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Preferences of Small-Scale Farmers for Innovative Farming Techniques in Volcanic Highlands in Rwanda

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Abstract

This paper attempted to identify the determinant factors of innovative technologies preferences by small-scale farmers in the Volcanic Highlands in Rwanda. Data used were collected from a random sample of 401 small-scale crop producers using a structured questionnaire in the study area. A logit regression model was specified, whereby a binary maximum likelihood estimation method was used to identify the factors affecting of the adoption of chemical fertilizers, the determinants of the combined use of chemical and organic fertilizers, the determinants of the adoption of improved seeds, as well as the determinant factors of appropriate use of pesticides. The results showed that farmer's education level, farming experience, membership to farm cooperative, the number of extension visits, and crop farming are the factors that affect positively the probability of adopting one or other of the four innovative farming techniques. From these results, we suggest the enhancement of extension services and other needed support to small-scale farmers (grants and subsidies, access to finance for example), the spread of professional trainings to farmers, and the increased farmers' access to high-yielding seed varieties if farming professionalization and innovative farming techniques are still among the development goals.

Keywords

Innovative farming techniques, sustainability, adoption of technology, volcanic highlands, Rwanda.

JEL Classification codes: O33, Q12, Q16, R11.

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Introduction

The adoption of innovative technology among farmers remains central to the completion of agricultural policy objectives (Ruto and Garrod, 2009). Asrat et al. (2010) underlined that both socioeconomic characteristics of individuals and/or households such as land size, livestock possession, farmer's years of experience, and institutional factors like the number of extension visits affected the farmers' adoption decision about the farming techniques. The adoption decisions of farmers for farming innovative techniques depend highly on the farmers' perceptions of the technology characteristics (Adesina and Baidu-Forson, 1995) and it appeals reasonable interventions of public institutions (BID, 2019). In this line, Wauters and Mathijs (2013) recognized the role of spillover and learning effects on the adoption of innovative technologies by farmers. The reason behind the adoption of innovative technology is just its role on farmers' welfare improvement (Yirga and Alemu, 2016) and in poverty reduction specifically in developing countries (Mwangi and Kariuki, 2015). The adoption of new and innovative farming techniques increase the productivity and efficiency in production than the rudimentary ones (Onubuogu et al., 2014; Mabe et al., 2018) even though this can be constrained by the agricultural risks such as financial risks, price risks, professional risks, natural risks and other risks (Mulumeoderhwa et al, 2019).

The farmer's access to information plays a crucial role in technological adoption (Uaiene et al., 2009) since it reduces the uncertainty about the performance of a specific technology; clear information moves individual's mindset from subjectivity to objectivity (Bonabana-Wabbi 2002). This means that the existence of new technologies is not enough for itself. It allows the farmers to learn about the existence and the effective use of innovative farming practices. The farmers adopt the new technologies only when they are aware of their existence, and their potential impact on the farmers' welfare (Mwangi and Kariuki, 2015) through the increase in farm income. Other factors that may influence the adoption of new farming technologies are the farmer's level of education, the access to extension services, and the access to credit (Namwata et al., 2010), and professional training (Jerop et al., 2018).

The technology areas that contribute substantially to the increase in farm income include high yielding crop varieties, weed and pest management techniques, irrigation and water management schemes (Loevinsohn et al., 2013) as well as the new farm management methods, especially those aiming at raising the output and reducing the average cost of production (Challa, 2013). It can also enable the adopter to perform the work more easily than before and hence lead to time and labour saving (Bonabana-Wabbi, 2002). The consequence of innovative farm technologies and thus improved farm productivity includes responding to increasing demand, which is the basis of salient assessment of the performance of the technologies (Challa, 2013). Under such circumstances, the adoption of farm innovative technologies may also lead to sustainable food security and development through the dynamic adoption of innovative technologies, which is expected to sustain food and fiber supply (Loevinsohn et al., 2013). Hardaker and Lien (2010) have also considered profit as one of the most influential factors for famers to adopt a new technology or a new crop.

There has been the impact of new farming innovations on the improvement of the majority of the population in developing countries via the increase in farm production and farm income stability (Feder et al., 1985), but the adoption of new farm technologies by small-scale farmers in Sub-Saharan Africa "seems to be slow" (Meijer et al., 2015). This paper aims to identify the factors affecting the adoption of selected innovative farming techniques (use of organic fertilizers, use of chemicals, adoption of improved seeds, and use of pesticides) by small-scale farmers in the Volcanic Highlands in Rwanda. The rest of this paper is organised as follow. Section 2 describes the conceptual framework of technology adoption. Section 3 presents the materials and methods, while section 4 summarises empirical results and their discussion. The paper ends with conclusions and policy recommendations.

Conceptual framework of technology adoption

The concept of technology adoption is well explained by the diffusion of innovation theory that was developed by Rogers in 1962, which is one of the oldest theories of the social science (Rogers, 1983). It was suggested that the diffusion of innovations is significantly influenced by the adopter's perception and situation (Rogers, 2003) as well as own characteristics of innovations (Robertson and Gatignon, 1986). This theory is rooted from the area of communication and aims to explain how a new innovative technology gains interest and spreads in a social system (Rogers, 1962). In terms of Schumpeter (1934), innovation can be simply defined as "the changes in the methods of production and transportation, production of a new product, change in the industrial organization, opening up of a new market, and new sources of energy".

Seven sources of innovations were identified, from which first four are rooted within a market or industry while other three are originated outside. Sources of innovation within a business, an industry or a market are as follows (Drucker, 1986):

- The unexpected: as a source of innovation, it is hereby considered the unexpected success, the unexpected failure, or the unexpected outside event.
- The incongruity: this is a gap between "what is" and "what ought to be". It is "a symptom for an opportunity to innovate".
- process need; here, there is a process need in the organization and everybody is aware of it. Even though nothing is done to find a solution, any innovation that will appear will be obviously accepted.
- industry and market structure: this may seem completely stable, but it is "quite brittle because it can disintegrate very fast following a small scratch". It was also remarked that a structure change requires entrepreneurial skills from every member to enable innovation process within an industry.

Beside the internal sources of innovation, there are also sources of innovation that are instigated outside a business, an industry or a market. These are changes prevailing in the social, philosophical, political, and intellectual environment (Drucker, 1986). They include:

- Demographics: this is concerned with changes in population, its size, age structure, composition, employment, educational status, and income, as well as their most predictable consequences.
- Changes in perception: this is taken as a source of innovation because it has created considerable opportunities to innovate.
- New knowledge: in knowledge-based economy, new knowledge (scientific, technical, or social) is normally referred to as innovation. But it is to note that all knowledge-based innovations are not important, as some of them are trivial.

Rogers (1962) identified also five characteristics of innovative technologies. The first is the relative advantage which is defined as the cost-effectiveness and the set of benefits of new technologies to adopters compared to preceding technologies (Chang, 2001; Sanson-Fisher, 2004). Compatibility, which is the second factor, means that a new technology should be compatible with the adopter's norms, values, past experiences as well as their needs (Rogers, 1962; Sanson-Fisher, 2004). It comes then the complexity (Rogers, 1962) that measures the extent at which a new technology is difficult to understand and use (Sanson-Fisher, 2004). For trialability, Rogers (1962) defined it as the way a technology can be tested while piloting its use, assess its acceptability by the users, and examine its potential outcomes. The last element is thus the visibility of a new technology (Rogers, 1962), which implies the visibility or advocation of that technology. Bero et al. (1998) argued that there is an increasing chance for a new technology to be adopted if it is discussed and advocated by role-models, respected and influential practitioners.

Rogers (1962, 1983, 2003) argued that the process of the spread of innovations depends deeply on human capital, and stressed that it is built mainly on four elements, namely the innovation itself, communication channels, time, and a social system. According to Rogers (1983) and Starmann et al. (2018), the process for the diffusion of innovation goes through five steps: knowledge, persuasion, decision, implementation, and confirmation. It was highlighted that researchers are firstly aware and acquire knowledge of the proposed technological change; secondly, individual practitioner or user (the adopter) is convinced with the advantages of innovations; thirdly, the user decides to adopt or reject the innovation; fourthly, the innovation is integrated in everyday activity; finally, the users seek to confirm the adoption of innovation as per their abilities to tolerate high degrees of risk and uncertainty (see also Sanson-Fisher, 2004). In consideration of the rate at which an innovation is adopted, Rogers (1962) identified five adopter categories from fastest to lowest adopters, namely innovators, early adopters, early majority, late majority, and laggards, bearing on their readiness to own innovative technologies. It is also worth important to note that adoption of a new technology is voluntary (Hightower and Brightman, 1994).

An innovator is referred to as the first fastest innovation adopter who is venturesome, young, and wealthy with high social status, characterized by the willing to accept risks and the closest contact with scientists as well as with other innovators (Rogers, 1962). Chamorro-Premuzic (2013) described a successful innovator as someone with such characteristics as creativity, opportunistic mindset, formal education or training, proactivity and high degree of persistence, a healthy dose of prudence, and social capital. An early adopter is the second fastest adopter of new technologies, who is the role model to the surrounding community, respectable, with high social status, with strong contact with local change agents (Rogers, 1962; Ali and Miraz, 2015). Early majority is composed of people who are willing to accept and use new technologies only after the peers have already adopted. Deliberate, such people are in considerable contact with change agents and early adopters (Rogers, 1962; Ali and Miraz, 2015). Late majority is a category of people who are skeptical, able to resist to the pressure of peers before adoption occurs, in relation with peers who are mainly late majority or early majority. Such people hardly use mass media (Rogers, 1962). Laggards, the slowest adopters of new technologies, are attached to the tradition and oriented to the past. Conservative and suspicious of change agents, they get information from neighbours, friends, and relatives with similar level of mindset (Rogers, 1962; Ali and Miraz, 2015).

Materials and methods

Data used for this study were collected through a farmer survey in October to December 2019. The questionnaire used to collect data included the socioeconomic factors characterizing the farmers and their households as well as the preferred farming techniques practiced on the farms. For details, data were collected on demographic characteristics of the farmer, access to productive assets (land, credit, livestock), crop production and farm supplies (crops grown, use of fertilizers and their costs, crop output, farm income, membership of farm cooperative), access to extension services, and the innovative farming techniques practiced. The study considered a sample of 401 small-scale farmers randomly selected from the Volcanic Highlands of Rwanda (also known as "*Birunga*" region). This region is extended on four districts and 101 farmers were surveyed Burera District, 101 in Musanze District, 100 in Nyabihu District and 99 in Rubavu District. The "*Birunga*" region is one of the 12 agro-ecological zones in Rwanda besides Imbo, Impala, Kivu Lake Borders, Congo Nile Crest, Eastern Plateau, Central Plateau, Buberuka Highlands, Mayaga, Bugesera, and Eastern Savannah (Verdoodt and van Ranst, 2003; Rushemuka et al., 2014). The Birunga agricultural region is well known for its essentially agricultural soil (altitude of 1600 to 2500 metres, highly permeable black volcanic soils with excellent agricultural value) (Ndindabahizi and Ngwabije, 1991), the main crops being the Irish potato, vegetables (red onion, white onion, etc.), corn, beans, wheat, etc. (MINAGRI, 2012). Delepierre (1982) and MINAGRI (1989) presented in details the specific characteristics of the agro-ecological zone of Birunga: regular rains; fairly shallow soil, hence the simple agricultural equipment and generalization of cropping; reduced risk of erosion thanks to bedding cultivation, soil permeability and often little uneven terrain; soils rich in humus (andosols or andepts) of black color with a good fertility, suitable for crops of temperate climate, but whose acidity is variable (from little acids to acids) throughout the region.

Farmers should choose the farming techniques that will enable them to take delight from the agricultural potentials of the region. Four farming techniques have been selected for this analysis, namely the adoption of chemical fertilizers (1=yes), the appropriate combination of chemicals and organic fertilizers (1=yes), the adoption of improved (or high yielding varieties of) seeds (1=yes), as well as the best practice of pesticides (1=yes). The descriptive statistics of all study variables are summarized in Table 1.

Variable	Variable definition	Mean	SD
	Dependent variables		
Chemicals	Appropriate use of chemical fertilizers (1=yes)	.26	.44
Combination	Appropriate combination of chemicals and org. fertilizers	.31	.46
Improved seeds	Appropriate use of improved seeds (1=yes)	.72	.45
Pesticides	Appropriate use of pesticides (1=yes)	.55	.49
	Independent variables		
Age	Age of the farm producer (in years)	40.57	9.04
Sex	Sex of the farm producers (1=female, 0 if otherwise)	1.48	.50
Marital status	Marital status of the farm producer (categorical)	2.17	1.93
Education	Education level of the farm producer (categorical)	3.26	1.67
Household size	Number of the household's members	4.96	2.03
Experience	The farmer's experience (in years)	17.76	8.75
Agriculture	If the farmer has agriculture as the sole activity (1=yes)	1.24	.43
Cooperative	If the farmer is a member of a farm cooperative (1=yes)	1.09	.29
Extension	The number of extension visits	1.22	1.03
Land size	The farm size (in square meters)	3,220.96	1,604.27
Farm income	Net farm income in Rwandan francs	870,000.00	1,130,000.00
TLU	Tropical livestock units held by a household	1.66	1.43
Credit	The loan amount in Rwandan francs	186,000.00	405,000.00
Crop	The crop grown (1=if onion, 0=otherwise)	.23	.42
Seed costs	The seed costs in Rwandan francs	83,309.82	68,323.87
Organic fertilizer costs	The cost of organic fertilizers in Rwandan francs	20,712.97	14,617.77
Chemical costs	The cost of chemical fertilizers in Rwandan francs	61,710.35	97,184.02
Pesticide costs	The cost of pesticides in Rwandan francs	45,056.73	46,219.27

Source: own processing

Table 1: Descriptive statistics of variables used in this study.

For data analysis, we specified a logit regression model for which we used a maximum likelihood estimation (MLE) method to identify the factors influencing the farmer's preference for an innovative farming technique. The results are represented in the Table 2. With the aim of identifying the factors affecting farmer's preference for a farming technique, with a dichotomous dependent variable Y_i with two values, 1 (when a farmer has practiced a technique) or 0 (otherwise), a binomial logistic regression model (Agresti, 2018; Breen et al., 2018). The set X of p explanatory variables (made of both push and pull characteristics) is made by continuous and categorical/dichotomous variables. The probability that a farmer i has practiced a farming technique is given by the function:

$$\pi_i(X) = \frac{e^{\beta_0+\beta_1 X_{i1}+\beta_2 X_{i2}+...+\beta_p X_{ip}}}{1+e^{\beta_0+\beta_1 X_{i1}+\beta_2 X_{i2}+...+\beta_p X_{ip}}} \qquad (1)$$

and then $\frac{\pi_i}{1-\pi_i}$ is the odd in favor of the famer's preference for a technique. Hence, by applying the natural logarithm on both sides of (1), the logit model is then written as:

$$Y_i = \ln\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + ... + \beta_p X_{ip} \qquad (2)$$

The equation (2) is estimated by the maximum likelihood estimation method and the basic assumptions of normality, linearity, and homogeneity of variance for the independent variables are not a requirement. The results from econometric estimation of the equation (2) are presented in the Table 2. The coefficients of the estimated models are the odd rations: if the coefficient is greater than 1, it implies that the factor affects positively the probability of adopting innovative farming techniques; otherwise, there is no or negative effect of the factor concerned.

Variable	Burera District	Musanze District	Nyabihu District	Rubavu District	Whole region of Volcanic Highlands
Age	41.17	39.58	39.72	41.81	40.57
Sex					
Male	45	53	58	52	208
Female	56	48	42	47	193
Crop selected					
Potato	33	82	11	6	132
Bean	31	8	0	0	39
Maize	15	9	0	0	24
Wheat	0	1	0	0	1
Pyrethrum	0	1	0	0	1
Sorghum	14	0	0	0	14
Onion	0	0	50	44	94
Carrots	1	0	19	26	46
cabbage	7	0	20	23	50
Education level of the respondents					
No formal education	9	17	23	15	64
Primary	60	50	41	41	
Secondary	22	18	23	31	
Technical and vocational	7	13	13	9	42
University	2	3	0	0	5
Farming techniques					
Use of chemicals	33	14	35	24	106
Use of organic fertilizers	77	89	54	78	298
Combination of fertilizers[a]	26	43	16	40	125
Use of pesticides	50	65	44	61	220

Note: [a] Chemical and organic fertilizers
Source: own processing

Table 2: Socioeconomic characteristics and distribution of the respondents by crops, level of education and farming techniques.

Results and discussion

The socioeconomic characteristics of the respondents and their distribution by crops, levels of education and farming techniques are presented in the Table 2. Alongside this study, we identified separately the determinant factors of the adoption of the use of chemical fertilizers, the appropriate combination of organic and chemical fertilizers, the adoption of improved (or high yielding) seeds, and the appropriate use of pesticides (Table 3) where the odd ratios are provided as coefficients. The results from econometric analysis of the determinants

Variables	Model 1. Use of chemical fertilizers	Model 2. Combination of chem. and org.	Model 3. Use of improved seeds	Model 4. Use of pesticides
	Coefficients¤ (Stand. Dev.)	Coefficients¤ (Stand. Dev.)	Coefficients¤ (Stand. Dev.)	Coefficients¤ (Stand. Dev.)
Age (X_1)	0.993 (0.027)	0.972 (0.024)	0.928** (0.027)	0.937** (0.024)
Sex (X_2)	0.850 (0.219)	1.034 (0.250)	1.103 (0.289)	1.102 (0.256)
Marital status (X_3)	0.921 (0.070)	0.941 (0.061)	0.978 (0.072)	0.964 (0.063)
Education (X_4)	1.070 (0.095)	1.142 (0.093)	0.911 (0.084)	1.152* (0.093)
Household size (X_5)	0.903 (0.093)	---	1.121 (0.118)	1.057 (0.100)
Experience (years) (X_6)	1.020 (0.027)	1.046* (0.027)	1.017 (0.027)	1.053** (0.026)
Agriculture (1=yes) (X_7)	0.526* (0.176)	0.590* (0.185)	1.301 (0.427)	1.033 (0.294)
Cooperative (X_8)	2.545** (1.114)	3.919*** (1.656)	1.479 (0.694)	1.362 (0.569)
Extension visits (X_9)	1.092 (0.141)	1.092 (0.133)	0.922 (0.121)	0.838 (0.099)
Land size (X_{10})	1.000*** (0.000)	1.000 (0.000)	1.001*** (0.000)	1.000*** (0.000)
Net farm income (X_{11})	1.000** (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
TLU (X_{12})	1.159 (0.146)	1.001 (0.119)	1.000(0.139)	0.875 (0.103)
Credit (FRW) (X_{13})	1.000 (0.000)	1.000 (0.000)	1.000(0.000)	1.000* (0.000)
Crop (1=if onion, 0=otherwise) (X_{14})	4.391*** (2.065)	1.961 (0.894)	5.214*** (2.851)	2.211* (0.980)
Seed costs (X_{15})	1.000 (0.000)	1.000 (0.000)	1.000* (0.000)	1.000 (0.000)
Org. fertilizer costs (X_{16}	--	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
Chemical fertilizer costs (X_{17})	1.000** (0.000)	1.000*** (0.000)	1.000 (0.000)	1.000 (0.000)
Pesticide costs (X_{18})	1.000 (0.000)	1.000* (0.000)	1.000*** (0.000)	1.000*** (0.000)
Constant	0.202 (0.233)	0.100** (0.110)	2.410 (2.847)	1.045 (1.097)
Observations	377	377	377	377
Chi-square	33.673	42.552	55.456	39.773
Prob > chi²	0.009	0.001	0	0.002

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$; Coefficients are the odds ratios
Source: own processing

Table 2: Socioeconomic characteristics and distribution of the respondents by crops, level of education and farming techniques.

of the use of chemical fertilizers (Model 1) reveal that the probability of adopting the use of chemicals is positively affected by the farmer's level of education, the farming experience, the cooperative membership, the number of extension visits, the number of domestic animals held, and if the farmer grows onion, where cooperative membership and onion farming are the most influential factors.

For the determinant factors of the combination of chemical and organic fertilizers (Model 2 on the Table 3), the results show that the sex of the farmer (being female), the farmer's education level, the farmer's experience, the cooperative membership, the number of extension visits, and the number of domestic animals held are the primary factors affecting the farmer's decision, farmer's experience and cooperative membership being the most significant ones. The analysis also shows that the adoption of improved (or high yielding varieties of seeds is positively affected by the sex of the farmer (being female), the number of household members, the farmer's experience, the farming practice as a sole economic activity, cooperative membership, the land size, and the onion farming (Model 3 on the Table 3). These results also indicate that land size and onion farming are the most significant determinants of the use of improved seeds.

As for the use of pesticides, the results (Model 4 on the Table 3) point to the sex of the farmer (being female), the farmer's education level, the number of household members, the farmer's experience, the farming practice as a sole economic activity, cooperative membership, and the onion farming as the determinants with positive effect on the farmer's decision to use pesticides, whereby the level of education, farmer's experience, and the onion farming are the statistically significant factors.

Previous studies proved that the adoption of new innovative farming technologies results in increasing production and reducing average cost of production (Challa, 2013), making easy the farming work, which consequently results in saving time and labor (Bonabana-Wabbi, 2002) in improving agricultural productivity (Challa, 2013), as well as in stabilizing farm income (Feder al., 1985). The results from econometric estimations show that the sex of the farmer (being female) leads to the increase in the probability of farmers to combine in appropriate proportions organic and chemical fertilizers, that of adopting improved seeds, and that of appropriate use of pesticides, which emphasizes the role of socioeconomic characteristics of farmers in their decisions to adopt new technologies (Asrat et al., 2010).

The results point specifically to the positive and significant effect of farmer's education and experience on different crop farming techniques (use of chemicals, adoption of improved seeds, and appropriate use of pesticides), which highlights the role of education as a measure of human capital in the adoption of agricultural technologies (Namwata et al., 2010). We have also found out that the cooperative membership and the number of extension visits affect positively the adoption of some innovative farming techniques, and this is aligned with the role of institutional factors (Asrat et al., 2010). It is important to note that cooperatives and extension services can also serve as information channels that may influence farmers to adopt new technologies (Bonabana-Wabbi 2002; Uaiene et al., 2009). For the crop grown, its positive effect shows that the farming techniques should be adapted to different crops through different localities during different periods of time (Shiferaw et al., 2009; Asrat et al., 2010; Lybbert and Summer, 2010). In contrast with the existing literature on the importance of credit (Sain and Martinez, 1999; Quddus, 2012 for example), this study showed that the access to credit has no effect on the adoption of innovative farming technologies. In line with Inter-American Development Bank, the adoption of innovative techniques enable farmers to shift from ineffective farming practices and consequently improve the fertility and the productivity of arable land, which is leveraged by significant intervention of Governments (BID, 2019).

Conclusion

This study aimed to identify the determinant factors of the adoption of innovative farming techniques by small-scale farmers in Rwanda. Data used were collected through the administration of a questionnaire to a sample of 401 crop farmers randomly selected in the Volcanic Highlands in Rwanda. This region is one of the most fertile zones, but it is important for farmers to practice innovative farming techniques if they want to take delight of all its potentials. The results from binary maximum likelihood estimates of a logit regression model show that the probability of adopting the use of chemical fertilizers is positively and significantly influenced by the membership to farm cooperative and the selection of onion as the primary crop. For the combined use of chemicals and organic fertilizers in appropriate rates, farmer's experience and cooperative membership have been identified as the most significant determinants of the adoption of this farming technique. The same results also reveal that the adoption of high-yielding varieties of seeds is positively but significantly influenced by the farm size and the onion exploitation as the primary crop. As for the appropriate use of pesticides, the level of education, farmer's experience, and the onion farming are the statistically significant factors have been identified as the most influential determinants of the farmers' decision. Based on these findings, we recommend that the government and the development partners should enhance farm technology subsidy and farmer's access to finance, enhance the farmers' professional trainings, align the extension services to farmers' needs and environment, and avail high-yielding varieties of seeds. For farmers, they should own the agriculture development policy and follow all advice and support from the government and the institutions partnering for agriculture development.

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