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RESEARCH ARTICLE

Adoption of agricultural innovations in risky environment: the case of corn producers in the west of Cameroon

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Abstract The use of modern agricultural inputs has been cited as a major factor for increasing productivity in most sub-Saharan African countries. A wide range of variables influence the adoption of such inputs. It is important to identify these variables in order to ensure the implementation of more effective programmes to promote the use of modern inputs. This article examines the determinants of adoption of three new agricultural technologies (improved maize seeds, inorganic fertiliser and pesticide) by corn producers in the west of Cameroon. Rather than the univariate probit model which is commonly used, the multivariate probit model is employed to take account of the correlation between the disturbances of the three adoption models. The results indicate that the decision to adopt agricultural innovations is significantly influenced by farmers' education, income and risk perception as well as farm size. Therefore, policies aimed at setting up sustainable risk management markets, increasing the level of education of farmers and their access to credit could greatly promote the adoption of agricultural innovations by farmers of Cameroon in general and in the western region in particular.

Keywords Adoption of agricultural innovations · Cameroon · Multivariate probit model · Risks

JEL classification O33 · Q12 · Q16

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Introduction

Agriculture continues to be a fundamental instrument for sustainable development, poverty reduction and enhanced food security in developing countries. It is a vital development tool for achieving the Millennium Development Goals (MDG). However, Africa faces huge food supply challenges due to increasing human population, limited opportunities to increase arable land and declining yields associated to continuous declining soil fertility. Agricultural productivity in Africa has continued to decline over the last decades whereas poverty levels have increased. Currently, agricultural productivity in sub-Saharan Africa lags behind that of other regions in the world. It is well below what is required to achieve food security and poverty goals. Increasing agricultural productivity in Africa is an urgent necessity, and one of the fundamental ways of improving agricultural productivity is the introduction and use of improved agricultural technologies. Yet, agricultural technology adoption has been substantially lower in Africa than in Asia and Latin America (Byerlee and Eicher 1997; Ariga et al. 2006). In Cameroon as in most countries of sub-Saharan Africa, agriculture is a predominant sector (Enete and Onyekuru 2011), although there is a low adoption of agricultural innovations particularly among producers of food crops. In fact, only 4, 11 and 7 % of producers of food crops use improved seeds, fertilisers and pesticides, respectively (INS/ECAM3 2007). In this regard, this study aims at identifying the factors influencing the adoption of improved maize seeds, inorganic fertiliser and pesticide by farmers (especially corn[1] producers) in the western region of Cameroon.

[1] This interest for corn stems from the fact that it is among the food crops that are most consumed in Cameroon. Indeed, almost 67 % of Cameroonians consume corn, about 12 million people; corn is also used in animal feed and in industry (ACDIC 2008). In addition, maize is consumed in all regions of Cameroon. It should also be noted that, today, this product is also used to make energy (corn is a bio fuel).

A common problem for many countries is how to speed up the rate of diffusion of a research innovation programme (Rogers 2003). Yet, speeding up the rate of technology adoption requires knowledge of the underlying factors that influence adoption decisions. Many adoption studies have been published, most of them have tried to identify constraints to technology adoption and the use of modern inputs. A large number of these studies are cross-sectional analyses of the determinants of technology adoption at the farm level. Several factors have been found to affect adoption. These include government policies, market forces (such as availability of labour, size of the farm and expected benefits), environmental concerns, social factors (such as age of potential adopter, social *status* of farmers, level of education and gender-related aspects, size of household and farming experience), institutional factors and access to information. Some studies classify these factors into broad categories: farmers' characteristics, farm structure, institutional characteristics and managerial structure (McNamara et al. 1991) while others classify them under social, economic and physical categories (Kebede et al. 1990). Others group these factors into human capital, production, policy and natural resource characteristics (Wu and Babcock 1998).

The site-specificity of agricultural practices led some authors to assert that adoption studies in every region experiencing a technological change are warranted. This is because populations are heterogeneous and individual behaviour is dynamic (Feder et al. 1985). Furthermore, there are numerous differences in factor endowments and farmers' characteristics among regions. Thus, a technology adoption study in a geographical setting does not imply that a similar study of the same technology is unwarranted in another geographical setting. Moreover, different regions have varying adoption patterns for the same type of technology. Yaron et al. (1992) assert that extrapolations of adoption results should be avoided and that specific regional studies should be encouraged where necessary. From this point of view, the objective of this article is to identify the determinants of adoption of three agricultural innovations (improved maize seeds, chemical fertilisers and pesticides) by farmers in the west of Cameroon [the western region of Cameroon is the largest agricultural production area (especially maize production)—MINADER 2012]. This is aimed at providing an empirical basis that would guide effective programmes to promote the use of agricultural innovations in this country. In Cameroon in general and in the western region in particular, a significant proportion of farmers still practise traditional agriculture, despite the low yields recorded. Furthermore, studies on the behaviour of Cameroonian farmers as concerns the adoption of new agricultural technologies are rare.

The contributions of this article are twofold: firstly, contrary to Suri (2011) and Mabah et al. (2013) where risks are not taken into account, farmers' perceptions of different types of risk are used as explanatory variables in our adoption models. In contrast to some studies which take risks into account (such as Koundouri et al. 2006; Kassie et al. 2013 and Teklewold et al. 2013), we also introduce the price of output (i.e. the price of corn) as a driver of adoption. In fact, facing some economic incentives such as the rising price of output, some atypical producers' behaviours (*i.e.* negative or absence of production/input demand response to output price incentives) can be better explained only if risks are introduced in the analysis. Secondly, in contrast to Mabah et al. (2013), we provide a more comprehensive and rigorous analysis of the interdependent adoption of agricultural innovations in Cameroon.

The remainder of the article is organized as follows: "Factors determining the adoption of new agricultural technologies" section reviews the literature; data and methods are discussed in "Materials and methods" section; "Results and discussion" section presents and discusses the results and "Conclusion" section concludes.

Factors determining the adoption of new agricultural technologies

The adoption of new technologies in the agricultural sector received special attention in the literature since the 1960s. The theory of induced innovation (concept borrowed from Hicks 1932) is the topic mostly discussed in the literature on technological change in agriculture. In a risk-free environment, this theory attributes the adoption of agricultural innovations to the scarcity of traditional factors of production (land, labour) and soil depletion due to population pressure. In short, according to the theory of induced innovation, adoption of modern inputs is one way to increase production per unit of scarce resource. In the 1970s, some critics stood against the theory of induced innovation, accusing it of being too restrictive as it attributes the adoption of innovations only to population pressure and resource scarcity (Feder 1980; Just and Zilberman 1983). The purpose of this section is to review the various theories on the determinants of the adoption of agricultural innovations.

Theory of induced innovation

The theory of induced innovation in agriculture defines a link between farmers' technological choices and the environmental constraints they are facing. It suggests that technological change is induced by changes in the availability and cost of traditional inputs, in particular land and labour (Binswanger and Ruttan 1978). This concept dates from theory of wages Hicks (1932). This author argued that rising wages motivate firms to adopt labour-saving innovations. In general, changes in prices of traditional factors of production led to the adoption of new production techniques to save the scarce or more expensive factor. Boserup (2005) also notes that population growth could lead to pressure on the use of inputs, in particular, the use of land that may become less profitable because of its exhaustion.

The theory of induced innovation represents technical change as a dynamic response to changes in resource endowments and growth in demand (Hayami and Ruttan 1985). Hayami and Ruttan (1985) return to the neoclassical tradition, which postulates an aggregate production function whose behaviour is similar to that of a microeconomic function. They argue that innovation efforts are designed to overcome constraints from scarce resources both at the microeconomic level and at the level of the whole economy.

In Hicks' tradition, the ratio K/L (capital/labour) is representative of a technique. It is determined by the relative factor prices. A change in relative factor prices resulting from a change in the relative scarcity of resources leads to a modification of the technique in the sense that it saves the factor whose relative price has increased (Mounier 1992). The sense of technical bias, in other words the direction of the change in K/L, is determined by the direction of the relative price ratio.

Risks and adoption of modern inputs

Farmers' decisions are likely to be influenced by the multiple risks they face in their agricultural activity (Foster and Rosenzweig 2010). The reluctance of farmers to adopt innovations may not be due to irrational behaviour but to their willingness to minimise risk (Ortiz 1980). Models of adoption of agricultural innovations in risky environments are explored in this section.

The expected utility approach forms the basis of much of the work on the effects of risk on technology adoption. For example, Feder (1980) shows that the optimal allocation of land for new crops declines with higher variability of the random variable and with higher degrees of risk aversion, under the assumption that the new crop exhibits a higher variability in yield or returns than the existing crop. This result was later expanded by Just and Zilberman (1983) who showed that the intensity of adoption depends on whether the new technology is risk-increasing or risk-decreasing and whether risk aversion is increasing or decreasing with wealth.

According to Feder (1980), with a binding credit constraint, an increase in credit availability will increase the use of modern inputs, and an increase in the size of the farm will increase fertiliser use and decrease the share of land allocated to the modern crop, if absolute risk aversion is decreasing. He also showed that contrary to the results obtained in a certain environment, in the presence of risks, the effect of output price on the adoption of agricultural innovations is undetermined. Theoretically, the optimal level of modern input use increases (decreases) with higher output price if the elasticity of the risk response to modern input is lower (higher) than the elasticity of the mean yield response to modern input.

The development of the conceptual framework linking risk with the adoption of new technologies was not accompanied by similar advances in empirical work (Feder et al. 1985). A small emerging literature attempts to empirically estimate the relationship between risk and new technology adoption (see Marra et al. 2003, for a more detailed review). We focus here on a few recent studies from sub-Saharan Africa to show that the effect of various factors that influence technology adoption is not always consistent with theory and that it also differs from one country to another despite the use of similar analytical models. For example, using a multivariate model and taking agricultural risks into account in contrast to the work of Suri (2011), Akudugu et al. (2012), Ebojei et al. (2012) and Mabah et al. (2013), authors such as Kassie et al. (2013), Teklewold et al. (2013) and Ogada et al. (2014) do not always obtain similar results. For instance, regarding the characteristics of the farm, while the size of the farm has a negative effect on the adoption of improved seeds and chemical fertilisers in Tanzania (Kassie et al. 2013), it has no effect on the adoption of these inputs in Kenya and Ethiopia (Teklewold et al. 2013; Ogada et al. 2014). Similarly, with respect to households' or farmers' characteristics, access to credit has a positive effect on the adoption of improved seeds and chemical fertilisers in Ethiopia (Teklewold et al. 2013) while it has a positive and negative effect on the respective adoption of chemical fertilisers and improved seeds in Kenya (Ogada et al. 2014). Concerning indicators of risk, although the works of Kassie et al. (2013) and Teklewold et al. (2013) provide a detailed analysis of the effects of different agricultural risks on the adoption of new agricultural technologies compared to the work of Ogada et al. (2014), all these authors, like most in the literature, do not take price risk into account in their analysis. However, risk affects most farmers especially in developing countries where markets for risk management do not exist or are imperfectly functioning. Moreover, unlike Ogada et al. (2014) who take into account the price of labour in their analysis, Kassie et al. (2013) and Teklewold et al. (2013) neglect (input and output) prices as drivers of adoption.

Materials and methods

In this section the econometric model that is used to estimate the adoption of innovation(s) is described as well as data collection.

Study area and data collection

This study was conducted in the west of Cameroon, one of the ten regions of this country. This region is known to be the barn of Cameroon since it is the main production area of food crops, especially corn. Corn production in the west of Cameroon represents around 20 % of national production (MINADER 2012). The west of Cameroon is divided into eight divisions among which four distinguish themselves in terms of their high density of maize production. These are the Hauts-Plateaux, Koung-Khi, Mbamboutos and Mifi. According to the Central Bureau of Census and Population Studies (BUCREP), regions in Cameroon are divided into divisions which are also divided into subdivisions, which in turn are subdivided into enumeration areas[2] (ZD) with known geographical boundaries. It is on the basis of these divisions that we designed our sampling strategy.

Data were collected using a three-stage sampling technique. At the first stage, subdivisions with the highest density in maize production were selected from the four highly dense divisions in maize production, making a total of seven subdivisions. At the second stage, and on the basis of BUCREP cartographic maps, we randomly selected from the selected subdivisions and in proportion to population size 25 ZD among the 282 ZD in the urban area and 17 ZD among the 291 ZD in the rural area. At the third stage, 11 corn farmers were randomly selected from each urban ZD and 17 corn farmers from each rural ZD. This choice was made in such a way that the number of producers surveyed was the same in the rural and urban areas. The sampling process ended up with a sample of 564 corn producers.

Six students were trained and hired for data collection. These students were divided into two teams of three. Every day, each team had to go to one selected ZD and within the ZD they would select, using the systematic sampling method, households by steps of eighteen households in urban ZD and by steps of eleven households in rural ZD.

Data were collected on the socio-economic characteristics of the farmers[3] and their farms, the use of the three agricultural innovations (improved seeds, chemical fertilisers and pesticides), farmers' corn selling price during the year preceding the survey and farmers' risk perception.

Data analysis: multivariate probit model and description of variables

Limited dependent variable models and in particular binary choice models are often used to assess the adoption of innovations by farmers. These models are based on the assumption that producers can choose between two alternatives (to adopt or not an innovation), and this choice depends on several socio-economic characteristics (Pindyck and Rubinfeld 1997). In several studies, including those of Knight et al. (2003) and Ariga et al. (2008), a probit or logit model was specified to explain whether or not the producers adopt an innovation without considering the interactions that may exist between the various decisions of adoption of agricultural innovations. The adoption of a given agricultural innovation is likely to depend on the adoption of other innovations since modern inputs may be complemented (Perkins et al. 2008; Feder et al. 1985). The number of sampled farmers who adopted different combinations of agricultural innovations is presented in Table 1. This table shows that 142 farmers adopted at least two innovations, representing more than 25 % of the total sample, which calls for the use of a multivariate probit model.

The probit multivariate model has also been used by Gillespie et al. (2004), Velandia et al. (2009), Kassie et al. (2013) and Teklewold et al. (2013), and it is specified as follows:

$$\begin{cases} y_1^* = \boldsymbol{\beta}_1'\mathbf{X}_1 + \varepsilon_1,\ y_1 = 1\left(y_1^* > 0\right) \\ y_2^* = \boldsymbol{\beta}_2'\mathbf{X}_2 + \varepsilon_2,\ y_2 = 1\left(y_2^* > 0\right) \\ y_3^* = \boldsymbol{\beta}_3'\mathbf{X}_3 + \varepsilon_3,\ y_3 = 1\left(y_3^* > 0\right) \end{cases} \quad (1)$$

where y_j^* ($j = 1, 2, 3$) represents the latent variable and y_j describes the adoption (or not) of technology j;

X_j is the vector of explanatory variables;

β_j is the vector of parameters to be estimated and

ε_j is the vector of error terms. The error terms are assumed to follow a multivariate normal distribution with mean vector equal to zero and a covariance matrix R with diagonal elements equal to 1; $\varepsilon_j \sim \mathrm{MVN}\ (O, R)$. The unknown parameters in model (1) are estimated by the method of simulated maximum likelihood that uses the Geweke-Hajivassiliou-Keane (GHK) smooth recursive conditioning simulator (see Cappellari and Jenkins 2003, for more details).

There is no firm economic theory that dictates the choice of explanatory variables to be included in the model of adoption of new technologies. However, the adoption of agricultural innovations is influenced by a number of interrelated elements in the decision-making environment in which farmers operate. For example, Feder et al. (1985) identified the lack of credit, limited access to information, risk aversion, size of the farm, inadequate land tenure, insufficient human capital, lack of adequate farm equipment and inadequate transportation infrastructure as key barriers to adoption of innovation in less developed countries. However, all these variables are not equally important in all countries or regions and for all farmers. In this study, the explanatory variables selected for the estimation of the model of agricultural innovations choice are based on Feder (1980), Just and Zilberman (1983) and Feder et al. (1985). These variables are presented in Table 2.

[2] An enumeration area is a geographical area that can accommodate approximately 200 households.

[3] In this study, a farmer is a person who operates a farm (farm owner). A farm owner or farmer is not necessarily the owner of the land that he/she cultivates.

Table 1 Proportion of producers adopting different combinations of agricultural innovations

Possible agricultural innovations combinations	Number of farmers	Proportion (%)
(1)No use of agricultural innovation	139	24.6
(2)Use of improved maize seeds only	19	3.4
(3)Use of chemical fertilisers only	249	44.1
(4)Use of pesticides only	15	2.7
(5)Use of improved maize seeds and chemical fertilisers	46	8.2
(6)Use of improved maize seeds and pesticides	8	1.4
(7)Use of chemical fertilisers and pesticides	48	8.5
(8)Use of all three agricultural innovations	40	7.1
Total	564	100

Table 2 provides descriptive statistics for the sampled farmers disaggregated by their adoption *status*. The results show that 425 farmers adopted at least one innovation, representing 75 % of the total sample. In the entire sample, only one out of five farmers (20 %) used improved maize seeds. More than two out of three farmers (68 %) applied chemical fertilisers on their crop. In addition, about one out of five farmers (20 %) used pesticides. This shows that adoption rates in general are low in the west of Cameroon although being higher than the national averages.

About 82 % of surveyed farmers were female[4], and this did not differ significantly between adopters and non-adopters. Similarly, 42 % of surveyed farmers have had primary education; this proportion did not differ significantly between the two groups. Thirty-seven percent of surveyed farmers have reached secondary or higher education, but the proportion of farmers who received secondary or higher education is higher among adopters (41 %) compared to non-adopters (27 %). The average farm size and annual income differed between adopters and non-adopters, implying that the two groups were not of comparable wealth *status* (12,331 and 8930 m^2 for farm size of adopters and non-adopters respectively and 652,802 FCFA *versus* 431,865 FCFA for annual income). Farmers' average agricultural experience was about 23.6 years, and there was a significant difference in experience between adopters and non-adopters. In contrast, household size, which averaged 6.5 members, did not differ significantly between the two groups.

Sixty nine percent of farmers belonged to producer organisations, but membership to these groups was significantly higher among adopters. Participation in groups is a proxy for social capital; therefore, this finding is consistent with the notion that social capital is positively associated with technology adoption (Saka and Lawal 2009). Access to credit did not differ significantly between adopters and non-adopters (36 versus 28 %). About 40 % of surveyed farmers have an off-farm activity, and this did not differ significantly between adopters and non-adopters. The average distance to the farm was about 11.6 km, and this did not differ significantly between adopters and non-adopters. In contrast, distance to the main market, which averaged 2 km, differed significantly between the two groups.

About 24 % of surveyed farmers perceived that the fertility of their farmland has increased over the past 5 years; this proportion did not differ significantly between adopters and non-adopters. In contrast, 24 % of surveyed farmers perceived that their soil fertility had declined, but there was a significantly higher proportion of farmers that perceived that their soil fertility had declined among adopters (26 %) than among non-adopters (16 %). Eighty-nine percent of farmers own their land[5], and this proportion did not differ significantly between adopters and non-adopters. Similarly, about 50 % of surveyed farmers lived in rural zones; this proportion did not differ significantly between the two groups. The average maize price was about 140 FCFA, and there was no significant maize price difference between adopters and non-adopters. In contrast, the cost of labour and manure differed between adopters and non-adopters.

Regarding risk perception variables, we first describe the measure of risk used in this study. Risk can be measured in different ways. The variance or the standard deviation is often used as a measure of riskiness in applied risk analyses. In this article, following Tonsor et al. (2009), Vargas (2009) and Kurihara et al. (2014), farmers' perception of the importance of events that could have a negative impact on their income is retained as a means of quantifying the main risks that farmers face. More precisely, farmers were asked to score their perception of the importance of events/shocks that could have a negative impact on their income based on previous shocks on a scale from 1 to 5 (where 5 indicates high negative impact on income). This variable is converted into a dummy variable, which takes the value 1 when the farmer perceives some

[4] This is in conformity with national estimations which reveal that Cameroonian women accomplish more than 75 % of agricultural work and contribute for 60 % to food production (FAO 2007).

[5] In the western region of Cameroon, most of the land belongs to families and all family members including women claim to be co-owners of land.

Table 2 Description of variables used in the model of adoption of agricultural innovations

Variables	Names of variables	Measure	All farmers (mean) $N=564$	Farmers who adopted at least one innovation (mean) $N=425$	Farmers who did not adopt any innovation (mean) $N=139$	Difference
Dependent variables						
sam	Use of improved maize seeds	1 if farmer has used improved seeds of maize, 0 otherwise	0.200	0.266	–	–
anch	Use of chemical fertilisers	1 if farmer has used chemical fertiliser, 0 otherwise	0.679	0.901	–	–
pest	Use of pesticides (herbicide or insecticide)	1 if farmer has used pesticides, 0 otherwise	0.197	0.261	–	–
Independent variables						
riskmala	Perception of risk of illness or death of a key member of the household	1 if a risk, 0 otherwise	0.521	0.508	0.561	0.053
riskprix	Perception of risk of decline in the price of corn	1 if a risk, 0 otherwise	0.943	0.943	0.942	−0.001
riskphyt	Risk perception of pest-disease infestations	1 if a risk, 0 otherwise	0.568	0.579	0.532	−0.047
riskclim	Perception of climate risk	1 if a risk, 0 otherwise	0.941	0.948	0.921	−0.027
riskfina	Risk perception of default to finance a crop production	1 if a risk, 0 otherwise	0.334	0.358	0.259	−0.099**
dist_ch	Average distance from home to the farm	km	11.664	11.826	11.166	−0.661
fem	Farmer's gender	1 if a woman, 0 otherwise	0.824	0.816	0.849	0.032
fertilbais	Evolution of the farmland fertility over the past 5 years	1 if the farmland fertility has declined, 0 if soil fertility has not changed	0.237	0.263	0.158	−0.105**
fertilhaus	Evolution of the farmland fertility over the past 5 years	1 if the farmland fertility has increased, 0 if soil fertility has not changed	0.248	0.242	0.266	0.024
primary	Farmer's education level	0 if no education, 1 if has primary education level	0.420	0.402	0.475	0.072
secondary	Farmer's education level	0 if no education, 1 if has secondary education level or higher	0.374	0.407	0.273	−0.134***
credit	Farmer's access to credit	1 if access to credit, 0 otherwise	0.342	0.362	0.280	−0.082*
div-act	Farmer has a non-agricultural activity	1 if has a non-agricultural activity, 0 otherwise	0.404	0.421	0.352	−0.069
asso	Farmer participation to a producer organisation	1 if member of a producer organisation, 0 otherwise	0.688	0.708	0.626	−0.082*
propr	Ownership of land cultivated	1 if owner, 0 otherwise	0.894	0.882	0.928	0.046
experience	Farmer's experience in corn production	Number of years	23.608	22.960	25.590	2.630*
tailmenag	Household size	number of persons	6.596	6.595	6.597	0.002
dist_mark	Average distance from home to market	km	2.026	2.119	1.740	−0.379*
super	Farm size	m^2	11493.010	12331.200	8930.216	−3400.984***
pmoy	Sale price of maize	FCFA/kg	140.971	141.443	139.526	−1.917
tauxsal	Cost of labour	FCFA/week	10,508	10,137	11,644	1507***

Table 2 (continued)

Variables	Names of variables	Measure	All farmers (mean) $N = 564$	Farmers who adopted at least one innovation (mean) $N = 425$	Farmers who did not adopt any innovation (mean) $N = 139$	Difference
revenu	Farmer's annual income	FCFA	598,351	652,802	431,865	−220,937*
rural	Area	1 if rural area and 0 if urban area	0.5124	0.518	0.496	−0.021
coutfiente	Cost of manure	FCFA/50 kg	1757	1781	1681	−100**

Note: *, ** and *** indicate that difference between adopters and non-adopters is statistically significant at 10, 5 and 1 % level, respectively (*t* tests are used for differences in means). In this study, the farmer is the farm owner who is also the interviewee

positive risk, and 0 otherwise. In our sample, 52 % of the surveyed farmers perceived some risk of illness or death of a key member of the household. The proportion is 94, 57 and 94 % for the risk of decline in the price of maize, the risk of pest or disease and climate risk, respectively. These proportions did not differ significantly between adopters and non-adopters. In contrast, the proportion of farmers that perceived a default to finance crop production was significantly higher in the adopters group.

Relevance of the chosen variables

The characteristics of the farmer and of his/her farm that may influence the adoption of an innovation include gender, agricultural experience, education, access to credit, farmer's participation to a producer organisation, the size of the farm, soil fertility, household size, farmer's income, the distance from home to market, the distance from home to the farm and the ownership *status* of the land cultivated by the farmer.

More experienced farmers are often found to be more likely to adopt innovations. Theoretically, the education level of an individual positively influences the likelihood of adoption of agricultural innovations. This reflects the fact that the instructed peasant has a greater ability to understand and apply new technologies (Knight et al. 2003). In African societies in general and in rural areas in particular, men are often more educated, more informed and have more money than women. Even when women play a key role in the decisions of agricultural production, they may however lack funds and technical information. Male farmers are thus supposed to be more likely to adopt modern inputs compared to women.

Household size could be an incentive for the farmer to use fertilisers to increase agricultural production to meet food consumption needs of the family (Kebede et al. 1990). In this sense, household size would have a positive impact on the adoption of modern inputs. On the other hand, household size can harm the adoption of innovations in areas where farmers are very poor. In fact, under these conditions, financial resources may be used for other family commitments, and a small portion of financial resources may be allocated to the purchase of modern inputs.

It is usually within producer organisations that farmers discuss their work with their peers and share information and their experience on new technologies and production techniques (Klerkx et al. 2012). In addition, according to the system of agricultural research and extension in Cameroon, extension agents go through producer organisations to reach the farmers. Farmers' contact with extension agents is controlled in this study through farmers' membership to one or more producer organisations. It is expected that farmers' membership will have a positive impact on the adoption of modern inputs. Farmers who own their land often take into account the negative long-term consequences of the use of chemical inputs. In addition, due to the fact that they can use other strategies of soil conservation or regeneration (for example by planting trees), it is likely that chemical inputs are less often used by landowners.

The size of the farm can positively or negatively influence the likelihood of the adoption of agricultural innovations. For Feder et al. (1985), large farms may be more likely to incur the (possibly high) fixed cost of adoption and to benefit from the use of new farming techniques. Other authors however refute the hypothesis of economies of scale in agriculture and argue that there is no a priori reason to believe that the adoption of agricultural innovations will be enhanced by a larger farm size (Shakya and Flinn 2008). Indeed, if the farmer has a large area to cultivate, his/her propensity to use fertilisers will be low since the farmer can restore soil fertility using fallow techniques.

Difficult access to credit (credit constraints) is usually found to be a barrier to the adoption of innovations; however, the measure of access to credit remains a problem. Doss (2006) suggests that a farmer who has received credit in the past is a better measure than the existence of a source of credit available to the farmer. In this study, we use a dummy variable that takes the value 1 if the producer has received credit in the past, and 0 otherwise. Access to credit (formal or informal) can loosen liquidity constraints; hence, we expect a positive influence on the probability of adoption of modern inputs. However, the credit can be diverted for other purposes rather than for production means. In this case, it may negatively influence the likelihood of adoption of innovations.

Farmers with substantial revenues should have sufficient financial resources to purchase modern inputs. A positive relationship is thus expected between income (and off-farm activities) and adoption of modern inputs. However, off-farm activities may divert time and effort away from agricultural activities, reducing investments in technologies. Thus, the impact of off-farm activities on the adoption of agricultural innovations is indeterminate (Pender and Gebremedhin 2008). The distance to markets and farm access can also influence farmers' decision to adopt new technologies. Transportation costs will increase with the distance from the farm to the market, so we expect distance to negatively affect the decision to use modern inputs. Finally, when soil fertility declines, farmers may compensate by using fertilisers. Thus, we expect that soil fertility would have a negative influence on the adoption of chemical fertilisers.

Results and discussion

Table 3 presents the estimation results. The likelihood ratio test [chi2(3) = 27.6035, Prob > chi2 = 0.000] of the independence of the disturbance terms is rejected, implying that the three unobserved components of the adoption equations are not independent, which supports the use of a multivariate probit model. In addition, the binary correlations between the error terms of the three adoption equations show that these practices are complements (positive correlation).

Our findings show that the perceived risk of illness or death of a key member of the household has a positive effect on the decision to adopt improved seeds and pesticides. Moreover, risk perception of pest-disease infestations and default risk to finance a crop production have a positive influence on the adoption of pesticides and chemical fertilisers, respectively. According to Just and Zilberman (1983), this suggests that these agricultural innovations reduce agricultural risks in our study area. Thus, farmers who perceive some risk of pest-disease infestation have a higher probability to adopt pesticides (whether insecticides or herbicides). Similarly, the cost of labour and the perceived risk of illness or death of a key member of the household increase the likelihood of adoption of pesticides. The use of pesticides (herbicides in particular) may be seen as a substitute for labour for households facing the risk of one key member being no longer available to work on the farm.

We find that the price of corn has no effect on the decision to use improved seeds and fertilisers, but it has a positive effect on the decision to use pesticides. According to Feder (1980), this can be due to the fact that, in the study area, the elasticity of the risk response to pesticides is lower than the elasticity of the mean yield response to pesticides. If the yield effect dominates its risk increasing effect, then a higher output price should provide the farmer with increased revenues in case of adoption of pesticides. But, for improved seeds and fertilisers, the yield effect of these modern inputs might be lower than their risk increasing effect. Conforming to the theory of induced innovation, increased labour costs lead to a decrease in the probability of adoption of chemical fertilisers that are labour intensive. Also, the decline in soil fertility and an increase in the cost of manure have a positive influence on the decision to use chemical fertilisers.

We also find that the decline in soil fertility has a negative effect on the probability of adoption of improved seeds, probably because in this case, farmers spend their income to purchase fertilisers. As expected, the producer's income and the size of his/her farm, which are both indicators of wealth, have a positive effect on the probability to adopt agricultural innovations. Farmers who have completed secondary or higher education are also more likely to adopt agricultural innovations, which confirm the findings of earlier studies. Given the danger of pests, farmers who have access to credit or those who have an educational background generally adopt pesticides. Contrary to what was expected, membership in a producer organisation has no effect on the adoption of an agricultural innovation.

We also noted as Nkamleu and Adesina (2000) that female farmers are less likely to use pesticides compared to men. In

Table 3 Estimation of the determinants of the decision to adopt agricultural innovations (multivariate probit model results)

	Parameter estimates			Marginal effects[a]		
Variables	Improved seeds (1)	Chemical fertilisers (2)	Pesticides (3)	Improved seeds	Chemical fertilisers	Pesticides
fem	0.0752	0.0554	−0.514***	0.0157	0.0263	−0.139**
	(0.401)	(0.323)	(−2.848)	(0.363)	(0.437)	(−2.559)
dist_ch	−0.0154	0.00314	0.0125	−0.00378	0.00157	0.00259
	(−1.608)	(0.436)	(1.477)	(−1.426)	(0.634)	(1.370)
fertilbais	−0.488**	0.356**	−0.152	−0.103***	0.120**	−0.0370
	(−2.297)	(2.130)	(−0.693)	(−2.725)	(2.376)	(−0.827)
fertilhaus	0.111	−0.0726	0.0227	0.0272	−0.0220	0.0111
	(0.693)	(−0.490)	(0.134)	(0.663)	(−0.427)	(0.286)
primary	0.356	0.0935	0.433**	0.0944	0.0307	0.110**
	(1.576)	(0.541)	(1.973)	(1.637)	(0.521)	(2.052)
secondary	0.775***	0.345*	0.611**	0.212***	0.112*	0.158**
	(3.101)	(1.677)	(2.439)	(3.005)	(1.690)	(2.375)
credit	0.0518	0.0440	0.415**	0.0136	0.0166	0.105**
	(0.331)	(0.309)	(2.555)	(0.352)	(0.342)	(2.502)
div-act	−0.00844	0.0299	0.160	−0.00274	0.0143	0.0426
	(−0.0554)	(0.216)	(1.004)	(−0.0741)	(0.303)	(1.147)
asso	0.265	0.192	0.137	0.0605	0.0660	0.0288
	(1.545)	(1.332)	(0.733)	(1.619)	(1.293)	(0.723)
propr	−0.108	−0.341	0.131	−0.0317	−0.105*	0.0284
	(−0.455)	(−1.573)	(0.472)	(−0.506)	(−1.703)	(0.522)
experience	0.00806	−0.0107	0.0240	0.00159	−0.00351	0.00609
	(0.428)	(−0.623)	(1.225)	(0.349)	(−0.603)	(1.365)
experience2	−0.000174	0.000224	−0.000276	−3.00e-05	7.04e-05	−6.74e-05
	(−0.513)	(0.747)	(−0.812)	(−0.368)	(0.701)	(−0.878)
super	1.85e-05***	1.69e-05**	1.97e-05***	4.47e-06***	6.42e-06**	4.08e-06**
	(2.597)	(2.288)	(2.695)	(2.626)	(2.491)	(2.465)
pmoy	0.00142	−0.000433	0.00333**	0.000349	−0.000103	0.000700**
	(0.945)	(−0.298)	(2.119)	(0.982)	(−0.214)	(2.021)
revenu	0.000281**	0.000287**	0.000204*	6.57e-05**	8.60e-05**	4.32e-05*
	(2.449)	(2.232)	(1.841)	(2.368)	(2.024)	(1.771)
tailmenag	0.0162	−0.00671	−0.0343	0.00380	−0.00223	−0.00829
	(0.689)	(−0.306)	(−1.376)	(0.668)	(−0.295)	(−1.473)
dist_mark	−0.00920	0.0550*	−0.0186	−0.00170	0.0187*	−0.00310
	(−0.262)	(1.764)	(−0.499)	(−0.204)	(1.746)	(−0.379)
riskprix	−0.415	−0.188	−0.0481	−0.120	−0.0674	−0.000384
	(−1.437)	(−0.692)	(−0.137)	(−1.280)	(−0.814)	(−0.00482)
riskclim	−0.462	0.0957	−0.197	−0.133	0.0481	−0.0665
	(−1.567)	(0.364)	(−0.575)	(−1.362)	(0.506)	(−0.712)
riskmala	0.364**	−0.155	0.332**	0.0911**	−0.0598	0.0813**
	(2.373)	(−1.155)	(2.049)	(2.509)	(−1.308)	(2.299)
riskphyt	−0.200	0.0953	0.270*	−0.0528	0.0364	0.0517*
	(−1.254)	(0.683)	(1.790)	(−1.332)	(0.754)	(1.828)
riskfina	−0.188	0.270**	−0.0958	−0.0471	0.0885**	−0.0289
	(−1.199)	(1.963)	(−0.571)	(−1.327)	(1.988)	(−0.806)
tauxsal	−0.00554	−0.0350***	0.0257**	−0.00106	−0.0122***	0.00551**
	(−0.416)	(−2.977)	(2.084)	(−0.331)	(−3.057)	(1.974)
coutfiente	7.54e-05	0.000624***	−3.59e-05	2.01e-05	0.000208***	4.96e-07

Table 3 (continued)

Variables	Parameter estimates			Marginal effects[a]		
	Improved seeds (1)	Chemical fertilisers (2)	Pesticides (3)	Improved seeds	Chemical fertilisers	Pesticides
	(0.457)	(3.965)	(−0.210)	(0.499)	(3.878)	(0.0126)
rural	−0.133	0.0827	−0.146	−0.0311	0.0270	−0.0332
	(−0.817)	(0.587)	(−0.849)	(−0.790)	(0.559)	(−0.860)
Constant	−1.251*	−0.651	−2.706***			
	(−1.907)	(−1.086)	(−3.596)			
Number of observations	562					
Wald chi2(.)	Wald chi2 (75) = 245.56					
Prob > chi2	0.0000					
Log likelihood value	−732.82026					
LR test of ρ_{ij}	27.6035					

LR test of independence of equations with uncertainty: $\rho_{21} = \rho_{31} = \rho_{32} = 0$; chi2(3) = 27.6035; Prob > chi2 = 0.0000; $\rho_{21} = 0.154$*, $\rho_{31} = 0.298$***, $\rho_{32} = 0.428$***

Note: Values in parentheses are z-statistics. * (**) {***} represent statistical significance at 10 % (5 %) {1 %}

Prices of improved maize seeds, fertilisers and pesticides were excluded because there is lack of variation in our data for these variables

[a] Here are the changes in the unconditional probability of adoption of each of the three technologies due to variation of each independent variable

fact, beyond the socio-cultural inequalities between males and females (in terms of access to information, knowledge, markets and services) as mentioned by Ndiritu et al. (2014), in order to justify gender differences in the adoption of some innovations, in this study, a gender effect on pesticide adoption may indicate women's lack of necessary skills. Finally, the distance to the market has a positive effect on the decision to adopt chemical fertilisers. This is contrary to our expectations but may be explained by the fact that the distance to the market also reflects the area of residence of a farmer. So, a positive effect of the distance on fertiliser demand may indicate that rural farmers (whose main source of income is agriculture) are more likely to adopt fertilisers than urban farmers.

Conclusion

The use of modern inputs is an important issue. Modern inputs have played a significant role in increasing agricultural production and productivity in the developing world over the last decades. Yield crop varieties, intensive agricultural practices and chemical inputs have formed foundations of the so-called Green Revolution. The benefits of adopting the new agricultural technologies are likely to vary across farmers that are heterogeneous in the availability of human capital and technical skills, and in other socio-economic characteristics. Therefore, specific information on the influence of farmers' socio-economic characteristics and their risk perceptions, as well as the characteristics of their farm, would be helpful in the design and implementation of more effective programmes to promote modern input use.

This study examines the determinants of new agricultural technology adoption by corn producers in the west of Cameroon. Rather than the univariate probit model which is commonly used, the multivariate probit model was employed to account for the possible correlation between the error terms of the three models. Our findings show that

(i) Apart from the effect of the price of corn on the decision to use pesticides, the price of corn has no effect on the decision to adopt improved seeds and chemical fertilisers. According to Feder (1980), this result might be linked to the presence of multiple agricultural risks that could make farmers insensitive to incentives by the output price, which may call for the development of risk management or insurance policies.

(ii) Farmer's characteristics, in particular his/her level of education and his/her income, positively influence the adoption of agricultural innovations. Hence, the persistence of traditional agriculture among a large number of farmers in Cameroon, despite the low agricultural yields recorded, may be explained by low education and poverty.[6] Therefore, all policies aimed at increasing the level of education of farmers and their access to credit could greatly promote the adoption of agricultural innovations.

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