CHAPTER 3
DETERMINANTS OF TECHNOLOGY ADOPTION

This chapter explores both the theoretical explanations and empirical evidence relating to technology adoption in developing countries. The theoretical context deals with the basic explanations of technology adoption, the conceptual framework underlying the theoretical models of technology adoption and the basic assumptions of these models. The purpose of this chapter is to select the model that best captures the crop management decisions of banana producers in Uganda. A section is also devoted to the model of the agricultural household, reviewing its relevance for the analysis of technology adoption in a developing economy.

The adoption and diffusion of innovations in agriculture has been studied extensively over the last 50 years. The unit of analysis in an adoption study is an individual decision maker (farmer) or decision-making unit (farm household). Diffusion studies refer to the cumulative adoption path or distribution of adoption (percentage of farmers, percentage of area) over time or space, with the community, region, nation or another geographical scale as the unit of analysis. Since the focus of this dissertation is the analysis of the determinants of the use of crop management practices on individual farms and the variations in their use across farms, the literature review will focus on adoption studies.

3.1. Determinants of farm-level adoption behaviour in the literature

Once a new technique of production becomes available, it usually takes some time before it is fully implemented. At the farm level, the transition period may be characterized by a time lag between awareness of the technology and actual adoption or by coexistence of the old and new technology. Economic modelling of technology adoption to explain such adoption behaviour has taken different approaches over time (Feder et al., 1985; Feder and Umali, 1993).

The early modelling of the 1970s emphasized the impact of information and knowledge on the adoption process and the time lag between awareness and actual adoption (Kislev and Shchori-Bachrach, 1973; Hiebert, 1974). Within the empirical

framework, information and knowledge were the intervening variables linking the empirical variables with adoption decisions. Differences in adoption rates were attributed to endogenous factors such as differences in skills (Kislev and Shchori-Bachrach, 1973), risk aversion (Hiebert, 1974) and prior beliefs (Feder and O'Mara, 1982). An innovation was conceptualised as first adopted by high-skilled and experimenting farmers and later diffused to low-skilled farmers as experience with the technology accumulated in the community (Kislev and Shchori-Bachrach, 1973). Education, through its positive influence on "the ability to perceive, identify, acquire, process information and respond to new events in the context of risk" (Schultz, 1975), was associated with early adoption of new technologies.

Similarly, risk preferences were identified as the determinant of adoption rates. Early adoption was associated with risk neutrality and late adoption attributed to risk aversion (Hiebert, 1974). Learning and information accumulation reduce uncertainty, making the parameters of the production function under the new technology, as perceived by farmers, shift from a low to a high pay-off, thereby persuading the potential adopters who are more risk-averse to also adopt (Hiebert, 1974).

In the light of the uncertainties (i.e. production, price or availability) associated with the new technology, much of the empirical analysis throughout the 1970s and early 1980s focused on the role of risk in the adoption process. Risk aversion reduces adoption because the risk-averse producer stops short of maximizing expected income when the variance of net income increases as the expected net income increases (Hiebert, 1974). Hence, a risk-averse farmer will trade off high yield (or profit) for low variability so as to reduce the extent of risk. A range of specifications and decision rules to depict farmer behaviour under risk and uncertainty were proposed and applied. The impact of both the objective and subjective risk was examined.

One widely used approach was that of portfolio selection formulation (Just and Zilberman, 1983), in which optimal decision depends on the mean, variance and covariance structure of the introduced and locally grown varieties. Under uncertainty, farmers maximize the expected utility of income or profits by choosing the level of variables they control, which can result in partial land allocation to the new technology rather than complete adoption.

In the case of risk neutrality, differences in the adoption rates were attributed to differences in prior beliefs about the new technology (Feder and O'Mara, 1981). Adoption of a new technology starts with farmers holding more positive prior beliefs about the profitability of a new technology because they do not need much information to be convinced compared to those who hold less favourable beliefs. With time, potential adopters update their beliefs about the profitability of the new technology with the new information generated by early adopters and are hence induced to adopt.

Other studies conducted in the 1980s show that farm-to-farm differences in the rate of adoption or extent of adoption of a new technology might be explained by other considerations. Transaction costs involved in learning and acquiring the new technology that are independent of scale were identified as important impediments to the rate of technology adoption (Perrin and Winkelmann, 1976). Because the fixed cost per unit of land decreases in scale, there is a threshold of farm size below which it is less profitable to adopt a technology (Feder and O'Mara, 1981). The fixed costs will be high if the subcomponents are forever changing to adapt to the changing environment or new components being introduced where decision makers have low levels of human capital (Schultz, 1975), as is often the case in developing economies. This critical farm size decreases over time as uncertainty is reduced because of learning and the dissemination of information from early adopters.

Credit constraints were also identified as an impediment to technology adoption in developing economies (Feder et al., 1985). Technologies introduced to increase agricultural productivity are often accompanied by increases in the input requirements, which may not be affordable to some farmers or readily available in specific locations. Even when the technology is neutral to scale and the presumable fixed pecuniary costs not large, credit constraints will limit adoption (Feder et al., 1985). Farmers will allocate land to the new technology up to the point where credit is binding and partial adoption will result.

Farm size emerges from the empirical studies of the 1970s and 1980s as an important surrogate for a large number of factors such as access to credit, capacity to bear risk, access to inputs, wealth, and access to information (Feder, 1980; Feder and O'Mara,

1981; Just and Zilberman, 1983). The fixed transaction costs decrease with an increase in farm size, which explains why the adoption of new divisible technology might begin with larger farmers. Second, because larger farmers have a greater ability to raise capital, to bear the cost of the innovations and to bear the risk of failure, they are likely to be less risk-averse compared to relatively small farmers and are more likely to make risky investments compared to smaller farmers.

The impact of complementarities between the interrelated innovations within a package on adoption behaviour was also examined (Feder, 1982), reflecting the way in which innovations were promoted at the time (seed, fertilizer, agronomic practices). Sequential adoption of individual components of a technological package was explained in light of risk and input scarcity (Byerlee and de Polanco, 1986). Further studies on sequential adoption behaviour were reviewed by Feder and Umali (1993).

In other studies, the static models were made dynamic by incorporating the "learning by doing" aspect of the adoption process. The Bayesian approach was used by a number of authors. For example, Leathers and Smale (1991) invoked Bayesian learning to explain why the step-wise adoption of components of a technical package can occur even in a risk-neutral context without credit constraints. This literature suggests that the main reason farmers may experiment with the technology is to develop skills on how to implement the technology and/or reduce uncertainty about its actual profitability. This is important when the technology is knowledge-intensive and/or the outcome is less obvious to the potential adopters. Within this framework, the adoption decision involves choosing an adoption path that will maximize the expected utility from a stream of profits, subject to a bounded rate of adoption. The impact of expectations on future prices also received attention in the dynamic modelling of technology adoption, where Tsur et al. (1990) likewise maintained the assumption of risk behaviour.

In some cases, advancing any single explanation against another can lead to biased results and policy recommendations. In the case of hybrid maize in Malawi, Smale et al. (1994) demonstrated that no single explanation (i.e. portfolio diversification, safety-first, experimentation or input fixity) explained the land allocation decisions to

new varieties, and proposed a nested model that includes all four major explanations as special cases.

It is critical to recognize that the models and approaches generated in early adoption studies reflect the type of technology and the institutional context of the green revolution (high-yield crop varieties and complementary inputs such as fertilizer, pesticides and timely planting practices). Both of these factors differ in important ways in this study. The institutional differences are mentioned in Chapter 1, involving a shift from the top-down, centralized, traditional model of research and extension. The major point of contrast with respect to technology is that the green revolution technologies were composed of largely external inputs that were disseminated to communities as physical technologies (seed, fertilizer). On the other hand, improved banana management practices are low external input technologies that rely on local resources for their implementation. Because these are knowledge-based and depend on local resources, they are knowledge-intensive and farm-specific (Lee, 2005). With the improved banana management technology, only information is disseminated to farmers. The actual physical technology (i.e. mulch, manure) is made on the farm by combining local resources (typically labour and by-products of other farm activities) with the acquired knowledge. Therefore, unlike the green revolution technologies, the improved banana production management technologies demand more of the farmer's local inputs and management capacity for their successful adoption, implying that the factors that influence their adoption may not necessarily be similar to those that were important in the adoption of green revolution type technologies.

Second, the green revolution technologies were applied to annual crops, while the improved banana production management technologies are used on a perennial crop, and hence have cumulative effects on the yield. This has implications for the modelling of decisions to be made by these farmers. For example, when a farmer is deciding on whether to apply the improved banana production management technology, he/she must not only look at the crop productivity as it is at the present but also as it will be in the future as a result of the cumulative effects. As such, the use of on-farm labour and non-labour inputs can be viewed as investments in systems that will presumably yield a time-path of positive anticipated benefits if adoption occurs

(Lee, 2005). When the crop is valued as an asset that can be passed on to coming generations, then the household composition is likely to come into play in making crop management decisions.

3.2. Determinants of the adoption of low external input crop management technologies

In the post-green revolution, there has been an increasing interest in agricultural systems that employ a reduced use of external off-farm inputs (inorganic fertilizers, pesticides, mechanical inputs), and in the use of improved management techniques and practices. This interest originates from a number of sources outlined in Lee (2005). To mention but a few examples, one of the related concerns has been the affordability of the external input (i.e. fertilizers, pesticides and mechanical inputs) whose price and/or lack of accessibility often make them unavailable or unaffordable to resource-poor farmers. Another source of interest has been the environmental effects of modern agriculture, and impacts such as pesticide contamination, deforestation and the degradation of ground water and surface water resources, which threaten environmental quality.

Low external input technologies have been commonly developed for land management and integrated pest management. The land management technologies (such as agro-forestry, alley farming and zero or minimum tillage) can be applied in the production of any crop on the farm, while integrated pest management technologies are often crop-specific. The improved banana production management technologies investigated in the present study cut across these two subcategories. Some components involve land management techniques (such as mulching, and manure application) while others, e.g. sanitation of the mat, are dual-purpose. For example, de-suckering and post-harvest management of banana residues is useful in the control of pests and diseases but also facilitates the recycling of nutrients and the maintenance of the soil nutrient status. The adoption of low external input technologies has been well documented (for a detailed review see Lee, 2005).

The properties or characteristics of low external input technologies are one of the most important determinants of adoption patterns. The role of technological

characteristics in determining the rate of technology adoption was established in earlier adoption studies (Rogers; 1983, 1995). Rogers (1995) hypothesized five technology attributes, as perceived by potential adopters, that affect the rate of adoption, namely, (1) relative advantage: the degree to which an innovation is perceived as being better than the idea it supersedes, whether measured by economic or social criteria or its convenience or the satisfaction it provides; (2) compatibility: the degree to which an innovation is perceived as being consistent with the existing values, past experience, and needs of potential adopters; (3) complexity: the degree to which an innovation is perceived as being difficult to understand and use - innovations that require more skills-building and learning would be more complex than innovations that are less knowledge-intensive; 4) trialability: the degree to which an innovation may be experimented with on a limited basis. (Innovations that are easy to experiment with on a partial basis are adopted more rapidly than innovations that are less easy to experiment with. Lump-sum innovations, for example, would be difficult to experiment with since one cannot acquire them in small units, whereas divisible innovations would be easy to experiment with); and (5) observability: the degree to which the results of an innovation are visible to the potential adopters.

In the light of the first two technological attributes, the location-specific nature of the low external input technologies puts a premium on their adaptation and appropriateness in meeting the agro-ecological and social-economic conditions relevant to specific regions, consequently limiting the set of farming constraints they can address in both biophysical and economic environments (Lee, 2005). For example, Adesina et al. (2000) show how a technology technically developed to enhance the physical environment was adopted due to its complementary economic attributes. In south-western Cameroon the authors found that farmers in villages facing a fuel wood scarcity were more likely to adopt alley cropping systems over conventional bush fallow rotations compared to farmers who did not face such constraints. Also, biophysical factors figure prominently in influencing the adoption patterns for integrated pest management, agro-forestry and soil conservation in Central America (Ramirez and Schultz, 2000). Shiferaw and Holden (1998) show that the adoption of conservation technologies is likely to increase with the slope of the land. Clay et al. (1998) find evidence that farmers in Rwanda tend to invest in soil conservation on slopes of medium grade.

The relatively high labour intensity of the low external input technologies has also been recognized (Lee, 2005). Generally, the seed-fertilizer technologies of the green revolution were hypothesized to be more labour-intensive than traditional varieties and practices. Unlike the green revolution type technologies, however, the low external input technologies tend to substitute labour for capital (high external inputs). This means that the availability of family labour, labour market imperfections and credit constraints all affect the adoption of low external input technologies. For example, Ersado et al. (2004) found that the health status of farm family members influences the adoption of productivity and land-enhancing technologies in northern Ethiopia. Market imperfections are also identified as important determinants of the adoption of low external input technologies (Shiferaw and Holden, 1998).

Many of the low external input technologies are complex. The adoption of improved banana management technology, to cite one example, involves a wide range of management decisions. The farmer has to decide as to whether to apply the technology or not, which practices to use for which constraint (i.e. match the appropriate technique with the respective constraint), which method to use and how to use it in implementing each technique, as well as the timing of the techniques (Tushemereirwe et al., 2003). The combination of the techniques and the timing of their labour inputs must be well managed to be optimal (Tushemereirwe et al., 2003). Such decisions require a high management capacity that may not have been so critical in the adoption of green revolution type technologies.

The management capacity of the farmer depends on a number of factors but probably no factor is as important in improving management skills as information dissemination and the knowledge it generates. Information may create a problem awareness that marks the beginning of change in the management system, including technology adoption. There is evidence that farmers' perceptions of soil erosion or fertility decline encourage the adoption of soil conservation practices and land productivity enhancing technologies (Ervin and Ervin, 1982; Shiferaw and Holden, 1998; Mbaga-Semgalawe and Folmer, 2000).

3.3. **The role of institutions and social networks in adoption decisions**

The critical role of management capacity and information in the adoption of low external input technologies means that the mechanisms through which information and knowledge are developed, transmitted and diffused are critical to these systems. Information about a technology can come from own experimentation and/or external sources. Information from external sources comes from formal institutions such as public sector extension services, non-governmental organizations (NGOs), the mass media, or through informal mechanisms such as farmers' organizations or networks of friends, relatives and acquaintances. Various sources of information have varying costs and, depending on the economic, social, location and demographic characteristics, different potential adopters may prefer different sources of information (Wozniak, 1993).

Institutions play a role at all levels, as in the high external input technologies (Lee, 2005). However, in developing economies, formal institutions are constrained by inadequate funding for public extension and most farmers rely on informal mechanisms for information about new technologies. The fact that farmers learn from other farmers underlies most studies of social learning in the adoption of agricultural innovations. Literature indicating the importance of social learning regarding technology adoption is extensive (e.g. Foster and Rosenzweig, 1995), but most of these studies do not explain how the information is diffused from early adopters to potential adopters. Nevertheless, as Montgomery and Casterline (1998) maintain, information about choices is likely to be drawn from the individual's social network rather than from the whole village. Conley and Udry (2001) also demonstrate that information generated by early adopters diffuses through sparse social networks, contrary to the assumption of free availability in the whole village.

Rogers (1995) identifies four key aspects of communication behaviour that encourage the adoption of innovations: (1) greater social participation, (2) a high level of interconnectedness, (3) being more cosmopolitan, and 4) opinion leadership. However, few economic studies on technology adoption have included such social factors in the econometric models of technology adoption, perhaps because they are not easily measured. Social capital has usually been linked to information diffusion

(Narayan, 1997; Collier, 1998), leading to a growing interest in social capital as a means of facilitating the adoption of new technologies (Isham, 2000).

3.4. Agricultural household models and technology adoption

The models developed in the early studies of technology adoption were conceptualised within the neoclassical theory of production. Within the neoclassical theoretical framework, profit maximization is assumed to be the only objective underlying the production behaviour. Factor allocation decisions are based on marginal productivity, which is assumed to be uniform across farms (producers). By assuming profit maximization, the modelling of household decision making postulated the existence of perfect markets for output and input goods, including labour and credit, thus implying that production and consumption decisions are recursive (Singh et al., 1986; de Janvry et al., 1991).

When all markets work and all prices are exogenous, the household decision making process becomes recursive and the profit maximization assumption is appropriate for analysing production behaviour. When not all markets work, the production and consumption decisions are interdependent (Singh et al., 1986; Sadoulet and de Janvry, 1995; Taylor, 2003), which inevitably makes the farm household's production decisions dependent on its consumption demand.

Perfect market conditions are rare, particularly in developing economies. Although this problem was recognized, few attempts were made in the early adoption literature to formally model the impact of market constraints on the adoption of new technologies. In particular, market imperfections arising from high transaction costs were ignored. The focus was more on the role of profits and risk in technology adoption. The role of risk was incorporated by assuming that farmers maximize expected utility over income or profits (Just and Zilberman, 1983). Subsistence production was dealt with under risk behaviour and analysed using safety-first approaches (Hammer, 1986).

Increasingly, the starting point for micro-economic research on small-farm economies, whether theoretical or applied, is an agricultural household theoretical framework. One of the earliest agricultural household models is associated with Chayanov (1925) cited in Singh et al. (1986). Chayanov used his model to examine the relationship between labour allocation to on-farm production and leisure by the

peasant households. He observed that peasant households were not simply maximizing profits but rather had a subjective equilibrium within which they equated the utility of household consumption with the marginal utility of leisure. He showed that, in the case of poor labour markets, on-farm labour supply was a function of household demographic factors (i.e. household size and composition) rather than the wage rate, as in the case of perfect market conditions. Since his analysis the agricultural household model has evolved in a variety of ways and has been applied extensively to analyse household consumption, production and labour supply behaviour. Some of these studies are reviewed in Singh et al. (1986).

The key feature of agricultural household models is the non-separability of the production and consumption decisions. The issue of separability depends on whether or not there is a difference between the market prices of production-consumption goods and their "shadow price" within the household (Sadoulet and de Janvry, 1995; de Janvry et al., 1991). Household production and consumption decisions cannot be separated unless the decision price is exogenously determined in the market. When the shadow price is endogenously determined by the interaction between household demand and supply, consumption choices affect production decisions. Consumption and production decisions are said to be "non-separable". Price endogeneity may arise under a number of circumstances (Singh et al., 1986; de Janvry et al., 1991; Sadoulet and de Janvry, 1995). It may be present due to production risks (Roe and Graham-Tomasi, 1986), price risk (Saha, 1994a; 1994b), or the high transaction costs that are endemic to poor economies (de Janvry et al., 1991; Edmeades, 2003).

High transaction costs in the rural areas of most developing economies result from the high transportation costs associated with poor infrastructure and long distances from the markets (Binswanger and McIntire, 1987; Sadoulet and de Janvry, 1995). The existence of transaction costs implies that even if a perfect market for the commodity existed in a particular distant location, agents would have to incur high costs to access this market, thus creating a wide band between the sale price and the purchase price. A household facing a wide price band for a particular commodity or factor may prefer to be self-sufficient in that commodity or factor when the gains from participating in the market are less than the transaction costs. Although there may be extreme cases of a complete absence of markets, in most cases a market for a commodity exists in

which some households may participate while others do not. Hence, market failure is characterized as household-specific rather than commodity-specific (de Janvry et al., 1991).

In the literature, most of the agricultural household models that examine the impact of market constraints on household behaviour take the household as acting independently of other households. Prices are endogenously determined by equating the household's demand with its own supply. The household is assumed to have fixed time, cash endowment and other productive assets. The role of social networks as an alternative productive asset through which the supply of goods and services (i.e. income or information) can be accessed has not been formally incorporated in agricultural household modelling despite its recognized role in overcoming transaction costs (Binswanger and McIntire, 1987; Bromley and Chavas, 1989; Fafchamps and Minten, 1999). With high market transaction costs and constraints in formal institutions, the exchange of goods and services among households in developing economies is known to take place within social networks (Bromley and Chavas, 1989). Therefore the present study attempts to extend the basic household model by allowing the household's exogenous income and knowledge accumulation process to be functions of social capital.

3.5. Summary

With the high population growth rates relative to the growth in agricultural productivity in Sub-Saharan Africa, problems associated with technology adoption have come increasingly to the fore. In the Ugandan agricultural sector, many important questions regarding technology adoption and agricultural productivity are evident. It has been the purpose of this chapter to cover most of these issues in an introductory manner. The objective is to establish key elements to be used in the economic analysis of technology adoption in the Ugandan banana sub-sector.

Among other things, the incidence and extent of technology adoption is determined by the nature of the technology. If the new technique is knowledge-intensive, its inter-farm and intra-farm adoption will be slow and most likely biased towards those with better access to information. The extent and pattern of adoption of scale-neutral

technologies is also subject to their technical and economic properties as evaluated according to the endogenous as well as exogenous factors characterizing the potential adopters. However, the nature of the technology is not the only determinant of technology adoption. Other social, economic, institutional and physical factors may intervene in the process. Technological change can therefore be biased towards certain producers even where the innovation involved is not of a highly capital-intensive type.

This chapter has also suggested that where market imperfections impede the participation of households in markets and hence economic decisions, social capital may be drawn upon to reduce the consequent transaction costs. Economic studies that explore the efficacy of social capital in shaping household production behaviour are still rare. Given the importance of social capital in this study, the next chapter will be devoted to exploring this concept in more detail, as well as the mechanisms through which it may influence adoption decisions.