Who adopt supplemental irrigation using farm ponds in Burkina Faso? An econometric analysis of the adoption of agricultural innovation

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ABSTRACT

Facing rainfall variability, Burkina Faso's agricultural research proposed an innovation: supplemental irrigation using water harvested in small farm ponds close to the fields. The technique consists in digging a farm pond, harvesting run-off water after rain, and irrigating crops during the dry spells of the rainy season. Despite the involvement of the government, local and international organizations, the innovation still has a low adoption rate. This article analyzes, using an econometric model, the factors determining the decision of farmers to adopt the innovation, by focusing on farmers' psychosocial characteristics. 315 farmers located in 42 villages were interviewed. The analysis showed that young farmers are more likely to adopt the innovation. Adoption is higher for farmers who have preferences for growing vegetables. Adoption is also higher for farmers who have more visits from agricultural field officers, and in villages where farmers need to have a prior collective agreement. Farmers with a high social status are more likely to adopt than those who do not. In addition, the perception of the recurrence of dry spells is a factor that involves the decision of farmers to adopt. However, adoption is lower for farmers who have access to another source of water around their farm, such as wells or dams. And, the perception that a failure in the adoption of the innovation might trigger mockery from neighbors or a loss of social prestige is a factor that limits the decision of farmers to adopt. Results showed that econometric modeling taking farmers' psychosocial characteristics into account and using socioeconomic and institutional variables can lead to a better understanding of the determinants of the farmers' decision to adopt an innovation.

Key words: Agricultural innovation, Adoption, Farmers, Farm ponds, Supplemental irrigation.

1. Introduction

Supplemental irrigation using farm ponds is an innovation that has recently spread in Asia (Oweis and Hachum 2006) but very little in sub-Saharan Africa. This agricultural innovation involves digging a farm pond about 300 cubic meters in size and collecting runoff water from the land. Using these individual or collective farm ponds, farmers can irrigate their crops during the dry spells of the rainy seasons (Zongo and al. 2015). Some tests were first conducted in Burkina Faso (Dugué 1987; Fox and Rockström 2000). The innovation is presented as a technique to better deal with the water deficit of rainfed crops (Fox and al. 2005; Pathak and al. 2009; Zongo and al. 2015; Sanfo and al. 2017).

With the support of some local and international organizations, the government of Burkina Faso is currently trying to promote the innovation to secure traditional rainfed crops such as corn. To that end, some farmers have received technical assistance or subsidies. It involves: 1) tools to dig the pond (e.g. pickaxes, shovels and wheelbarrows) or irrigating equipment (e.g. pedal pumps and motor pumps); 2) support in the form of "food for work" (e.g. bags of rice or cowpeas); and 3) in the form of cash (ranging between 50,000 and 100,000 CFA francs, i.e. between 75 and 150 euros). Despite this support, few farmers are implementing the innovation, and this situation tends to be similar to other cases in Burkina Faso (Venot and al. 2017).

The reasons of the low adoption rate are not well known in Sahelian countries, where drought has a strong impact on agricultural production (FAO 2018). Most studies on the adoption of agricultural innovations focus on socio-economic factors, such as property rights, age of the farmer, farm size or household income (Binswanger 1978; Feder and Umali 1993). It is now recognized that the process of an innovation adoption does not only depend on socio-economic factors, but also on preferences and perceptions related to the characteristics of the technique and the risk involved (Adesina and Baidu-Forson 1995; Ghadim and Pannell 1999; Roussy and al. 2017), and on institutional variables (Adesina and al. 2000).

The aim of the present study was to analyze, using an econometric model, the factors that determine the decision of farmers to adopt an innovation, by focusing on farmers' psychosocial characteristics. After presenting the theoretical framework (first part) and the methodology of the study (second part), we discuss the results obtained (third part).

2. Theoretical framework of the study

We analyze the adoption of the innovation according to the paradigm of methodological individualism and assuming that the individual is led in his or her choices by two types of motivation: intrinsic (seeking to maximize individual utility) and extrinsic (taking social constraints into account) (Ryan and Deci 2000).

2.1. Intrinsic motivation, or the adoption by maximizing expected utility

A farmer is considered as an agent who maximizes his or her utility by optimizing innovation adoption choices (Faure and al. 2018), and taking his or her level of risk preference and perception into account.

Innovation as a set of characteristics

Most economic studies on the adoption of agricultural innovations are based on consumer theory, which analyzes individuals' consumption choices by combining preferences and budgetary constraints. The consumer theory makes it possible to identify the combination that gives the most satisfaction to the consumer, i.e. consumer utility maximization.

Based on this neoclassical framework, Lancaster (1966) developed the new consumer theory stipulating that the utility of a property or service is determined by its characteristics. It thus makes the notion of "utility" more concrete by linking it to the characteristics. For instance, if we consider supplemental irrigation using farm ponds, it is not the object adopted that gives satisfaction to the farmers, but rather the service provided by adoption. The service can consist in securing yields during the dry spells of the rainy season or using the farm pond for other purposes, such as manufacturing bricks or watering livestock. Some authors, for example Asrat and al. (2010) confirmed that decisions to adopt an innovation by farmers mainly depend on the characteristics of the innovation.

The characteristics of the innovation are also mentioned in the theory of innovation diffusion developed by the sociologist-statistician Everett Rogers. Rogers (1983, p. 211-233) describes the five characteristics that explain the adoption of an innovation: relative advantage (choice over other types of innovation, usually in terms of profitability), compatibility (nature of existing social norms, experiences and individual needs), complexity (difficulty related to understanding and use), trialability (basic experimentation) and observability (results visible in other adopters). These different characteristics are the attributes of the perception of the innovation. They are interrelated but conceptualized differently. Their role is to predict or determine the rate of adoption of an innovation. Rogers' work is confirmed by most subsequent empirical studies.

Similarly, early studies also showed that perceptions related to the characteristics of an innovation play an important role in the decision to adopt (Ruttan 1996). For instance, perceptions of the quality of sorghum seed varieties (used to make a dish called *tô*, based on semolina) in Burkina Faso and the cooking time of mangrove rice varieties in Guinea are factors that influence the decision to adopt these varietal innovations (Adesina and Baidu-Forson 1995).

Risk preferences and perceptions

Risk preferences and perceptions also play a role in the adoption of agricultural innovations (Roussy and al. 2017). Several studies conclude that the adoption rate of agricultural innovations is hindered by farmers' risk aversion (Feder and Umali 1993; Ghadim and al. 2005; Duflo and al. 2008; Menapace and al. 2015). For example, Duflo and al. (2008) explain that the possibility given to Kenyan farmers to purchase inputs in small quantities reduces their risk aversion, thus justifying at least the use of a small amount of fertilizer.

Similarly, studies show that the perception of risk is a determining factor in adoption decisions (Shapiro and al. 1992) and identify a positive correlation between risk aversion and risk perception (Menapace and al. 2012). In addition, the perception of the risk in the decision to adopt can change over time, as farmers receive information (Ghadim and al. 1999) or technical and financial support. This may be the case of some farmers in the adoption of this innovation, since most of them did receive either technical assistance or subsidies.

2.2. Extrinsic motivation, or the influence of social pressure on the farmers' choices

Social norms

Some decisions to adopt an innovation fall outside the scope of economic analysis. They depend on arbitration between personal (e.g. profit maximization) and collective (e.g. protection of a natural resource) interests (Lynne 1995). Lynne (1995) criticized neoclassical economic models, by referring to the pioneering work of Sen (1977), Hirschman (1985) and Etzioni (1986). In Sen's opinion (1977), an economic agent cannot be purely selfish. Economic agents make decisions that account for their personal interest (first-order preferences) but also their social commitment (second-order preferences). And if economists base their analyses on a purely selfish individual, namely homo economicus, it may be because economists can only take decisions related to profit into account.

In general, economic analysis should take into account both individual and social norms that govern them (Hirschman 1985). Two main types of utility can be then identified: pleasure or personal satisfaction, and moral values (altruism, voluntary or collective action) (Etzioni 1986). The moral values are the rules of society. They represent the social processes that shape farmers' decision (Jones and Boyd 2011). For example, the fear of being mocked by others or the fear of losing social prestige, when there is a failure to adopt an innovation, may be a barrier to adoption.

Interpersonal networks

Early work on the adoption and the diffusion of innovation was led by rural sociology (Rogers 1983). The "S"-shaped adoption curve was first developed by American rural sociologists (B. Ryan and Gross 1943), in their analysis of the spread of hybrid corn seed in Iowa describing the adoption of innovations over time. Furthermore, rural sociologists developed an analytical model based on socio-psychological aspects, through an analysis of interpersonal networks of information exchange. It is about the information exchanged between individuals who have already adopted an innovation and those who would potentially be influenced to adopt (Ruttan 1996). In developing countries, the first studies also revealed the importance of communication in the process of the diffusion of an innovation (Rogers 1976). In our research, the interpersonal networks of information exchange are analyzed by integrating the institutional actors (i.e. Government, NGO and research centers) that are strongly involved in the implementation of the innovation.

This study also makes use of the "profit-sharing" scheme. Indeed, the profit-sharing scheme helps to have a good understanding of the adoption and diffusion of the innovation, by stressing that: "adopting an innovation means to adapt it" (Akrich and al. 1988b). Then, the innovation is analyzed with its attributes of perception and the environment in which the innovation evolves. This scheme allows to take into account the different actors who participate to its promotion and adoption, and their links to it. These actors are: (1) institutional actors who visit farmers and support some of them to adopt; and (2) all farmers who further the innovation according to their environment.

3. Methods

3.1. Study area

Agriculture in Burkina Faso is mainly manual and almost entirely rainfed, oriented towards grain production, including millet, corn, sorghum, beans and groundnut, and some vegetables. Soil fertility is gradually deteriorating because of the disappearance of fallow due to rapid population growth. Producers apply very little fertilizers. Traditional soil fertility management methods, such as agroforestry, manure, compost and rotation with legumes, do little to compensate for the organic and mineral deficit of the soil. More mineral and organic nutrients should be provided, but the impact of these inputs on yields is very often reduced by dry spells. Supplemental irrigation can make fertilization economically more attractive.

There are already a few hundred farm ponds in Burkina Faso, thanks to the involvement of the government, international organizations and research centers. In addition, harvesting rainwater in ponds is a very old practice in Burkina Faso (Marchal 1986; Guillaud 1993). These traditional ponds, commonly known as "*boulis*" in the Mooré language, collected water mainly for watering livestock or for other uses, such as manufacturing bricks.

Our study area is characterized by small family farms, in average less than 4 hectares in size. The areas are mainly populated by the Mossi ethnic group. In general, farmers have traditional rights on their land holding. Land is transfered from one generation to another. Land ownership was ensured by a traditional land chief. Land tenure is usually obtained within the lineage or through loans. Land grabbing by urbans has led some farmers to sell part of their land. However, selling land is the subject of disapproval in these areas, as, according to the traditional values, land is inalienable.

3.2. Field surveys

Two surveys were conducted. Firstly, semi-structured interviews (conducted by the same person, between May and July 2019) with 33 farmers who dug farm pond and the main institutional actors of the innovation (16 professional actors and 2 traditional actors)[1]. Each interview lasted about one hour. The data were collected in writing following an interview guide, and supported by voice recordings that enabled the transcription of the statements. The main topics discussed were the adoption of supplemental irrigation using a farm pond, farmers' preferences and perceptions of the characteristics of the technique, the social norms, and the role of institutional actors. Interviews were conducted either in local language or in French, as appropriate.

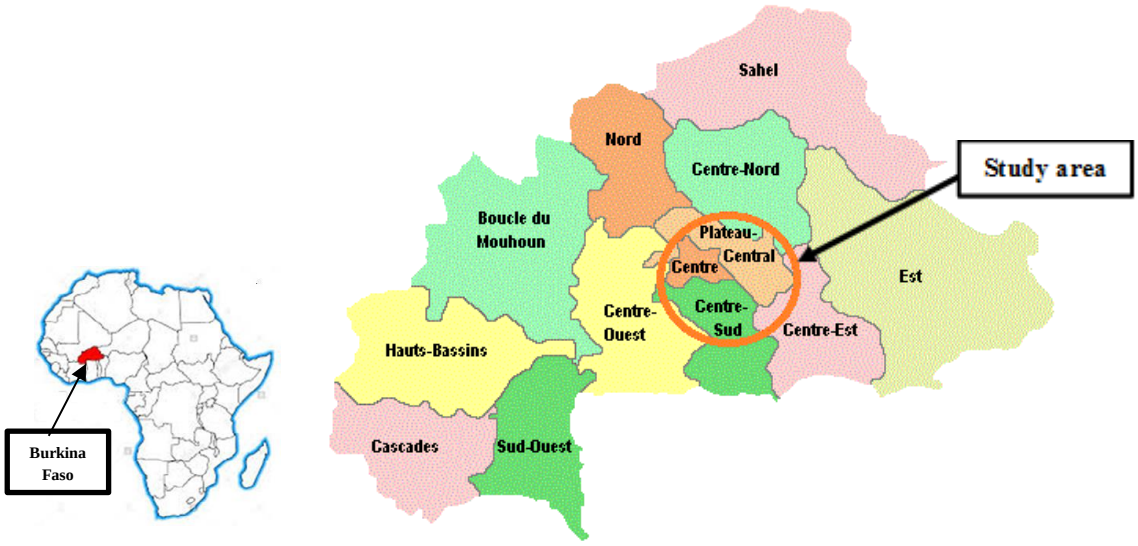
This first survey helped us to design a questionnaire that we aim to address to highlight determinants of farm ponds' adoption. 315 farmers located in 42 villages were interviewed for this purpose in February 2020, by 4 investigators. The survey lasted about 40 minutes per farmer. The data were collected in writing by following guideline.

Farmers who adopted the innovation were randomly selected from the list of adopters provided by the Government department of agriculture which supported the survey. However, this selection was reduced taking the accessibility of villages into account, as some farmers resided in areas not recommended or prohibited at the time of the survey for security reasons. Thus, we conducted the surveys in villages located within a radius of about 50 kilometers around Ouagadougou (Figure 1). This radius includes 3 regions: the Central Plateau, the Center and the South-Center. The surveys were carried out in all the villages (42) in these 3 regions, located in the survey area and having at least one adopter. 128 adopters were surveyed. Based on the list of the Government department of agriculture, it means 17% of all the adopters in Burkina Faso and 73% of the adopters in the study area.

[1] Professional actors belong to local and international organizations. They are the main actors who promote supplemental irrigation in Burkina Faso, by piloting or financing its implementation. Traditional actors are among the proponent of traditional habits and customs in Burkina Faso.

The non-adopters were also selected randomly, according to the following way: only villages referenced in the list of the Government department of agriculture as having at least one adopter were considered; a non-adopter was selected by respecting a distance of 200 meters between his or her concession to an adopter. As the results of the first survey showed that being owner is a necessary condition to adopt (because only farm owners can get technical or financial support from institutional actors), we excluded non-adopters who specified that they did not own their land. Finally 187 non-adopters were surveyed.

Figure 1: Field survey localization in Burkina Faso



3.3. Analytical model

Let Y be the variable measuring the decision of farmers to adopt or not the innovation. By considering a sample of farmers with indexes i = 1, ..., n (in this study n=315). For each farmer, we observe whether there is adoption or not.

$$Yi = \begin{cases} 1 \text{ if the farmer has adopted the innovation} \\ 0 \text{ if the farmer has not adopted the innovation} \end{cases}$$

Yi is a dichotomous (binomial) variable to explain. Since we consider that the decision to adopt {1} or to do not adopt {0} is not due to chance, we assume that the observed values of Yi depend on a set of explanatory variables denoted Xi following a functional relationship. The explanatory variables Xi are independent, in the sense that their variations are observed independently of the functional relation with the variable to explain Yi (Manski and McFadden 1981; Greene 2011, p.680).

The probability to observe Yi = 1, conditionally to the explanatory variables Xi, is the variable of interest in the model. Thus, based on Wooldridge (2018, p.681), this probability is written as:

$$P(Yi = 1 / Xi) = F(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k) = F(\beta_0 + X\beta) \quad \textbf{(1)}$$

The function F is positive and comprise between 0 and 1[2]: $0 < F(z) < 1$ for any real number z.

In general, the specification of discrete choice models is done by using two distribution functions: the normal distribution and the logistic. The probit model is based on the normal distribution, and it has been widely used by economists (Wooldridge 2018, p.682). Logistic regression allows the coefficients to be interpreted in terms of odds ratios (e.g. the ratio between the probability of an event occurring and the probability of it not occurring; or the ratio between the probability of an event occurring in one group and the probability of the same event occurring in another group). In this study, the probit model is used to perform the econometric analysis. Indeed, the likelihood ratio test showed that the p-value of the chi square test of the change in deviance and degrees of freedom between this probit model and the model with only a constant (intercept) is very significant ($P < 0.001$). Thus, our model as a whole fits significantly for the econometric analysis and the conceptual model is given as:

$$F(x) = \int^{x}_{-\infty} \varphi(t)\, dt = \phi(x), \quad \textbf{(2)}$$

[2]The use of linear probability (*E (Yi/Xi) =P (Yi=1/Xi) =Xiβ)*, to estimate the parameters of the model by ordinary least squares method – OLS, presents some weaknesses (e.g. the error term is not normally distributed, and the value of the dependent qualitative variable Yi is not necessarily between 0 and 1). Thus, the better estimation is by maximum likelihood, using logit or probit models.

With ϖ (t) density of the standard normal distribution:

$$\varpi(t) = \frac{1}{\sqrt{2\Pi}} \exp\left(-\frac{1}{2} t^2\right) \quad \textbf{(3)}$$

3.4. Empirical model

The qualitative dependent variable Y is named ADOP, which takes the value 1 if the farmer adopted supplemental irrigation using farm pond and 0 if no adoption occurred. The set of explanatory variables X are presented below, and descriptive statistics for all the variables in the empirical model are given in Table 1.

Results of the first survey showed that being farm owner is very important. Land right is positively linked to adoption of the innovation and without land right no adoption can be done. Thus, our sample excluded non-adopters who did not have land right (i.e. traditional or other rights). However, following numerous studies (Oloo and al. 2013; Ngigi and al. 2018), we assume that women may be less likely to adopt the innovation, as in rural areas they do not use to have land rights. Land right is correlated with the gender of the farmer. For instance, only 9% of the sample are women.

In addition, we observed the compatibility between the spiritual beliefs of the farmer and the adoption of the innovation. This compatibility was not obvious at first, because in Burkina Faso there are ceremonies at which offerings and sacrifices are made to ancestors to bring rain. Even if rainwater harvesting in ponds is a very old practice in Burkina Faso (Marchal 1986; Guillaud 1993), people did not use this rainwater harvested to irrigate grain crops. However, the results of the surveys showed that there is a social acceptability of the innovation. For instance, 45% of adopters in the first survey attend traditional ceremonies made for bringing rain.

Table 1: Sample statistics of variables used in the empirical econometric model

Variables	Mean	Standard deviation	Minimum	Maximum
AGE (age of farmer)	44.08	12.0428	19.00	75.00
EDUC (educational level of farmer on a scale of 0 to 5)	0.90	0.9967	0.00	5.00
ADVEN (number of times the farmer went to adventure)	0.60	0.6223	0.00	4.00
FSIZE (total size of the farms of the farmer in hectare)	3.55	2.2484	0.25	20.00
HIRE (index of labor force hiring by the farmer)	0.41	0.4925	0.00	1.00
NFINC (incomes in CFA francs related to non-farm activities)	25,548	32,702.39	0.00	250,000
FAID (financial aids in CFA francs given by institutional actors to farmers to adopt the innovation)	53,144	39,226.38	0.00	200,000
LOAN (index of the farmer's access to loan)	0.23	0.4206	0.00	1.00
WATER (access to water around the farm, such as well or dam)	0.54	0.4989	0.00	1.00
VEGET (area in hectare of vegetables grown)	0.38	0.4072	0.00	2.50
SOSTA (social status in the village, such as chief of village)	0.43	0.4961	0.00	1.00
VISIT (number of visits a farmer has per year)	3.79	4.2419	0.00	20.00
RISKPOND (perception of the risk linked to the adoption)	0.35	0.4785	0.00	1.00
RISKDROWN (perception of the risk of drowning)	0.45	0.4980	0.00	1.00
DROUGHT (perception of dry spells during these last years)	0.93	0.2606	0.00	1.00
DIFFI (perception of the level of difficulties linked to adoption)	2.15	0.8558	0.00	3.00
CONNOT (+ / - connation of 3 words linked to the innovation)	0.55	0.3829	0.00	1.00
SHAM (fear of mockery from family or neighbors)	0.62	0.4856	0.00	1.00
AGREEMT (need to have the agreement of traditional chiefs in the village before to adopt an innovation)	0.58	0.4937	0.00	1.00
MYSELF (own decision maker to adopt in his or her farm)	0.89	0.3148	0.00	1.00
OBSR (adoption or not by observing existing farm ponds)	0.60	0.4925	0.00	1.00

AGE is a variable that measures the age of farmers. Some studies have shown that young farmers are more innovative because they have a longer planning horizon (Gould, and al. 1989; Adesina and al. 2000). It was hypothesized that AGE is negatively related to adoption of the innovation.

EDUC is a variable that measures the level of education of farmers. The variable takes value on a scale of six points, from 0 to 5: 0 (farmers did not go to school), 1 (farmers studied in local language school or in religious school), 2 (farmers studied in elementary school), 3 (farmers studied in college), 4 (farmers studied in high school) and 5 (farmers studied in university). Farmers who went to school may have high capacity to adopt a new agricultural technology. It was hypothesized that EDUC is positively related to adoption of the innovation.

ADVEN is a variable that measures the number of times the farmer went to adventure. We assume that farmers who have already gone to adventure are opened mind and they are able and more receptive to try new technology. It was hypothesized that ADVEN is positively related to adoption of the innovation.

FSIZE is a variable that measures the size of the farm. Farmers need space in their farm to adopt the innovation. Thus, farmers, who do not have enough space to dig the pond, cannot adopt the innovation. Large farm owners are assumed to be more favorable to adopt the innovation.

HIRE is a dummy variable that takes the value of 1 if the farmer hires labor force (i.e. paying wages for workers or ensuring the food intake of a community labor) and 0 otherwise. The variable allows to see if the farmer used to hire labor force and if he or she has the financial capacities for that. Digging a farm pond to practice supplemental irrigation requires a high labor. For example, more than 90% of adopters dug and excavated their farm pond by hand using shovels and pickaxes. Family is the main source of labor for most farmers. But, more often, only family labor is not enough, because the implementation of the farm ponds involves hard work. Thus, farmers who can have more labor supply would be expected to adopt this innovation. It was hypothesized that HIRE is positively related to adoption of the innovation.

NFINC is variable that measures the level of incomes in CFA francs related to non-farm activities of the farmer. This variable allows to see if the farmers have others sources of incomes and the impact of that on their decision to adopt a new technology. We assume that the more farmers have incomes, the more they will be able to adopt new technologies. It was hypothesized that NFINC is positively related to farmers' decision to adopt.

FAID is a dummy variable that takes the value of 1 if the farmer received financial support to implement the technique and 0 otherwise. During the first survey, we noticed that 85% of adopters received financial support. Farmers' behavior can differ depending on whether or not they receive support (Ghadim and Pannell 1999). It was hypothesized that FAID has a positive impact on farmers' decision to adopt.

LOAN is a dummy variable that takes the value of 1 if the farmer has already taken out a bank loan and 0 otherwise. To adopt the innovation, farmers need to have financial capacities. Thus, having access to a bank loan may improve the capacity of farmers to adopt new technologies. It was hypothesized that if farmers have access to bank loans, it influences positively their decision to adopt the innovation.

WATER is a dummy variable that takes the value 1 if the farmer has access to a source of water, such as a well or a reservoir and 0 otherwise. We suspect that farmers who already have access to water around their farm may not want to dig pond to practice supplemental irrigation. It was hypothesized that having access to a source of water is negatively linked to adoption of the innovation.

VEGET is a variable that measures the area of vegetables grown. Through the promotion of the innovation, institutional actors are currently focusing on subsistence crops, mainly corn. Corn is among the most important grain crops produced in Burkina Faso. The dry spells during rainy seasons caused by rainfall variability reduce the yields of corn. However, according to the results of the first survey, farmers adopt the innovation to irrigate cash crops, or for other profitable uses, but not to irrigate subsistence crops. We noticed that even farmers who produced corn using the farm pond sell it as fresh corn, like a vegetable, which is economically more interesting than bags of dry corn. We assume that farmers who have preferences for growing vegetables are more likely to adopt the innovation than those who do not. It was hypothesized that VEGET is positively related to adoption of the innovation.

SOSTA is a dummy variable that takes the value of 1 if the farmer has high social status and 0 otherwise. Having high social status, such as village chief, son of the village chief, or president of farmers' groups or communities, may favor the adoption. This social status gives to farmers the role of "leader" in their village (see Bierschenk and al. 2000) and it may allow them to be supported by agricultural field officer to adopt the innovation. It was hypothesized that SOSTA is positively related to adoption of the innovation.

VISIT measures the number of visits a farmer receives per year from the agricultural field officer. This variable allows to see if the farmer is in contact with agricultural technicians, and if the farmer has access to information on new technologies. We assume that the more farmers receive visits, the more they are able to adopt new agricultural technology. In general, farmers who receive more visits are considered as model farmer (i.e. exemplary farmers who are usually innovators) and they use to benefit support to learn and experiment new technologies from agricultural field officer. It was hypothesized that VISIT is positively related to adoption of the innovation.

RISKPOND is a dummy variable that takes the value of 1 if the farmer perceives that the risk to dig a farm pond to practice supplemental irrigation is very high or high and 0 otherwise (i.e. moderate risk, low risk and no risk). This risk perception is based on the investment needed to dig a farm pond and to purchase irrigation equipment, such as motor pump. Farmers' own experience and the different information they received about an innovation are ways to define their risk perception related to the innovation adoption (Marra and al. 2003). The study also takes the preferences of farmers into account. By using the declarative method, we asked farmers to give their level of risk aversion. Following numerous studies (Feder and Umali 1993; Ghadim and al. 2005; Duflo and al. 2008; Menapace and al. 2015), the results of the first

survey showed that risk aversion is negatively correlated with the adoption. Furthermore, the results showed that the majority of farmers who adopted the innovation perceived the risk to be low. This strong perception of low risk is also explained by the fact that most farmers declared themselves to be very risk takers. Indeed, the risks of loss are generally perceived to be high in people with high risk aversion (Menapace and al. 2015). There is a correlation between farmers' risk aversion and their perception of the risk linked to innovation adoption, and this is confirmed by the correlation test. It was hypothesized that RISKPOND is negatively linked to adoption of the innovation.

RISKDROWN is a dummy variable that takes the value of 1 if the farmer perceives that the risk of drowning linked to the farm pond is very high or high and 0 otherwise (i.e. moderate risk, low risk and no risk). By digging the farm ponds, farmers face to risk of drowning either for their children and their livestock. RISKDROWN is assumed to be negatively linked to adoption of the innovation.

DROUGHT is a dummy variable that takes the value of 1 if the farmer perceives that dry spells of the rainy seasons are more recurrent and then lead to droughts, and 0 otherwise. Since this innovation is presented to farmers as a technique that allows them to cope with rainfall variability, we asked the farmers about their perception of rainfall variability. For example, the results of the first survey showed that more than 90% of adopters considered that there have been long and recurrent periods of dry spells during these last years. The strong perception of rainfall variability may be an important factor in the adoption of the innovation. It was hypothesized that DROUGHT influences positively the decision of farmers to adopt the innovation.

DIFFI is a variable that measures the perception of farmer about the level of difficulties related to the adoption of the innovation (i.e. digging, stabilization, solving leakage problems and securing against drowning). The variable takes value on a scale of four points, from 0 to 3: 0 (not difficult at all), 1 (moderately difficult), 2 (difficult), and 3 (very difficult). During the first survey, data on farmers' perceptions of the innovation showed that 97% of farmers perceived it as difficult. This perception can be explained by the fact that more than 90% of adopters dug and excavated their farm pond by hand using shovels and pickaxes, and 79% of them irrigate their crops manually with buckets. For example, below is a farmer's statement about the perception of the difficulties linked to the practice: "*The main problem I have with the farm pond is permeability. It's not yet stabilized. It wasn't lined with plastic or cement. Our children and animals risk drowning because there is no wire netting. Another problem I'd like to mention is how to water the crops. Watering crops by hand is difficult*". The perception of possible difficulties related to the implementation of the technique can be a limit to its adoption. It was hypothesized that DIFFI is negatively linked to adoption of the innovation.

CONNOT is a dummy variable that takes the value 1 if the farmer gives a positive connotation to the innovation and 0 otherwise. Indeed, interviewees were asked to choose three pictures among ten that represent the innovation according to them. In this study, based on Montginoul and Vestier (2018) methodology, farmers needed to rank each picture and give them a positive or negative connotation. This process allows to see the importance and the connotation given to the three main pictures associated to the innovation by each farmer, and avoiding any subjective interpretation of their responses. Then, we considered that a farmer has a positive connotation of the innovation if between the three pictures chosen there are at least two of them which are connoted positively and vice-versa. This variable will show the level of satisfaction of farmers who adopted the innovation.

SHAM is a dummy variable that takes the value 1 if the farmer think that a failure in the adoption of the innovation may lead to mockery from family or neighbors and 0 otherwise. The fear of mockery from the member of the community is linked to the social prestige. The fear of mockery and losing of social prestige appear as a social norm or value and may be an obstacle to the adoption of the innovation. The results of the first survey showed that the shame to fail in the implementation of the farm pond is one of the factors that can limit the decision of farmers to adopt. It was hypothesized that SHAM is negatively linked to adoption of the innovation.

AGREEMT is a dummy variable that takes the value of 1 if the farmer mentioned that the adoption of an innovation in the village necessarily requires the agreement of traditional chiefs and 0 otherwise. As in Burkina Faso there are ceremonies at which offerings and sacrifices are made to ancestors to bring rain in the village, we suspect that the need of agreement before to adopt an innovation may be a factor limiting adoption in some villages. It was hypothesized that AGREEMT is negatively linked to adoption of the innovation.

MYSELF is a dummy variable that takes the value of 1 if the farmer is the own decision maker of the adoption of the innovation in his or her farm and 0 otherwise. We assume that farmers are more able to adopt the innovation if they can make the adoption decision by themselves, without needing other person agreement such as the husband or the eldest member of the family. It was hypothesized that MYSELF is positively related to adoption of the innovation.

OBSR is a dummy variable that takes the value of 1 if the farmer decide to adopt or not the innovation by observing the existing farm ponds around them and 0 otherwise. The presence of farm ponds in a village may have an impact on the diffusion of the innovation. Indeed, if the implementation of the technique by the early adopters in a village is a success, it will positively influence the decision of adoption of others farmers and negatively otherwise. As the results of the first

survey showed that there are lot of failures in the implementation of the technique, it was hypothesized that OBSR is negatively related to adoption of the innovation.

4. Results and discussion

The model correctly predicted 62% of the decision of both adopters and non-adopters. The results of the empirical model showed that eight variables were significant in the explanation of the adoption of supplemental irrigation using farm ponds (Table 2) : age of farmer (AGE), access to water around the farm, such as well or dam (WATER); area in hectare of vegetables grown (VEGET); social status in the village, such as chief of village (SOSTA); number of visits a farmer has per year (VISIT); perception of dry spells during these last years (DROUGHT); fear of mockery from neighbors or loss of social prestige (SHAM); and need to have the agreement of traditional chiefs in the village before to adopt an innovation (AGREEMT). These eight variables include socioeconomic, institutional and psychosocial variables.

Table 2: Econometric model results of factors affecting farmers' adoption

Variables	Parameter estimate	Standard error	Pr (>|z|)
INTERCEPT	-7.182e-01	8.338e-01	0.3890
AGE (age of farmer)	-2.029e-02	1.095e-02	0.0639 .
EDUC (educational level of farmer on a scale of 0 to 5)	1.049e-01	1.222e-01	0.3908
ADVEN (number of times the farmer went to adventure)	2.454e-01	1.799e-01	0.1727
FSIZE (total size of the farms of the farmer in hectare)	5.654e-02	4.927e-02	0.2512
HIRE (index of labor force hiring by the farmer)	3.648e-01	2.480e-01	0.1413
NFINC (incomes in CFA francs related to non-farm activities)	-1.863e-06	3.277e-06	0.5698
FAID (financial aids in CFA francs given by institutional actors to farmers to adopt the innovation)	2.564e-04	7.406e-03	0.9724
LOAN (index of the farmer's access to loan)	-9.495e-02	2.911e-01	0.7442
WATER (access to water around the farm, such as well or dam)	-1.378e+00	3.038e-01	5.75e-06 ***
VEGET (area in hectare of vegetables grown)	7.628e-01	3.377e-01	0.0239 *
SOSTA (social status in the village, such as chief of village)	5.050e-01	2.613e-01	0.0532 .
VISIT (number of visits a farmer has per year)	6.856e-02	3.295e-02	0.0374 *
RISKPOND (perception of the risk linked to the adoption)	-1.369e-02	2.586e-01	0.9578
RISKDROWN (perception of the risk of drowning)	-1.402e-01	2.446e-01	0.5666
DROUGHT (perception of dry spells during these last years)	1.001e+00	5.280e-01	0.0579 .
DIFFI (perception of the level of difficulties linked to adoption)	-9.587e-02	1.459e-01	0.5110
CONNOT (+ / - connation of 3 words linked to the innovation)	-4.394e-02	3.801e-01	0.9080
SHAM (Fear of mockery from neighbors or loss of social prestige)	-1.143e+00	2.381e-01	1.57e-06 ***
AGREEMT (need to have the agreement of traditional chiefs in the village before to adopt an innovation)	4.417e-01	2.620e-01	0.0918 .
MYSELF (own decision maker to adopt in his or her farm)	2.187e-01	3.669e-01	0.5511
OBSR (adoption or not by observing existing farm ponds)	-2.570e-01	2.656e-01	0.3332

NB : Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

4.1. Socioeconomic variables

The negative sign on the age of farmer (AGE) means that older farmers are less likely to adopt the innovation. The access to other source of water such as well or reservoir (WATER) is not favorable to the adoption of the innovation. Indeed, farmers who have access to water for irrigating their crops do not need to dig a farm pond to collect rain water. The fact that they already have access to water does not motivate them to adopt the innovation. The positive sign on area in hectare of vegetables grown (VEGET) means that farmers who have preferences for growing vegetables are those who would adopt the innovation. As, they look for more water to irrigate vegetables, they will be more interested to adopt regarding the characteristics of the innovation (Asrat and al. 2010). According to farmers, the use of the farm pond to grow vegetables allow them to maximize their utility (Faure and al. 2018), as mentioned in the following statement of a farmer interviewed: "*My farm pond allows me to grow vegetables (e.g. eggplants, tomatoes, zucchini and okra) and corn. Last year at this time in July, I had already sown and my garden had started to produce vegetables. The sale of tomatoes alone brought me about 500,000 CFA francs*". The high social status in a village (SOSTA) has a positive impact on the decision

to adopt. This high social status gives favors to farmers who have it to adopt. In general, their adoption are facilitated and motivated by the technical and financial support they may receive, because of their status in the village.

Some socioeconomic variables are not significant, but they can allow to do some suggestions. The positive sign on the variables about educational level of farmer (EDUC), number of times the farmer went to adventure (ADVEN), total size of the farms of the farmer in hectare (FSIZE), index of labor force hiring by the farmer (HIRE) and financial aids in CFA francs given by institutional actors to farmers to adopt the innovation (FAID) suggests that: educated farmers are more able to adopt the innovation; farmers who have already gone to adventure will be more receptive for trying new technologies; having more space in the farm influence positively the decision to adopt; farmers who are able to hire labor force are more likely to adopt the innovation; and farmers who receive financial support are more motivated to adopt. Furthermore, the negative sign on incomes in CFA francs related to non-farm activities (NFINC) and index of the farmer's access to loan (LOAN) suggest that having more incomes or access to loan does not necessarily lead to the adoption of the innovation. For example, it means that the promotion of the innovation adoption by a credit system will require a strong follow-up to avoid the investment of the money borrowed in other activities.

4.2. Institutional variables

The variable about the number of visits a farmer has per year from the agricultural field officers (VISIT) is significant with a positive sign. It means that the innovation is adopted by farmers who are the more in contact with agricultural technicians. Farmers who receive visits have easily access to information about innovation and they also have more possibilities to learn and experiment the innovation. In general, these farmers are considered as "model farmers" by institutional actors who provide them financial and technical support for adopting new technologies.

4.3. Psychosocial variables

The positive sign on the perception of farmers about dry spells during these last years (DROUGHT) means that the more the farmers have a high perception of drought, the more they will be motivated to adopt. The negative sign on fear of mockery from neighbors or loss of social prestige (SHAM) means that the innovation is not adopted by farmers who have the perception that a failure in the adoption of the innovation might lead to mockery in their village. Contrary to our hypothesis, the results showed that the sign is positive for the variable about the need to have the agreement of traditional chiefs in the village before to adopt an innovation (AGREEMT). Thus, the adoption is higher in villages where it requires to have collective agreement before. Social norms or second order preferences, such as collective action (Sen 1977; Hirschman 1985) are important in the decision of farmers to adopt. For example, below is a statement from a proponent of traditional habits and customs interviewed: "*A farmer alone cannot decide to adopt an innovation in a village. The decision to adopt is collective and it is initially made with the agreement of the land chief. It is once the land chief or the village chief gives the agreement that each farmer can adopt. For example, if you ask farmers about their adoption decision when faced with a technique that is already known, they might tell you that it is up to their personal or individual willingness. However, if it is a new technique that no one has already adopted in the village, they will tell you that the decision to adopt is up to the land chief. Very often, even the village chief cannot decide on the adoption of an agricultural innovation without consulting the land chief. There are traditional values to be respected at the risk of being sanctioned by the community*".

Some psychological variables included in the model are not significant. The negative sign on the perception of the risk linked to the adoption (RISKPOND) suggests that the innovation is more adopted by farmers who have the perception that the risk linked to the adoption is low. The negative sign on the perception of the risk of drowning (RISKDROWN) also suggests that the innovation is not adopted by farmers who perceive that the risk of drowning is very high or high either for humans and their livestock.

In addition, the negative signs on the perception of the level of difficulties linked to adoption (DIFFI) and the adoption or not by observing existing farm ponds (OBSR) suggest that: the more farmers perceive that the difficulties linked to the innovation are high, the less they will adopt it; and the implementation of the innovation by early adopters in a village does not impact positively the diffusion of the innovation. The low rate of adoption can be explained by the fact that there are lot of failures in the implementation. Indeed the words "leakage" and "difficult" are mainly associated with the innovation. The negative sign on the connation of the main 3 words linked to the innovation by each farmer (CONNOT) also suggests that most adopters have a negative perception of the innovation, mainly because of the difficulties and eventually the risk involved. Then, policy makers should work in a participatory way with farmers to improve the innovation, for a better diffusion and adoption.

Lastly, the variable about own decision maker to adopt in the farm (MYSELF) has a positive sign and suggests that after the collective agreement, farmers who cannot make their own decision to adopt in their farm, because they need the agreement of a family member, are less likely to adopt then those who can act by themselves.

5. Conclusion

This study determined the factors that influence the decision of farmers to adopt supplemental irrigation using farm pond, by focusing on the role of psychosocial variables. The econometric analysis showed that the adoption of the innovation is higher for: (1) young farmers; (2) farmers who have preferences for growing vegetables; (3) farmers with a high social status in the village; (4) farmers who have more visits from agricultural field officers; (5) farmers who have a high perception of dry spells occurrences during these last years; and (6) farmers who are living in villages where they need to have a collective agreement before adoption. However, the adoption of the innovation is lower for: (7) farmers who have access to a source of water around their farm, such as well or dam; and (8) farmers who have the perception that a failure in the adoption of the innovation might reduce their social prestige or lead to mockery from neighbors.

We demonstrate using an econometric model that psychological factors play an important role in the decision of farmers to adopt an innovation. The psychosocial variable related to the fear of mockery from neighbors or a loss of social prestige due to a failure in the adoption has more influence in the decision of adoption of farmers, than some classical variables such as the level of education, the size of farm and the incomes related to non-farm activities. Results showed that econometric modeling taking farmers' psychosocial characteristics into account and using socioeconomic and institutional variables can lead to a better understanding of the determinants of the farmers' decision to adopt an innovation.

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