm household heterogeneity, i.e. unobserved differences in farm households. Also note that the estimation method that is used to empirically analyze adoption and abandonment, the conditional maximum likelihood fixed effects logit model, explicitly uses *changes* in model variables. This section describes this estimation approach and the included model variables.

Fixed Effects Logit model

Assume that the expected difference in farm income with and without the technology and conditional on available information as given in equation (1) is a linear function of its determinants leading to the following model specification:

$$y_{it}^{*} = x_{it}^{'}\beta_{t} + \mu_{i} + \varepsilon_{it} \qquad i = 1, ..., N;\; t = 1, ..., T \tag{2}$$

$$y_{it} = 1(y_{it}^{*} \geq 0)$$

where $1(A)$ is the indicator function which is equal to 1 if A is true and 0 otherwise. The index i represents the producer and index t represents time; $x_{it}^{'}$ is a vector of factors that influence the individual farm income and the expectation formation process including a constant term, $\beta_{t} \in \Re^{k}$ represents a vector of parameters to be estimated, μ_{i} is an unobserved farm-specific effect capturing heterogeneity in adoption/abandonment decision making and ε_{it} is a vector of remainder error terms. Instead of observing $(y_{it}^{*}, x_{it}^{'})^{'}$ one observes $(y_{it}, x_{it}^{'})^{'}$ where y_{it} is a binary observed outcome and y_{it}^{*} is an unobserved latent variable reflecting the preference for the innovation.

We assume that $x_{i} = [x_{i1}^{'}, x_{i2}^{'}, ..., x_{iT}^{'}]^{'}$ and $\varepsilon_{i} = [\varepsilon_{i1}^{'}, \varepsilon_{i2}^{'}, ..., \varepsilon_{iT}^{'}]^{'}$ are independent. The mutually independent disturbances ε_{it} are assumed to follow logistic distribution with mean zero and variance σ^{2}.

Let $Y_{it} = 1$ denote the decision of a producer i to adopt the new technology in time period t. The probability of adoption is then given by:

$$\Pr\left(Y_{it}=1\middle|x_{it}^{'},\mu_i\right)=\Pr\left(y_{it}^{*}\geq 0\middle|x_{it}^{'},\mu_i\right)=\Pr\left(\varepsilon_{it}\geq -x_{it}^{'}\beta_t-\mu_i\middle|x_{it}^{'},\mu_i\right)=F\left(x_{it}^{'}\beta_t+\mu_i\right) \qquad (3)$$

where $\Pr\left(Y_{it}\middle|x_{it}^{'},\mu_i\right)$ is a conditional density while $F\left(x_{it}^{'}\beta_t+\mu_i\right)$ defines the logistic functional form and emphasizes the vectors of parameters to be estimated. By treating μ_i as a fixed effect implies that each μ_i becomes an unknown parameter.

Specification of equation (3) shows that the estimator for β_t is also a function of *n* unknowns unit-specific parameters μ_i. This is the incidental parameters problem because the number of parameters increases with the number of individuals. In the fixed-effects linear model the estimation of the parameters was made possible by a transformation of the data to deviations from group means which eliminated the unit-specific constants μ_i. In the non-linear specification (3) such a transformation is not possible. An alternative solution enables estimation however. Although $F\left(x_{it}^{'}\beta_t+\mu_i\right)$ is a function of μ_i, $F\left(x_{it}^{'}\beta_t+\overline{Y}_i\right)$ is not a function of μ_i (Greene, 2008, p. 803). This latter expression is used to enable estimation of the parameters β_t. In this expression, $\overline{Y}_i$ is a minimal sufficient statistic for μ_i. Estimation of equation (3) requires, for a fixed number of time periods *T* and sample size *N*, the existence of such a sufficient statistic for μ_i, which depends upon the functional form of *F* (Verbeek, 2003, p. 337; Greene, 2008, p. 803). If a sufficient statistic for μ_i exists, then conditional upon *T*, an individual's likelihood contribution no longer depends upon μ_i, but only upon the parameters β_t to be estimated. The sufficient statistic for μ_i does exist for the fixed effects logit model and it is the mean $\overline{Y}_i$. Thus estimates from this model are consistent for fixed *T*. The fixed effects logit model is therefore used in this study and allows us also to look at determinants of changes in the adoption status of storage innovations.

Following Greene (2008, p. 803), the fixed-effects logit model corresponding to equation (3) is depicted as:

$$\Pr\left(Y_{it}=1\middle|x_{it},\mu_{\mathrm{i}}\right)=\frac{e^{\mu_i+x_{it}^{'}\beta}}{1+e^{\mu_i+x_{it}^{'}\beta}} \text{ and } \Pr\left(Y_{it}=0\middle|x_{it},\mu_{\mathrm{i}}\right)=\frac{1}{1+e^{\mu_i+x_{it}^{'}\beta}} \qquad (4)$$

The minimum sufficient statistic for μ_i is $\sum_{t=1}^{T} y_{it}$. The conditional likelihood function for balanced panel is:

$$L^c = \prod_{i=1}^{n} \Pr\left(Y_{i1} = y_{i1}, Y_{i2} = y_{i2}, \ldots, Y_{iT} = y_{iT} \;\middle|\; \sum_{t=1}^{T} y_{it} \right) \tag{5}$$

For $T = 2$ only those producers for whom the sum of adoption indicators over T is one contribute to the conditional likelihood function. Therefore only producers who change status are used in estimation, i.e. initial non-adopters that adopted later and early adopters that abandoned the technologies. For the pairs of observations for which the sum is one, that is $y_{i1} = 0$ and $y_{i2} = 1$ or $y_{i1} = 1$ and $y_{i2} = 0$, the conditional probability is respectively

$$\begin{aligned} \Pr\left(y_{i1} = 0, y_{i2} = 1 \;\middle|\; \sum_{t=1}^{T} y_{it} = 1 \right) &= \frac{e^{x_{i2}'\beta}}{e^{x_{i1}'\beta} + e^{x_{i2}'\beta}} \\ \Pr\left(y_{i1} = 1, y_{i2} = 0 \;\middle|\; \sum_{t=1}^{T} y_{it} = 1 \right) &= \frac{e^{x_{i1}'\beta}}{e^{x_{i1}'\beta} + e^{x_{i2}'\beta}} \end{aligned} \tag{6}$$

The product of the terms in (6) for observation sets for which the sum is one yields the conditional likelihood function. The unobserved heterogeneity is removed from the conditional probability and consistent estimation is performed by maximizing the resulting conditional likelihood function by conventional ML methods. Hence, a CML fixed effects logit model is estimated separately for improved wooden granaries and Sofagrain® to analyze the determinants of observed changes in adoption status of these storage innovations.

Included model variables

Since in the fixed effects specification, the slope coefficient β_t are only identified if the corresponding regressors x_{it} vary over time, the variables that change over time are that hypothesized to influence changes in the storage innovations adoption status of producers. Drawing from the reviewed literature and the conceptual model, the time-varying variables assumed to affect the likelihood to abandon the use of storage innovations are the following:

- *Participation in demonstrations and on-farm trials*. Lack of knowledge about storage innovations can limit their adoption in the earlier stage of diffusion. Similarly, lack of knowledge on how to build an improved wooden granary leads to its discontinuance because farmers are not able to reconstruct it themselves. Participation in field days, on-farm trials or visits to adopters of the storage innovations fills the gap in knowledge of farmers about these innovations (Guerin, 1999). Furthermore, Cameron (1999) argues that village-level learning may explain why some farmers are late adopters. Moreover, risk averse farmers can change their attitude towards a storage innovation after participating in demonstrations and on-farm trials and then adopt it. Oladele (2005) finds that the lack of extension visits to farmers who have adopted the improved varieties of maize leads to their discontinuance. He argues that sustained contact with extension reinforces the message and enhances the accuracy of implementation of the new technology. Therefore it is expected that a decline in contact with extension service will lead to abandonment of the two storage innovations.
- *Quantity of maize produced*. Factors such as decreasing family size or climate change can lead farmers to reduce the production of maize while an increase in food prices can incite them to increase their production. A change in maize production also changes the need for maize storage. Some farmers ascribed the discontinuance of the use of the improved wooden granary to the low production of maize. Therefore, it is expected that a substantial decline in the quantity of maize harvested may lead to the abandonment of the storage innovations.
- *Availability of family labor*. Improved wooden granary and Sofagrain® are labor-using innovations. Studies indicated that farmers with limited family size are unlikely to adopt labor intensive innovations (Doss, 2006). Following the life-cycle of a household, we argue that the size of available family labor will vary over time. Furthermore, farmers

reported that they discontinue the use of storage innovations because they require more labor than they can provide. Therefore, any shift in family labor over time is likely to decide farmers to change their adoption status of storage innovations. For example, a decrease in the availability of family labor will lead to abandonment of both storage innovations.

- *Access to the village throughout the year (road condition)*. Road condition affects the decisions to store or sell maize soon after harvesting, through prices and discount rates for the future cash flows (Feder et al., 1985). Several projects are financed during last years to improve road conditions. However because of heavy rains, flood damaged some of the roads. We hypothesize that improvement in road conditions reduces the need for maize storage and therefore lead to abandonment of storage innovations.
- *Availability of Sofagrain® and building materials of granaries*. The factory that produces Sofagrain® closed and this contributes greatly to the discontinuance of the use of the conservation product. About 60% of the farmers mentioned the non-availability of Sofagrain® as the major reason for its disadoption. Similarly the materials recommended for the building of the improved granary became less available because they are over used. The alternative conservation measures such as Spintor powder (spinosad 0.125) and improved wooden granary building materials like *Dchapelium guinensis, Azadirachta indica*, *Hollarrhena floribunda* and *Uvaria chamae* are still unknown to producers.
- *Perception of the length of conservation with storage innovations.* To ensure food security and sell later in the post-harvest season at higher prices, farmers are searching for storage facilities and protection methods which permit storage over long periods of time. Thus, length of the conservation is one of the most important characteristics that farmers use to choose both granaries and protection methods. Therefore if either the improved wooden granary or *Sofagrain®* meets this need of the farmers, then a faster rate of adoption can occur (Guerin, 1999; Rogers, 2003, p. 246). As such, having a negative perception in the length of conservation will lead farmers to abandon the storage innovations.
- *Perception of investment cost of storage innovations.* High costs of adopting a new technology have frequently been mentioned as obstacles to rapid adoption (Martin et al., 1988). A farmer with positive perceptions of other important attributes of improved wooden granary and Sofagrain®, such as effectiveness against pests, but who lacks the required capital to use them will not adopt storage innovations (Kulshreshtha and Brown, 1993). About 50% and 20% of disadopters cited the investment cost as the main reason

for discontinuing the use of improved wooden granary and Sofagrain® respectively (Table 6.2). High construction cost of improved wooden granary may prevent poor resource farmers from replacing it when it is written off. Indeed, the construction cost of a wooden granary depends on its capacity and the type of building materials used. In addition, irrespective of the capacity of the granary, the construction costs of improved wooden granaries are higher than those of traditional granaries. For example building an improved wooden granary of a capacity of 1400 kg costs US$ 51.36[4], while the building cost of the traditional granary of same capacity is US$ 35.46. In other respects, application of Sofagrain® to protect stored maize costs US$ 6 to US$ 9 per ton of maize (Arouna, 2002, p. 69). Using Sofagrain® to protect stored maize costs about 4 to 6 times than protecting stored maize with farmer's methods. Changes in the perceived cost of any storage innovation will therefore lead to adoption or abandonment over time.

- *Perception of the effectiveness of storage innovations against pests*. At a given point in time the intensity of holding a certain attitude towards a technology is a major determinant of anticipated behavior. Moreover, earlier adopters have a more favorable attitude towards new technologies than do late adopters (Rogers, 2003, p. 290). Changing from a negative to a positive attitude towards a new technology can lead a previous non adopter to adopt it later. During the surveys for this study, most of later adopters cited effectiveness of storage innovations against pests as reason to adopt the storage innovations (Table 6.2). A positive change is therefore assumed to positively change the adoption status of the storage innovations, but a negative perceived effectiveness against pests may lead to abandonment.
- *Severity of storage problems felt by the producer*. Empirical studies indicate that perception or awareness of a problem is the first stage in the sequential individual decision making process that leads to adoption of an innovation (Guerin and Guerin, 1994). Current storage innovations adoption status is therefore determined by the present severity of storage problems felt by the producer. In the absence of a storage problem, farmers are likely to abandon the use of the storage innovations.

[4] US$ value of 2003

6.5 Data and descriptive statistics

This section describes the patterns of the adoption of the improved wooden granary and Sofagrain® observed over time in the data and the major reasons mentioned by farmers to change their adoption status. Moreover, the data used to estimate the CML fixed effects logit models for improved wooden granary and Sofagrain® are described. The summary statistics of the variables included in the two models are also presented.

The panel data used in the empirical analysis was derived from two surveys on maize producers in southern Benin. The first survey data were collected in 2002 on a sample of 743 maize producers randomly drawn from 30 villages. From this first survey, the 523 maize producers who were aware of the storage innovations were surveyed again in 2008. From these 523 aware producers, 50 were missing in 2008 so that a balanced panel of 946 observations on 473 producers could be constructed. Table 6.1 gives for each survey year the status of adoption of the farmers who are aware of the improved wooden granary and Sofagrain®, respectively. Based on the use over time of each storage innovation four adoption categories are identified. The never-adopters are the dominant categories accounting for 52% and 47% of the surveyed farmers in 2008 for improved wooden granary and Sofagrain®, respectively. They are farmers who report never having used these two innovations. The next category is that of dis-adopters which represent 22% of the 2008 respondents for granaries and 32% for Sofagrain®. These farmers were not using the storage innovations anymore during the survey of 2008, but they had adopted them in the 2002 survey. Early adopters is the third category accounting for about 17% (granary) and 12% (Sofagrain®) of the sample. These farmers are adopters of the storage innovations in or prior to 2002 and are still using them in 2008. Finally, late adopters represent approximately 9% of the sample for improved wooden granary and Sofagrain®, respectively. They were non-adopters of the storage innovations during the survey of 2002, but they are currently using them.

Table 6. 1 Numbers of farmers aware of storage innovations divided into their adoption status in 2002 and 2008

	Improved wooden granary		Sofagrain®	
	2002	2008	2002	2008
Adopter	**205**	**121**	**229**	**98**
Early adopter	-	81	-	58
Later adopter	-	40	-	40
Missing farmers		19		17
Non adopter	**318**	**352**	**294**	**375**
Never adopter	-	247	-	223
Disadopter	-	105	-	152
Missing farmers	-	31	-	33
Total	**523**	**473***	**523**	**473***

Note: * sum of adopters and non adopters without missing farmers

The dependent variable for each fixed-effects model indicated for each year period whether the respondent adopted or rejected the storage innovation. However, as indicated above in estimating the CML fixed-effects model only the respondents who change adoption status over the two years period are used. Farmers who are currently using a storage innovation, but were not using it at the time of the first survey are referred to as having a positive change. Similarly farmers are considered to have a negative change when they discontinue the use of a storage innovation. For the improved wooden granary, 145 out of the 473 producers changed adoption status between 2002 and 2008. This 145 includes initial non-adopters who had adopted the improved granary by 2008, but also initial adopters who had abandoned the technology by 2008. Therefore 290 of the total 946 observations are used to estimate the fixed-effect model for the improved wooden granary. Similarly, for Sofagrain® 192 producers changed their adoption status so that 384 of the total of 946 observations are used to estimate the fixed-effect model for Sofagrain®.

Table 6.2 reports the main reasons mentioned by farmers for changing their adoption status between the two periods. Two main reasons were raised by farmers to shift from non-adoption to adoption. First, effectiveness of storage innovations against pests convinced 47% and 43% of late adopters to decide to use the improved wooden granary and Sofagrain® respectively. Second, high length of conservation with the storage innovations explains why 26% and 57% of initial non-adopters adopt these two innovations later. Similarly, farmers mention several reasons to explain the abandonment of the storage innovations. The reasons mentioned by most of the farmers to abandon the storage innovations were the high construction cost for the improved wooden granary (49%) and the non availability of

Sofagrain® (61%). The next major reasons were the lack in knowledge on improved wooden construction technique (19%) and the high price of Sofagrain® (19%). Finally, 18% of the respondents report the low quantity of harvested maize as a reason to abandon the use of the improved wooden granary while 12% mention the high labor need to use the Sofagrain® as a reason to disadopt.

Table 6. 2 Percent of respondents by main reason for changing adoption status

Reason for changing adoption status	Improved wooden granary	Sofagrain®
LATE ADOPTER		
Effectiveness of storage innovations against pests	47	43
High length of conservation	26	57
Good quality of stored product	16	-
Have a thorough knowledge on improved wooden construction techniques	8	-
DISADOPTER		
High construction cost of improved wooden granary or Price of Sofagrain®	49	19
Do not have a thorough knowledge on improved wooden construction techniques	19	-
Low quantity of harvested maize	18	3
High labor need	9	12
Non-availability of granaries' building materials and Sofagrain®	4	61
Bad quality of "akassa"	-	6

Note: Akassa is a local maize based meal in Southern Benin.

Table 6.3 provides the definitions and some descriptive statistics of the explanatory variables used in the CML fixed effects logit models. These descriptive statistics are calculated for the farmers who changed their adoption status over the two years period. The significance of the shifts in the explanatory variables required attention, since we are interested in their changing influence over time on the adoption decisions. Simple t-tests were performed to test whether changes in the means of the variables included in the models between the two years are significantly different from zero.

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Table 6. 3 Definition and sample means of variables used in the models of changes in adoption decisions of storage innovations (Standard deviation in parentheses).

Description	Unit	Wooden granary		Sofagrain®	
		2002	2008	2002	2008
Participation in on-farm trials	1 if the farmer participated in farm trials; 0 otherwise	0.558	0.827	0.453	0.755
		(0.498)	(0.379)	(0.499)	(0.431)
Quantity of maize produced	Tons	2000	1962	2139	2682
		(2194)	(3421)	(2266)	(5601)
Availability of family labor	Man-equivalent	4.754	2.503	4.910	2.734
		(3.405)	(1.961)	(3.394)	(2.131)
Access to the village (road condition)	3 for a paved road, 2 for graded road, 1 for ungraded road and 0 for footpath	1.296	2.124	1.593	2.161
		(1.291)	(0.705)	(1.330)	(0.723)
Availability of building materials/ Sofagrain®	1 if granaries'' building materials and Sofagrain® are available in the village; 0 otherwise	0.627	0.868	0.072	0.036
		(0.485)	(0.338)	(0.260)	(0.187)
Perception of the length of conservation	1 if the length of conservation with storage innovations is perceived to be higher than that of the farmer's current technology; 0 otherwise	0.931	0.820	0.864	0.739
		(0.254)	(0.384)	(0.343)	(0.440)
Perception of investment cost	1 if the perceived investment cost of a storage innovation is lower than that of the farmer's technology; 0 otherwise	0.137	0.068	0.067	0.078
		(0.346)	(0.254)	(0.251)	(0.269)
Perception of effectiveness against pests	1 if a storage innovation is perceived to be more effective than the farmer's; 0 otherwise	0.924	0.841	0.734	0.791
		(0.265)	(0.366)	(0.442)	(0.407)
Severity of storage problems	1 for severe maize storage problem; 0 otherwise	0.682	0.855	0.703	0.916
		(0.467)	(0.353)	(0.458)	(0.277)
Number of observations		290		384	

Availability of granary building materials and Sofagrain® and perceived effectiveness against pests are the two variables for which the shifts in the means are significantly different from zero in the improved wooden granary, but insignificant in the Sofagrain®. The significance of the change over time in the means of perceived effectiveness against pests in the improved wooden granary is in accordance with supplementary survey where the effectiveness against pests of this innovation was mentioned by the most of respondent as the reason for its late adoption. However, the insignificant difference in means for availability of Sofagrain® is very surprising because most of the famers reported that the protection method became scarce, which could explain its abandonment. The biggest changes in means of variables over time are observed for the variable availability of family labor and are negative. The next big changes in means of variables are observed for access to the village and perceived length of conservation for improved wooden granary and Sofagrain®. The change in the mean for quantity of maize produced is highly insignificant for the wooden granary (t=0.011), but less insignificant in Sofagrain® (t=1.245). In contrast, perceived costs is highly insignificant (t=0.392) for Sofagrain® but less so for the wooden granary (t=1.934). These results are still somewhat surprising since perceived high cost of the improved wooden granary was cited by about 50% of the disadopters and the high purchase price of Sofagrain® by 19%, as one of the major reason of their abandonment, so one would expect significant differences here. Similarly, the low quantity of harvested maize is the reason cited by 18% of disadopters to explain the abandonment of the improved wooden granary.

6.6 Estimation results

This section reports the results of the fixed effects models for improved wooden granary and Sofagrain® (Eq. (6)). Estimates and test statistics of the CML fixed-effects logit models for improved wooden granary and Sofagrain® are presented in Table 6.4. The values of the Pseudo-R^2 for the fixed effects logit models of the improved wooden granary and Sofagrain® are 0.447 and 0.469 respectively. These values indicate that variables included in each model explain satisfactorily the observed changes in the adoption status of each storage innovation. For each model a likelihood ratio test (LR) (distributed as χ^2 with *k* degrees of freedom) is performed to test the null hypothesis that all slope parameters are equal to zero. The test statistics are 33.58 and 73.33 for the CML fixed effects logit models of the improved wooden granary and Sofagrain®, respectively. These values exceed the 1% critical value of 21.67 for a χ^2 distribution with 9 degrees of freedom, implying that the null hypotheses of all parameters jointly equal to zero are rejected for both granary and Sofagrain® models.

Table 6. 4 Fixed effects logit estimates of changes in adoption status of maize storage innovations.

Parameter	Improved wooden granary		Sofagrain®	
	Estimate	St. Error	Estimate	St. Error
Participation in on-farm trials	0.601*	0.321	-0.463*	0.278
Quantity of maize produced	-0.065	0.061	0.029	0.042
Availability of family labor	0.142**	0.056	0.234***	0.063
Access to the village (road condition)	-0.375***	0.139	-0.400***	0.127
Availability of building mat./Sofagrain®	-0.493	0.364	1.118*	0.656
Perception of the length of conservation	0.438	0.426	1.287***	0.376
Perception of investment cost	-0.358	0.494	0.226	0.489
Perception of effectiveness against pests	0.221	0.423	-0.614*	0.326
Severity of storage problems	-0.540*	0.326	0.250	0.356
LR chi2 (df)	33.58 (9)***		73.33 (9)***	
No. of observations	290		384	
Number of farms	145		192	
Pseudo-R²	0.447		0.469	

*$P < 0.1$, **$P < 0.05$, and ***$P < 0.01$.

Estimation results show that four and six out of nine explanatory variables included respectively in the improved wooden granary and Sofagrain® CML fixed effects logit models, are significantly different from zero. The estimated coefficients of the participation of farmers in on-farms trials and demonstrations are significant in both models. But in contrast to the expectation, a negative sign is registered for in the Sofagrain® model while its mean increased significantly during the two periods. The significance and positive sign in the improved wooden granary model indicates the importance of acquiring knowledge for its use from the extension agents. Thus a lack of knowledge in improved wooden granary construction and utilization will lead to its abandonment. This is in line with the lack in knowledge of improved wooden construction techniques mentioned by 19% of farmers to abandon its use. Quantity of maize produced has no significant effect on adoption or abandonment of one of the two storage technologies. This is a surprising result, since a low quantity of harvested maize was one of the major reasons mentioned by farmers to abandon the use of the storage innovations and the reviewed literature suggested that this was an important variable. The estimated coefficients of availability of family labor are significant but with unexpected positive signs both in the improved wooden granary and Sofagrain® model. This could be an indirect effect. Farm households with much labor available might be more involved in maize production and therefore more often have an improve storage system and vice versa. As expected, the estimated coefficient of road condition is negative and significantly different from zero at the 1% critical level both in improved wooden granary and Sofagrain® models. This suggests that improvement in road condition induces abandonment of storage innovations because farmers can sell their maize easily to the market. Availability of building materials in the village does not matter for adoption of granaries, but availability of Sofagrain® has a significant impact on its adoption. This also implies that non-availability of Sofagrain®, as was indicated by farmer to be a problem, leads to abandonment of it.

Perception variables do not seem to have a significant impact on adoption and abandonment of granaries. This result is different for adoption and abandonment of Sofagrain® however. Here the perceived length of conservation with storage innovations has a significant positive impact on adoption, also implying that if farmers perceive the length of conservation time of Sofagrain® not to be that long, they abandon it. Also the estimated coefficient for perceived effectiveness against pests is significant in Sofagrain® model. However, the negative sign is contrary to our expectations and hard to explain since it suggests that the more effective Sofagrain® is considered to be, the more its use is abandoned. Surprisingly, perceived cost of the storage innovation is not found to be statistically significant in either model, whereas the high construction cost of improved wooden granary and purchase price of Sofagrain® were reported by most of the farmers as reasons to abandon these two storage innovations. Finally, the estimated coefficient of severity of storage problems is negative and significant in the improved wooden granary model (not significant for Sofagrain®), which is counterintuitive. It could be that farmers with continued severe storage problems consider the improved wooden granary not to be more effective and therefore abandon its use. Some farmers also reported that the improved granary becomes ineffective to control pests' attacks when the conservation duration is long and also when the damage is severe.

To provide more insight into the implications of the estimation results, marginal effects were computed. They refer to changes in the probability of change in adoption status of improved maize storage innovations due to changes in the difference of the values of an individual explanatory variable between the two periods. Marginal effects are calculated at the means of the difference in the values of each independent variable between the two periods and given in Table 6.5. The three largest and significant marginal effects are associated with participation in on-farm trials, severity of storage problems and access to the village in the model of the improved wooden granary. For the Sofagrain® model, the three largest and significant marginal effects are associated with perceived conservation length, availability of Sofagrain® and effectiveness against pest damage. These results indicate that for each storage innovation, these three variables affect greatly its abandonment and should be considered in any diffusion policy.

Table 6. 5 Marginal effects of fixed effects logit models for adoption status of maize storage innovations.

Parameter	Improved wooden granary		Sofagrain®	
	Marginal effect	St. Error	Marginal effect	St. Error
Participation in on-farm trials	0.147*	0.078	-0.097	0.067
Quantity of maize produced	-0.016	0.015	0.006	0.009
Availability of family labor	0.035**	0.014	0.051***	0.011
Access to the village (road condition)	-0.094***	0.034	-0.086***	0.032
Availability of building mat./Sofagrain®	-0.122	0.089	0.190*	0.097
Perception of the length of conservation	0.107	0.106	0.301***	0.083
Perception of investment cost	-0.088	0.118	0.046	0.097
Perception of effectiveness against pests	0.055	0.105	-0.123*	0.071
Severity of storage problems	-0.134*	0.081	0.055	0.075

*$P < 0.1$, **$P < 0.05$, and ***$P < 0.01$.

6.7 Conclusions

This chapter uses two-period panel data from maize producers in southern Benin for the years 2002 and 2008 to analyze the dynamics of adoption and abandonment decisions of storage innovations. Adoption of storage innovations is key to food security and household income in southern Benin where farmers experience serious pest damage of maize in storage. Improved wooden granaries and Sofagrain®, an insecticide protectant, have been promoted since 1992. However their abandonment has been registered after a widespread adoption. The results of the surveys undertaken for this study show that 56% and 73% of the farmers who were in 2002 adopters of the improved wooden granary and Sofagrain®, respectively and visited again in 2008 had abandoned them. Most of the disadopters reported the high construction cost to abandon the improved wooden granary and the non availability of Sofagrain® to abandon its use. The next major reasons that were mentioned were the lack in knowledge on the improved wooden construction technique and the high price of Sofagrain®. Another potential important reason not reported by farmers is the incentive provided by the project to allow construction of the improved wooden granary. They cannot afford the replacement of the improved wooden granary constructed with the help of the project.

A CML fixed-effects logit model is used to capture the changing influence of characteristics of farmers and technologies on the adoption decisions over time. The analysis provides useful insights regarding the explanations for abandoning either the improved wooden granary or the insecticide protectant Sofagrain®. Indeed the estimation results indicate that farmers living in villages with good access throughout the year, who have fewer family labor, who do not participate in on-farms trials and demonstrations have a higher probability to abandon the use of the improved wooden granary. On the other hand, farmers living in villages with improved road conditions, farmers who are short of family labor, and those who perceived that it becomes difficult to store over a long periods of time with Sofagrain® are likely to abandon its use. An important reason for abandonment of Sofagrain® is also non-availability. Several implications can be drawn from these results. First, the insecticide protectant, Sofagrain® should be supplied again or an alternative method of protection of stored grains should be found. Secondly, because farmers living in communities with better road access are likely to abandon the storage innovations, the promotion efforts of extension service could benefit from tailoring efforts toward remote rural areas. Thirdly, better access to credit will allow farmers to hire labor for improved wooden granary construction. Lastly, these results also imply that special attention should be paid to training of farmers and their participation in on-farms trials and demonstrations in order to provide them with the required skills and knowledge on improved wooden granary and Sofagrain®.

CHAPTER 7

CONCLUSIONS AND DISCUSSION

7.1 Introduction

Pest damage during storage is a serious constraint to food security and incomes of households in sub Saharan Africa. Insects cause both losses in grain weight and quality (Stathersa et al., 2002). The main reason is that in many countries production is harvested in the wet season, when it is difficult to dry grain properly. Traditional post harvest systems are often not equipped to dry and store large quantities properly. These losses can be reduced through new drying and pest management systems (Goletti and Wolff, 1999). In southern Benin, the high content of the air moisture and the temperatures varying between 22°C and 33°C are very favorable to insect pests and mould proliferation. Therefore, drying and storing grains such as maize is a major challenge. The damage rates of maize after six month of storage are estimated at 10 to 15% for maize from the second raining season and over 25 to 30% for maize from the first raining season (Fiagan, 1994). To control pest damage in stored maize, a package of complementary innovations of improved wooden granary and Sofagrain® was designed and introduced in 1992. On-farm trials have indicated that after six months of storage, the losses were reduced from 30% to only 5% for maize treated with Sofagrain® and stored in an improved wooden granary (PADSA, 2000). Although the storage innovations were shown to be effective against pests and the many years of storage innovations research and diffusion in southern Benin, there remains a dearth of empirical information on their impacts. It is important to understand by whom, how and when the storage innovations are used and what their impact is (Doss, 2006). Such information is essential to researchers and the national agricultural extension service to measure the persistence of the adoption process and the social relevance of the storage innovations.

The objective of this study is therefore, to analyze the adoption patterns of the maize storage innovations promoted in southern Benin since 1992 and assess the impact of their adoption on the well-being of adopters. To achieve this objective an analytical framework was developed to investigate the adoption decisions-making process and adopting impact of storage innovations on the wellbeing of households. In this framework, farmers move from awareness of the storage innovations to adoption and to continued use or abandonment of the technologies over time. At each time period, impact of adoption can be assessed. Factors such as information gathering and characteristics of both users and technology are considered important in explaining adoption behavior and the adoption process. Drawing from this analytical framework, several estimation methods were used in the previous chapters to achieve the specific objectives of this dissertation. First, an index approach and a bivariate probit model were applied in the third chapter to analyze farmers' perceptions of the characteristics of storage technologies. Secondly, a selection model was used in the fourth chapter to correct for the non-exposure bias and estimate the factors that affect adoption of the storage innovations according to the sources information of farmers. Thirdly, in the fifth chapter the correction function approach was used to address the issues of selection bias and statistical dependence between the adoption variable and the unobserved gain from adoption raised in impact evaluation literature. In addition the heterogeneity of impact of adoption on schooling expenditure was assumed. Finally, a conditional fixed-effects model was developed in the sixth chapter to determine the time-varying factors that influence the decisions of abandonment of storage innovations.

The objective in this concluding chapter is to present and discuss briefly the main findings of this research as well as their implications and future research. This final chapter is laid out as follows. In next section, the empirical findings of each chapter are summarized and discussed briefly. Section 7.3 discusses lessons and implications of the research findings. In section 7.4, some indications for future research are given.

7.2 Summary and discussion of main findings

Analysis of farmers' perceptions

The third chapter deals with the first two objectives of this thesis that focus on farmers' perceptions of the characteristics of the traditional and improved technologies. Specifically, the first objective aims at measuring the extent to which the storage innovations provide characteristics that are consistent with the needs of the maize producers. The second objective examines the impact of farmers' participation in the storage innovations extension program on the perceptions of the quality of the most desired characteristic embodied in the storage innovations.

The estimation results indicate that perceived effectiveness against insects, perceived effectiveness against rodents and the storage length are the most important characteristics on which farmers based their decision to use a granary. The improved wooden granary provides these three most desired characteristics of a granary. Similarly, the most desired characteristics for a protection measure are effectiveness against pests, conservation length and ease of application. The first two characteristics are well provided by Sofagrain® while ease of application is not. In general, farmers' perceptions of storage innovations characteristics are consistent with research and field experience, except for initial investment cost of improved wooden granary and purchase price of Sofagrain®. Similar results are obtained by Llewellyn et al. (2004) regarding growers perceptions of integrated weed management practices. They find that a very high proportion of growers perceived a high efficacy of selective herbicides. These results are in accordance with the participatory approach as it was implemented in the project. The project addressed primarily the causes of the ineffectiveness of indigenous maize storage technologies. Hence, using a participatory approach the most effective indigenous granary was improved and promoted together with Sofagrain®, one of the best synthetic organophosphate insecticides for protecting grain against insect attack during storage. However, scientists did not pay great attention to other farmers' constraints to adoption of storage innovations such as operating and investments costs, labor requirement in labor pick-season and availability of conservation measures and building materials of granary. These constraints can prevent poor-resources farmers and those with limited family labor from taking advantage of the effectiveness of the storage innovations against pests' attacks. However, scientists found alternative building materials of improved wooden granary such as *Dchapelium guinensis, Azadirachta indica*, *Hollarrhena floribunda* and *Uvaria chamae,* but still unknown to farmers (PTAA, 1999). Similarly results of on-farms trials of Spintor powder (Spinosad 0.125) show that this alternative conservation measure is effective against pest damage and can replace Sofagrain® (PTAA, 2005). Neither the alternative building materials of wooden granary nor the conservation measure Spintor powder is being promoted yet.

Furthermore the results indicate that, except for the perception of length of conservation of Sofagrain®, participation in the extension program of the project increases the probability of farmers to have positive perceptions on the quality provided by the storage innovations of the five most important characteristics used to select a new storage technology. The highest probability of having positive perceptions on the quality of characteristics provided by improved wooden granary and Sofagrain® is obtained with the effectiveness against insects (approximately 82% and 25%, respectively). This result confirms the strategy of the project to address primarily ineffectiveness of the storage innovations against insects. This result is consistent with findings from studies by Guerin (1999) and Negatu and Parikh (1999). These authors find that perceptions of the characteristics of an innovation are affected by extension visits and messages of the extension agents. The findings imply that perceptions of farmers towards quality of characteristics provided by the storage innovations could be attributed to the participatory approach to research and extension used in the project. However, application of this approach was limited to the design of the improved wooden granary based on the option of granary selected by the farmers, demonstrations and on-farm trials of the new storage technologies and their promotion. Little attention has been paid to the opinions of famers regarding their constraints to adoption of the storage innovations. This implies that agricultural research does not take into account adequately the characteristics of storage innovations that are demanded by farmers (Kshirsagar et al., 2002; Chianu et al., 2006).

Adoption and modification of maize storage innovations and effect of information sources

Chapter 4 is devoted to the third objective of this dissertation, which is to analyze factors that affect adoption and modification of maize storage innovations according to farmers' sources of information on these new technologies. The empirical findings confirm that estimation of the adoption and modifications equations should be conditional on being aware of the storage innovations. Otherwise the estimated coefficients would be inconsistent and biased (Saha et al., 1994; Dimara and Skuras, 2003; Diagne and Demont, 2007). Furthermore, the analysis reveals that the factors that influence the adoption and modification decisions of the storage innovations depend on whether the farmers have been informed by extension agents or by their peers. Thus farmers who are informed by extension and who produce large quantities of maize and/or have severe storage problems are likely to adopt the improved wooden granary but introduce some modifications to adapt it to their situation. In addition, the perceived effectiveness of the improved wooden granaries against pests among farmers of this group is an important factor that affects their adoption decisions. However, the perceived effectiveness of the improved wooden granaries against pests is of less importance for farmers informed by peers. The estimation results for the protection method Sofagrain® show that access to the village, perceptions on costs and ease of use of the technology are important determinants of adoption for farmers informed by extension. Adoption of Sofagrain® by farmers informed by other farmers only depends on perceived costs and education level. Modification decisions with respect to the use of Sofagrain® are not much different for both groups. According to Rogers (2003), extension agents are the most important information channels for earlier adopters. These earlier adopters in turn communicate their experiences to later adopters (Rogers, 2003, p. 213). Moreover earlier adopters and later adopters are different in their characteristics (Rogers, 2003, p. 288; Barham et al., 2004). Accordingly it is not surprising to observe that the factors that affect the adoption and modification of the storage innovations depend on the sources of information. These results are also consistent with previous studies which show that farmers and technology characteristics affect adoption of agricultural innovations (Adesina and Zinnah, 1993; Negatu and Parikhb, 1999; Doss, 2006). This suggests that technical characteristics as well as farmers' subjective preferences for characteristics of new technology should be taken into account during the generation process of new technology, if adoption is to be achieved (Wossink et al., 1997). Moreover the result on the effect of road conditions on adoption of storage innovations is in accordance with a study by Ahmed and Hossain (1990). These authors argue that infrastructure affects agricultural production indirectly through prices, diffusion of technology and use of inputs.

Assessing adopting impact of storage innovations on schooling expenditure

In the fifth chapter, we use a counterfactual framework to evaluate the impacts of adopting a maize storage innovation on the schooling expenditures. Following this framework, the endogeneity of the adoption variable in the schooling expenditure equation was corrected for and heterogeneous impacts were assumed and modeled. Hence, this study is consistent with recent work on impact of adoption of new agricultural technologies (Adekambi et al., 2009; Agboh-Noameshie et al., 2007). However, we assume in this study that the unobserved gain from adopting a storage innovation is associated with the adoption dummy variable and use consequently the correction function approach developed by Wooldridge (2007b) to estimate the average adoption effects. The studies above estimate the Local Average Treatment Effect (LATE). In other respects, except for the study by Adekambi et al. (2009), the measure of impact of adopting a new agricultural technology at farm level mostly focuses on profit, income or a poverty index (Alwang and Siegel, 2003; Agboh-Noameshie et al. 2007; Mendola, 2007). Hence, this study fills important gaps in the literature on impact assessment of agricultural innovation adoption. The results of this study are two-fold. First, the estimation results yield factors that influence the schooling expenditure in southern Benin. In this respect our findings are consistent with other studies in Benin as well as with similar ones conducted in different parts of the world. For example participation of children in farm activities is often reported in rural areas of Benin as the most common reason for children to not attend school (World Bank, 2003, p.76). The negative sign of children participating in farm activities shows a substitution effect of child time away from school activities to labor in farms and suggests that the returns to child time in agriculture in the study area are high (Huffman and Orazem, 2007, p. 2329). In other respects, age of household head, distance to communal county town and access to credit have been found to be important determinants of schooling expenditure. These findings are consistent with other studies in developing countries (Kim and Lee, 2001; Brown and Park, 2002; Tansel, 2002; Tansel and Bircan, 2006). Surprisingly neither household income nor distance to school is significant, although having the expected positive signs. Secondly, the magnitude of impact of adopting a storage innovation on schooling expenditure depends on age of the household head, his access to credit and the distance to the primary school. Conditional on these variables, adopting the storage innovations increases the schooling expenditure of adopters on average by 187% and 182% for a farmer randomly selected. This slightly greater magnitude of the impact on adopters compared to the impact on a randomly selected farmer confirms the endogeneity of the adoption variable in the schooling expenditure equation. Moreover the correction function is statistically different from zero and implies that the gain from adoption of a storage innovation is correlated to the adoption variable. The findings are consistent with those of Adekambi et al. (2009) who estimate a Local Average Treatment Effect (LATE) and show that adoption of NERICA, a new variety of rice, has significantly improved household expenditures.

Dynamic decisions-making process of storage innovations adoption

Chapter 6 addresses the issue of dynamics of storage innovation adoption decisions. More specifically, we investigate the effect of changes in time-varying variables on the adoption decisions of the producers over time. Survey results show that high proportions of earlier adopters of the improved wooden granary and Sofagrain® abandon their use by 2008. High initial costs were reported by most farmers as one of the major reasons for abandoning both storage innovations. Estimation results indicate that farmers living in villages with good access throughout the year, who have limited family labor and do not participate in on-farms trials and demonstrations in the years subsequent to adoption, are likely to abandon the use of the storage innovations. Several studies find similar results about abandonment of new technologies. Indeed, Moser and Barrett (2006) studying the dynamics of the system of rice intensification (SRI) in Madagascar find a high average disadoption rate of 40% among adopters. Barham et al. (2004) also find that about 40% of Wisconsin farmers who have tried recombinant bovine somatotropin (rBST) abandoned it. Boys et al. (2007) project a complete abandonment of the cowpea drum storage technology in Senegal by 2012 based on their assessed abandonment rates. As with the abandonment of the storage innovations in southern Benin, the high initial cost of cowpea drum storage technology was also reported in Senegal by some farmers as the reason for abandoning its use. In other respects, the relationship between road conditions and storage innovations abandonment is similar to the finding of Neil and Lee (2001). These authors also find that road access to community of residence of farmers is an important factor explaining the abandonment of the use of cover crops in Northern Honduras. In contrast to findings of Neil and Lee (2001) and similar to those of Moser and Barrett (2006), the availability of labor affects the abandonment of storage innovations significantly. The estimation results indicate that the quantity of maize produced does not affect the probability of abandoning the use of the storage innovations. This finding is consistent with that of Neil and Lee (2001), who found that the farm size does not affect the probability of abandoning the use of cover crops.

7.3 Policy implications

Maize in southern Benin is subjected to high storage losses with rates of more than 25 to 30% after six month of storage of maize harvested in the first, main raining season. Hence, reducing maize storage losses is key to achieving food security and improving agricultural household income. This section provides some implications of the findings of this research for the design of policies for the sustainable dissemination and diffusion of storage innovations in Southern Benin.

The static adoption and modification study yields characteristics of the adopters and non-adopters. Extension services could use these characteristics to classify their clientele and appropriately design their extension programs and strategies for each category. This will help to shorten the adoption process and use funds more economically. To mitigate constraints to adoption, some farmers attempt to make changes in the original innovation to fit their situation better. Changes in storage innovations can affect their effectiveness against pests. To design storage innovations which take into account farmers circumstances and that are effective against pests, research on the adapted storage innovations should be conducted in collaboration with farmers. In addition to these changes in storage innovations, findings show that farmers' subjective preferences for some characteristics of storage innovations are important determinants of adoption behavior. These results imply that the conventional focus in technology development on technical characteristics such as effectiveness of storage innovations against pests is much too narrow. Focus needs to be changed to also include farmers' perceptions of other technological characteristics and socio-economic constraints. Consequently, in the future scientists have to go beyond a mere involvement of farmers in the development process of an innovation and take into account the storage innovations characteristics they desire and the constraints they face in adoption of the new technologies. This implies a need for multidisciplinary research and a greater emphasis on a farming systems approach to research and extension for storage innovations. The results also show that factors affecting adoption and modification vary depending on whether farmers are informed on the storage innovations by extension service or peers. Because near peer adopters opinions on the innovation are accessible and convincing, farmers rely on information from them. Visits by extension agents to adopters who do not belong to their target groups are important to evaluate how they are using the storage innovations and provide them with accurate knowledge.

Results from the analysis of dynamics of adoption decisions-making of the storage innovations indicate high rates of abandonment. High labor requirement in peak-season, high initial costs and availability of Sofagrain® and granary building materials are major constraints to adoption and continuing use for many farmers. These factors were also raised in the static adoption study as constraints to adoption. A program to provide credit for maize producers will allow them to hire labor to construct improved wooden granary and avoid abandonment. Similarly, effective alternatives to Sofagrain® such as Spintor powder

(Spinosad 0.125) as well as the existent alternative wooden granary building materials (*Dchapelium guinensis, Azadirachta indica*, *Hollarrhena floribunda* and *Uvaria chamae*) should be promoted. Public agricultural extension and research services should pay more attention to the post-harvest activities. However, because farmers who live in areas with better access are likely to abandon storage innovations, extension services should target remote areas for their promotion. Based on evidence from the analysis of dynamics of adoption decisions-making of the storage innovations, adoption studies of new technologies must be conducted at several periods in time. The same farmers should be visited over time with a very similar questionnaire, allowing by then to observe the changing patterns in the adoption of new technologies and related factors and reasons. This will help to sustain the adoption of promising new technologies or to replace those with high abandonment rates.

Finally, impact assessment of the storage innovations should be extended to other indicators of poverty such as income, health expenditures, food security and nutrition status. This will give a precise contribution of agriculture to the fulfillment of the Millennium Development Goals.

7.4 Future research

Study of dynamics of adoption decisions-making of storage innovations has been limited by the availability of panel data on farmers over two time periods only. Therefore we were not able to estimate a dynamic binary choice model that explicitly allows for lagged effects to analyze the state dependence effects (current behavior dependent on past behavior). Moreover, it was not possible to control for the potential problem of endogeneity in some explanatory variables such as perceptions of technological characteristics. Indeed, a farmer who has adopted a storage innovation may be more likely to have a positive attitude towards it compared to a farmer who has not yet adopted it. Thus, in cross-section data, farmers' perceptions of technological characteristics may be compromised by problems of endogeneity. In the context of a panel data model, lagged values make reasonable instruments because they are likely to be uncorrelated to the dependent adoption variable, but correlated with the contemporaneous dependent adoption variable.

The main issue in impact assessment is to establish the causal effects of new technologies adoption on observed outcomes such as income, expenditure, food, nutrition, health etc. The treatment effects estimators is used in this dissertation to evaluate the impact of adopting a storage innovation on the schooling expenditure. Future research on impact assessment of adopting new agricultural technologies may use the treatment effects estimators assuming that the responses are heterogeneous. To assess the robustness of the results, we recommend the application of different approaches of treatment effects estimators such as control function, correction function, local average treatment effect (LATE) and the marginal treatment effect (MTE). In addition, further research may attempt to extend the treatment effects estimators to panel data using for example the model of the composite causal effect for time-varying treatments. Moreover, assessing the impact of adopting agricultural innovations on farmer welfare is a major concern to policy-makers and donors. Therefore future research in impact assessment of adopting new agricultural technologies may go beyond the usual effect on income and focus on the poverty indicators using treatment effects estimators.

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SUMMARY

In Sub-Saharan Africa population increases so fast that the main objectives of policy-makers and donors are to provide food security and combat poverty. Increasing agricultural productivity is recognized to have a direct impact on food security and poverty reduction. Moreover, increased agricultural productivity is considered as the primary lever of economic development in least developed countries. Diffusion of new agricultural technologies is one of the most applied drivers for increasing agricultural productivity. However, crops are often harvested in the wet season but traditional storage systems are often not equipped to dry and store large quantities of products properly. Accordingly, storage losses of agricultural products can be very high. Recent studies have shown that pest damage during the storage of produce are also a serious constraint to food security and agricultural income of households.

In southern Benin, the atmospheric conditions are favorable to insect pests and mould proliferation. Moreover, traditional post-harvest practices are inadequate and the granaries used for storage are often inappropriate. Therefore, drying and storing agricultural products is a major challenge. Maize is a major staple food and an important source of income and employment for many farmers in southern Benin. Almost all maize produced in southern Benin is harvested in the wet season, stored in traditional storage structures and treated with protectant products at farm level. Drying and storage of grain are therefore difficult and often lead to high losses. To control pest damage in stored maize, a package of complementary innovations of improved wooden granary and Sofagrain® was designed and introduced in 1992. On-farm trials have indicated that after six months of storage, the losses were reduced from 30% to only 5% for maize which is treated with Sofagrain® and stored in an improved wooden granary. Despite efforts to improve maize storage systems, few studies have dealt with the economic aspects of such new storage innovations. The general objective of this study is therefore to analyze the adoption patterns of the maize storage innovations promoted in southern Benin since 1992 and assess the impact of their adoption on the well-being of adopters. From this general objective, five specific objectives were defined and analyzed in separate chapters.

The study was conducted in southern Benin where farmers face high storage losses of products such as maize and where post-harvest innovations are experimented with since the seventies. Farmers from villages both involved and not involved in projects on improved wooden granary and Sofagrain® promotion are randomly selected for surveys. Primary data

have been collected from these surveys to achieve each specific objective of this dissertation. Chapter 2 describes the study area and post-harvest systems along with sampling and collection methods used to achieve each objective of this thesis. Data used to analyze farmers' perceptions of the technological characteristics and the determinants of the storage innovations adoption come from two surveys. First, focus group discussions were conducted in twenty-one villages during the dry season of 2001. Second, farm-level cross-section data were collected from a random sample of 743 maize producers aware and not aware of storage innovations and living in 30 villages of the six rural departments of southern Benin. This survey was conducted from March to May 2002 using a structured questionnaire refined based on the qualitative data gathered during the previous step. Impact assessment of adopting storage innovations on schooling expenditure is also based on data collected from two series of surveys. First, focus groups discussions were organized between February and March 2003 in six villages located in three rural departments. Next, a sample of 306 maize producers aware of storage innovations was surveyed to collect detailed farm-level cross-section data. The sampled maize producers were drawn from the sample of the previous study. Finally the sample of 743 maize producers surveyed in 2002 was visited again in 2008 with a similar questionnaire to collect data for the analysis of the dynamics of the storage innovations.

In chapter 3, two methods are used to analyze the farmers' perceptions of storage technological characteristics. Firstly, an index approach is used to measure the extent to which the improved wooden granary and Sofagrain®, respectively provide characteristics that are consistent with the needs of the maize producers. Secondly, a bivariate probit model is used to assess the causal effect of participation in the extension program on the perceptions that farmers have on the quality provided by the new storage technologies of the three most important characteristics that affect their technological choice decisions. The estimation results indicate that perceived effectiveness against insects, perceived effectiveness against rodents and the storage duration are the most important characteristics on which farmers based their decision to use a granary. The improved wooden granary embodies these three most desired characteristics in a granary. Similarly, the most desired characteristics for a protection measure are effectiveness against pests, conservation length and ease of application. The first two characteristics are only well provided by Sofagrain®. In other respects, except for the perception of length of conservation of Sofagrain®, participation in the extension program increases the probability of farmers to hold positive perceptions on the quality provided by the storage innovations of the five most important characteristics of the farmers. The highest probability of having positive perceptions on the quality of characteristics provided by improved wooden granary and Sofagrain® is obtained with the effectiveness against insects (approximately 82% and 25%, respectively). The findings imply that perceptions of farmers towards the characteristics of the storage innovations could be attributed to the participatory approach to research and extension used in the project. However, little attention has been paid to the opinions of farmers regarding their constraints to adoption of the storage innovations. Addressing these constraints could prevent long term discontinuance of these storage innovations.

In chapter 4, a sample selection framework is used to account for non-exposure bias that will occur if all farmers are not aware of the storage innovations. The main finding is that factors that influence the adoption and modification decisions of the storage innovations depend on whether the farmers have been informed from extension agents or from their peers. Thus the farmers who are informed by extension and producing large quantities of maize and/or having severe storage problems, are likely to adopt the improved wooden granary but introduce some modifications to adapt it to their situation. In addition the perceived effectiveness of the improved wooden granaries against pests among farmers of this group is an important factor that affects the adoption decisions. However the perceived effectiveness of the improved wooden granaries against pests is of less importance to farmers informed by peers. On the side of the protection method Sofagrain®, the estimation results indicate that the variables: access to the village, perceptions on costs and easiness of use of the protection measure are important determinants of the adoption decisions within the group of the farmers informed by extension agents. Adoption of Sofagrain® by farmers informed by their peers only depends on perceived costs and education level. Modification decisions with respect to the use of Sofagrain® are not much different for both groups.

A correction function approach applied to a binary heterogeneous treatment effect model is used in the next chapter to evaluate the impact of storage innovations adoption on schooling expenditure. The estimation results are two-fold. First we found that participation of children in farm activities is negatively associated to school expenditures. This finding suggests that the returns to child time in agriculture are high in the study area. This result is consistent with other studies in Benin. In other respects, age of household head, distance to communal county town and access to credit were found to be important determinants of schooling expenditure. Secondly, tests statistics show that the correction function approach is appropriate to estimate the impact of adopting a storage innovation on the schooling expenditures. Moreover, the magnitude of impact of adopting a storage innovation on schooling expenditure depends on age of the household head, his access to credit and the distance to the primary school. Conditional on these variables, adopting the storage innovations increases the schooling expenditures of adopters on average by approximately 187%.

In chapter 6 a conditional logit model with fixed effects is used to investigate the relationship between the changes in adoption status and the changes in time-varying variables. The main finding is that when the road conditions improve or when farmers have less family labor, they are likely to disadopt both the improved wooden granary and Sofagrain®. Furthermore, farmers who do not participate in on-farms trials and demonstrations are likely to abandon the use of the improved wooden granary. An important reason for abandonment of Sofagrain® is also non-availability. The findings imply that extension service might target the remote areas for storage innovations promotion and sustain farmer's participation in on-farms trials and demonstrations. Credit should be provided for farmers to hire labor for granary construction and apply the conservation measure. Lastly, alternative effective conservation measures such as Spintor powder could be promoted to address the non availability constraint of Sofagrain®.

The final chapter summarizes and discusses the findings resulting from the research works undertaken to achieve each specific objective of this dissertation. It also discusses lessons and implications of the research findings. This chapter ends with some indications for future research topics regarding the use of panel data to analyze the dynamics of adoption of storage innovations and the application of treatment effects estimators assuming the heterogeneity of responses, to assess the impact of adoption on poverty indicators.

SAMENVATTING

In Sub-Sahara Afrika stijgt de bevolking zo snel dat voedselzekerheid en armoedebestrijding de belangrijkste doelstellingen van beleidsmakers en donoren zijn. Productiviteitsstijging in de landbouw heeft op beide zaken een belangrijke invloed en wordt vaak gezien als de belangrijkste pijler voor economische groei in ontwikkelingslanden. Verspreiding van nieuwe agrarische technologieën is een van de meest toegepaste strategieën om de productiviteit in de landbouw te doen stijgen. Gewassen worden echter vaak in het regenseizoen geoogst en traditionele bewaarsystemen zijn niet geschikt om gewassen te drogen of om grote hoeveelheden goed op te slaan. Verliezen van opgeslagen producten kunnen dan ook aanzienlijk zijn. Recent onderzoek laat zien dat schade door insecten tijdens de opslag ook een serieuze bedreiging is voor voedselzekerheid en de inkomens in de landbouw.

In het zuiden van Benin zijn de atmosferische omstandigheden dusdanig dat dit leidt tot insecten- en schimmelproblemen. Traditionele conserveringsmethoden zijn veelal niet adequaat en de opslagsilo's zijn vaak ook niet geschikt om deze problemen tegen te gaan. Het vinden van betere manieren om agrarische producten te drogen en op te slaan blijft daarom een belangrijke uitdaging. Maïs is een van de belangrijkste voedselgewassen en een belangrijke bron van inkomsten en werk in het zuiden van Benin. Bijna alle maïs die hier geproduceerd wordt, wordt geoogst in het regenseizoen en vervolgens door individuele boeren opgeslagen in traditionele bewaarsystemen na behandeling met eenvoudige conserveringsmethoden. Opslag van maïs is dan ook problematisch en leidt tot grote verliezen. Om opslagschade van maïs te verminderen is een pakket van innovaties, bestaande uit verbeterde houten silo's en het conserveringsmiddel Sofagrain®, ontwikkeld en geïntroduceerd in 1992. Testen op verschillende bedrijven laten zien dat na zes maanden de opslagverliezen zijn terug gebracht van 30% tot slechts 5% voor maïs behandeld met Sofagrain® en opgeslagen in een verbeterde houten silo. Ondanks de ontwikkelingen in deze verbeterde opslagmethodes voor maïs, zijn er weinig studies die de economische aspecten van dergelijke innovaties voor voedselopslag belichten. De hoofddoelstelling van dit proefschrift is dan ook om de adoptie van deze innovaties voor maïsopslag die sinds 1992 in het zuiden van Benin zijn geïntroduceerd te analyseren, en om de impact daarvan op de welvaart van boeren te onderzoeken. Op basis van deze hoofddoelstelling zijn vijf specifieke doelstellingen geformuleerd die in afzonderlijke hoofdstukken van dit proefschrift zijn uitgewerkt.

Dit onderzoek is uitgevoerd in het zuiden van Benin waar boeren te maken hebben met grote verliezen tijdens de opslag van producten als maïs en waar al sinds de jaren zeventig wordt geëxperimenteerd met betere opslagsystemen. Boeren uit dorpen die wel en dorpen die niet betrokken zijn bij projecten betreffende verbeterde bewaarsystemen zijn willekeurig geselecteerd in verschillende enquêtes. Primaire gegevens van deze enquêtes zijn gebruikt om de verschillende doelstellingen van dit proefschrift waar te maken.

Hoofdstuk twee beschrijft het gebied waar dit onderzoek is uitgevoerd, de oogst bewaarsystemen, en de steekproeftechnieken en methoden van dataverzameling die gebruikt zijn om de verschillende doelen van dit proefschrift uit te werken. Gegevens die gebruikt zijn om percepties van boeren met betrekking tot technologische eigenschappen van de bewaarsystemen te analyseren komen van twee enquêtes. Ten eerste zijn focus groep discussies gehouden in 21 dorpen gedurende het droogte seizoen van 2001. Ten tweede zijn kwantitatieve gegevens verzameld middels een steekproef van 743 willekeurig geselecteerde maïsboeren uit 30 dorpen in de zes rurale departementen in het zuiden van Benin die al dan niet op de hoogte waren van verbeterde maïs bewaarsystemen. Deze tweede enquête is gehouden van maart tot mei 2002, waarbij gebruik is gemaakt van een gestructureerde vragenlijst die mede gebaseerd is op de uitkomsten van de eerste kwalitatieve enquête. Onderzoek naar de effecten van gebruik van opslag innovaties op de huishouduitgaven voor onderwijs is ook gebaseerd op gegevens uit twee verschillende enquêtes. Ten eerste zijn tussen februari en maart 2003 in zes dorpen, gelegen in drie verschillende departementen, focus groep discussies gehouden. Vervolgens is een groep van 306 maïs producenten die op de hoogte waren van verbeterde maïs bewaarsystemen geënquêteerd om gedetailleerde kwantitatieve gegevens te krijgen. Deze boeren zijn gekozen uit de eerder gehouden steekproef onder 743 boeren. Tenslotte zijn de 743 maïsboeren uit de enquête van 2002 in 2008 opnieuw geënquêteerd om zo de benodigde gegevens te krijgen voor een analyse van de dynamiek in het gebruik van verbeterde bewaarsystemen.

In hoofdstuk drie zijn twee methodes gebruikt om de percepties van boeren m.b.t. technologische karakteristieken van maïs bewaarsystemen te analyseren. Allereerst is een index methode gebruikt om te meten in hoeverre de verbeterde houten silo's en Sofagrain® eigenschappen hebben die overeen komen met door boeren belangrijke geachte eigenschappen. Vervolgens is een bivariaat probit model gebruikt om te analyseren of deelname aan demonstratieprogramma's van verbeterde bewaarsystemen een causaal effect heeft op de percepties van boeren m.b.t. de drie meest belangrijke eigenschappen van verbeterde bewaarsystemen. De schattingsresultaten laten zien dat de veronderstelde effectiviteit tegen insecten, veronderstelde effectiviteit tegen knaagdieren en de bewaarduur de meest belangrijke eigenschappen zijn waarop boeren hun beslissing baseren om verbeterde silo's te gaan gebruiken. De verbeterde silo's komen op deze drie punten inderdaad overeen met door boeren gewenste eigenschappen. De meest belangrijk geachte eigenschappen van een conserveringsmiddel zijn effectiviteit tegen plagen, bewaarduur en gebruiksgemak. Sofagrain® voldoet volgens de analyse alleen aan de eerste twee eigenschappen. Het tweede deel van de analyse laat zien dat behalve voor veronderstelde bewaarduur met Sofagrain®, deelname aan demonstratieprogramma's leidt tot een grotere kans dat boeren de belangrijkste eigenschappen van de verbeterde maïs bewaarsystemen positief waarderen. De hoogste kans op het hebben van een positief oordeel over de eigenschappen van de verbeterde silo's en Sofagrain® is m.b.t. effectiviteit tegen insecten (ongeveer 82% en 25% respectievelijk). Deze resultaten impliceren dat positieve percepties van boeren m.b.t. eigenschappen van de verbeterde bewaarsystemen kunnen worden toegeschreven aan de participatieve benadering bij de ontwikkeling ervan en de demonstratieprojecten. Echter, algemeen wordt weinig aandacht besteed aan door boeren aangegeven beperkingen m.b.t. aanschaf van deze verbeterde bewaarsystemen. Serieus rekening houden met deze beperkingen kan voorkomen dat boeren op langere termijn stoppen met het gebruik van deze systemen.

In hoofdstuk vier is een zogenoemd selectie model gebruikt om te corrigeren voor schattingsfouten die kunnen ontstaan omdat niet alle boeren die de verbeterde bewaarsystemen niet gebruiken op de hoogte waren van het bestaan ervan. De belangrijkste conclusie is dat het uitmaakt waar boeren hun informatie over verbeterde bewaarsystemen vandaan hebben, d.w.z. van officiële voorlichters of van hun collega boeren. Voor deze twee groepen van boeren zijn ook verschillende factoren van doorslaggevende betekenis in aanschaf of aanpassing van bewaarsystemen. Boeren die informatie van voorlichters hebben en die een grote hoeveelheid maïs produceren en behoorlijke opslagproblemen hebben, zijn meer geneigd de verbeterde maïs bewaarsystemen te gaan gebruiken, maar passen deze ook aan hun eigen situatie aan. Ook de veronderstelde effectiviteit van de verbeterde houten silo's tegen plagen is een belangrijke factor die van invloed is op de beslissing om deze te gaan gebruiken. Deze factor is voor boeren die hun informatie van collega's hebben echter minder van belang. M.b.t. het conserveringsmiddel Sofagrain® laten de schattingsresultaten zien dat bereikbaarheid van het dorp, veronderstelde kosten en gebruiksgemak belangrijke factoren zijn die leiden tot gebruik, als boeren hun informatie voornamelijk van voorlichters hebben. Al dan niet Sofagrain® gebruiken door boeren die hun informatie van andere boeren hebben hangt af van veronderstelde kosten en opleidingsniveau. Beslissingen om de innovaties zelf aan te passen verschillen niet veel tussen beide groepen.

In hoofdstuk vijf wordt een correctiefunctie methode gebruikt om het heterogene effect van gebruik van verbeterde bewaarsystemen op onderwijsuitgaven door huishoudens te meten. De schattingsresultaten zijn tweeledig. Ten eerste bleek dat werkzaamheden van kinderen een negatieve invloed hebben op de uitgaven voor scholing. Dit suggereert dat er in het studiegebied een relatief hoge opbrengst is van arbeid door kinderen op de eigen boerderij, iets wat ook door andere studies bevestigd wordt. Leeftijd van het gezinshoofd, afstand tot de dichtstbijzijnde school en toegang tot krediet zijn andere belangrijke factoren van scholingsuitgaven. Uit toetsen blijkt dat de correctiefunctie methode gebruikt dient te worden om op een juiste manier het effect van gebruik van verbeterde maïs bewaarsystemen op scholingsuitgaven te schatten. Gebruik van verbeterde bewaarsystemen leidt gemiddeld tot ongeveer 187% hogere scholingsuitgaven.

In hoofdstuk zes wordt een zogenoemd conditioneel fixed effects logit model gebruikt om te onderzoeken hoe veranderingen in adoptiestatus samenhangen met veranderingen van verklarende variabelen. De belangrijkste conclusies zijn dat wanneer wegen verbeteren en families minder arbeid tot hun beschikking krijgen, ze eerder geneigd zijn om de verbeterde houten silo's en Sofagrain® niet meer te gebruiken. Verder zijn boeren die niet deelnamen aan demonstratieprojecten meer geneigd om de verbeterde silo's niet meer te gebruiken. Een belangrijke reden voor het stoppen met het gebruik van Sofagrain® is de soms beperkte beschikbaarheid. Deze resultaten suggereren dat voorlichtingsprogramma's zich het beste kunnen richten op afgelegen gebieden en dat ze er verstandig aan doen om boeren toch deel te laten nemen aan demonstratieprogramma's. Kredietverschaffing is belangrijk om benodigde arbeid in het construeren van de silo's en de Sofagrain® te kunnen betalen. Verder zouden alternatieve conserveringsmethodes als Spintor kunnen worden aanbevolen om het tekort aan Sofagrain® op te lossen.

Het laatste hoofdstuk van het proefschrift vat de belangrijkste conclusies van het proefschrift samen en plaatst deze in een breder perspectief. Ook implicaties van de onderzoeksresultaten worden besproken. Het laatste hoofdstuk eindigt met enkele aanbevelingen voor vervolgonderzoek, in het bijzonder voor het gebruik van panel data in vervolgonderzoek naar de dynamiek van technologie adoptie en het gebruik van schattingstechnieken om causale effecten van technologie op armoede te onderzoeken.

TRAINING AND SUPERVISION PLAN

of Social Sciences
MANSHOLT GRADUATE SCHOOL

Description	Institute / Department	Year	ECTS*
Courses:			
Specific Training Workshop on Impact Evaluation/Study Groups	IITA and Africa Rice Centre (WARDA)	2003 to 2006	4.5
Writing Research Proposal	Mansholt Graduate School of Social Sciences (MG3S)	2004	6
Economic Models	Wageningen Graduate Schools (WGS)	2004	6
Advanced Econometrics	MG3S	2007	6
Techniques for Writing and Presenting a Scientific Paper	WGS	2007	1.2
Mansholt Introduction Course	MG3S	2007	1.5
Panel Data Analyses	MG3S	2007	1.5
Discrete Choice Modelling	MG3S	2007	1.5
Food Policy for Developing Countries: governance, institutions and markets in global, national and local food systems	MG3S	2007	4
Presentations at conferences and workshops:			**3**
Mansholt Multidisciplinary Seminar at Wageningen (Mansholt Ph.D.)		2004	1
Meeting on the socio-economic impact of disease prevention at the International Atomic Energy Agency (IAEA) in Vienna, Austria		2009	1
Discussion at meeting on the socio-economic impact of disease prevention at the IAEA in Vienna, Austria		2009	1
Teaching and supervising activities:			**4**
MSc Student Guirguissou A. Maboudou: Adoption and diffusion of improved maize storage technologies in centre and northern Benin		2003	1
MSc Student Djalalou-Dine Adémonla Alamou Arinloye: Analyse of determinants of rice demand in centre and southern Benin		2006	1
MSc Student Morènikè Cendrine Ahouandjinou: Adoption and socioeconomic impact of the semi mechanization of the process of transformation of the kernels of shea-tree in butter in north Benin		2008	1
MSc Student Babatoundé Alain Rivaldo Kpadonou: Socio-economic analysis of credit constraint in agricultural households of Ouémé valley in Benin		2009	1
Total (minimum 30 ECTS)			**39.2**

*One ECTS on average is equivalent to 28 hours of course work

CURRICULUM VITAE

Patrice Ygue Adegbola was born on 17th, 1959 in Cotonou, Republic of Benin. He studied at the Agricultural Sciences Faculty of National University of Benin (FSA/UNB) from 1981 to 1985, obtaining a degree of Agronomist Engineer with the major in Agricultural Sociology. He worked from 1986 to 1987 for the Ministry of Agricultural, Livestock and Fish (MAEP) as extension agent, in the districts of Adjarra and Adja-Ouèrè in the Ouémé department. From 1987 to 1990 he worked as agricultural economist scientist in the Rural Economy and Sociology Laboratory (LESR) of the Benin National Institute of Agricultural Research (INRAB). In 1990 he was appointed as socio-economist of a farming system research project (RAMR), financed by the Netherlands Ministry of Co-operation. In 1994 he was awarded a World Bank scholarship and studied rural economy from 1995 to 1997 in Laval University at Quebec. He obtained the degree of Master of Sciences in Rural Economy with major in farm management and agricultural policy analysis. His initial academic training has been reinforced by upgrading and re-training in participatory approaches, impact assessment methods, farm modeling, project evaluation, sub-sector analysis, etc. From January 2001 on he is in charge of Agricultural Policy Analysis Program (PAPA) (former LESR) of INRAB. He is involved in several collaborative research projects and conducted several studies in agricultural sub-sector analyses; farm management, adoption and impact assessment of new technologies, agricultural policy analysis. He supervises several Master students in Benin Universities. In April 2004 he joined the Agricultural Economics and Rural Policy Group of Wageningen University as Ph. D. student with the financial support of the Mansholt Graduate School of Social Sciences. In 2006, he was awarded a grant by the Netherlands Fellowship Programs (NFP) for both the fellowship and research costs. He is author of several technical reports and published in national and international peer-review journals. He is also reviewer of scientific articles for the Bulletin de la Recherche Agronomique du Bénin, an occasional reviewer for the Agricultural Economics, journal of the International Association of Agricultural Economists, Water Policy, Water Resources Management. Patrice is married to Elisabeth Adechina and he is father of five kids.

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- Front page: Farmers' granaries, improved wooden granary and pupils in Benin.
- Back page: Isosceles Triangle.

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