Agricultural Sciences, 2022, 13, 1234-1258
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Factors Explaining the Dynamics of Agricultural Technological Innovations Adoption: Evidence from Senegal's Rain Maize Farmer

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How to cite this paper: Diagne, A., Tamini, L.D. and Fall, F.S. (2022) Factors Explaining the Dynamics of Agricultural Technological Innovations Adoption: Evidence from Senegal's Rain Maize Farmer. *Agricultural Sciences*, **13**, 1234-1258.
https://doi.org/10.4236/as.2022.1311076

Received: September 27, 2022
Accepted: November 19, 2022
Published: November 22, 2022

Abstract

This paper analyzes the adoption dynamics of improved rainfed maize seeds disseminated in Senegal in 2013 by the West African Agricultural Productivity Program (WAAPP). We group maize producers into five groups (non-adopters, laggards/abandoners, late adopters, followers and pioneers/innovators) and take into account the heterogeneity of unobservable characteristics of the producers. In the pioneers/innovators group, the availability of labour, household size, shocks, and frequency of access to advice positively influence adoption, whereas financial constraints and high numbers of plots reduce the probability of adoption. Producers in the followers' category tend to be older and more educated than those in the other categories. However, food insecurity and shocks such as diseases hamper adoption. For the group of late adopters, household size and available storage infrastructures explain adoption. However, the number of plots and shocks reduces their probability of adoption. Laggards tend to face shocks and food insecurity. The authors recommend to consider the dynamics of the adoption of technological innovations and heterogeneity of the characteristics of adopters groups in future research. They also recommend farmers to increase their adoption rate of the "*Early Thai*" and "*Suwan 1*" seed varieties thanks to their higher yields compared to traditional varieties. Also, a higher adoption rate would positively impact the food security of maize farmers in Eastern Senegal and High Casamance, especially in terms of availability. Other studies measuring the number of years needed for large-scale adoption of improved seed varieties should be conducted.

Keywords

Adoption, Technological Innovations, Multinomial Logit Model, Endogeneity, Unobservable Heterogeneity, Senegal

1. Introduction

Agricultural technological innovations show promise in scaling solutions in agricultural sectors with low productivity, which causes low incomes for farmers and food insecurity [1] [2] [3] [4].

In Senegal, the West Africa Agricultural Productivity Program (WAAPP) disseminated agricultural technologies. However, after almost ten years of implementation, few studies have analyzed the impact of this program.

In the literature, several studies have attempted to explain the adoption of technological innovations in agriculture. Most of them analyze it as dichotomous (e.g., [3] [5]-[11]). However, following the seminal work of Tarde (1907) cited by [12], some authors see it as "dynamic" [13] [14] [15], as a "process" [16] [17] [18] or as having several "stages" [19] [20] [21] [22] [23]. Ryan and Gross (1950) [24] studied the adoption of hybrid maze seeds in Iowa and distinguished five groups of adopters:[1] the pioneers, first adopters, majority, late majority and laggards. Their results showed significant differences between groups related to education, knowledge, plot size and land titles. Barham *et al.* (2004) [13] analyzed and distinguished the adoption factors for bovine somatotropin among non-adopters, late adopters and early adopters and found that the past use of technology, herd size, and education have a positive impact on adoption, whereas age influences it negatively. Their results are similar to those of [25] in Connecticut, except for the age variable. Moser and Barrett (2006) [14] found that the poorest farmers abandon technologies due to seasonal liquidity constraints. Their study shows, however, that the learning effects of both extension agents and other farmers have a significant influence on adoption decisions. Läpple and Van Rensburg (2011) [22] also studied the dynamics of adoption by distinguishing early adopters from followers and late adopters. Their results reveal that the factors influencing adoption play a different role in adopter categories, especially factors related to agricultural intensity, age, information and farmer attitudes. Moreover, Lambrecht *et al.* (2014) [18] studied the adoption of fertilizers in South Kivu and modelled it as a process with three stages, including awareness and discovery, essay, and continued adoption. Their results indicate that farmers' education, social capital and membership organization determine their awareness. This article is highly relevant, because it analyzes adoption as a three-phase process rather than in terms of groups and highlights the importance of access to information and of membership in organizations for agricul-

[1]Diederen *et al.* (2003) ([23]) analyzed agricultural technologies adoption using three groups: precursors, followers and laggards.

tural technology adoption as did [2] [19] [25] [26]. Finally, in one of the most recent papers on agricultural innovations adoption, Barham *et al.* (2004) [13] clearly confirm the dynamics of adoption by using, on the one hand, a multinomial logit model as a preview study, and on the other hand, a survival model combined with experimental economics.

This paper aims to study the dynamics of and factors affecting the adoption of improved rainfed maize seeds in Senegal, more precisely in the areas of Eastern Senegal and High Casamance. Following [13] [19] [22] [27], and [28], we classify maize producers into five groups (non-adopters, abandoners/laggards, late adopters, followers and early adopters) and analyze the factors affecting adoption in each group while accounting for the heterogeneity of individual characteristics among the groups.

This paper is organized as follows. The first part provides an introduction, including an overview of related literature on dynamic adoption of technological innovations in agriculture in general and improved maize seeds in particular. The second part describes the study area and provides data. The third part presents the methodological approach. The fourth part presents the results of the econometric models with and without unobservable heterogeneity and the results of the endogeneity test of the membership organization variable. The fifth and last part is devoted to the conclusions.

2. The Study Area and Data

The data used in this paper come from the survey by the Consortium for Economic and Social Research (CRES) of Senegal, which is the structure responsible for evaluating the impact of the twelve clusters of WAAPP technologies disseminated in Senegal for the World Bank. The project disseminated two varieties of improved seeds of maize, namely, "*Early Thai*" and "*Suwan 1*"[2]. Maize has a high potential for yield in Senegal and is one of the few cereals with the dual attribute of being a food crop and a cash crop. It can also be grown in the rainy season as well as in fall. In addition, it was found that maize production in Senegal from 1980 to 2014 has evolved a sawtooth, largely due to the irregular rainfall during this period and constraints on access to inputs, including improved varieties [29].

The survey was conducted between the end of 2015 and the beginning of 2016, with 336 producers of rainfed maize. It covers 32 villages in eight departments (Kedougou, Saraya, Medina Yoro Foulah, Vélingara, Bakel, Goudiry, Koumpentoun and Tambacounda) and three regions (Kédougou, Kolda and Tambacounda). These Senegalese regions form the agroecological zone called Eastern Senegal and High Casamance (see **Figure 1**). Streams, abundant lands, a large forest reserve, fauna, flora, important minerals and a zoo characterize this area. A significant portion of its soils is poor and vulnerable to wind and water erosion. Agricultural lands are abundant but underutilized [30].

[2]For more information about improved maize seed benefits, see the WAAPP project document (2013).

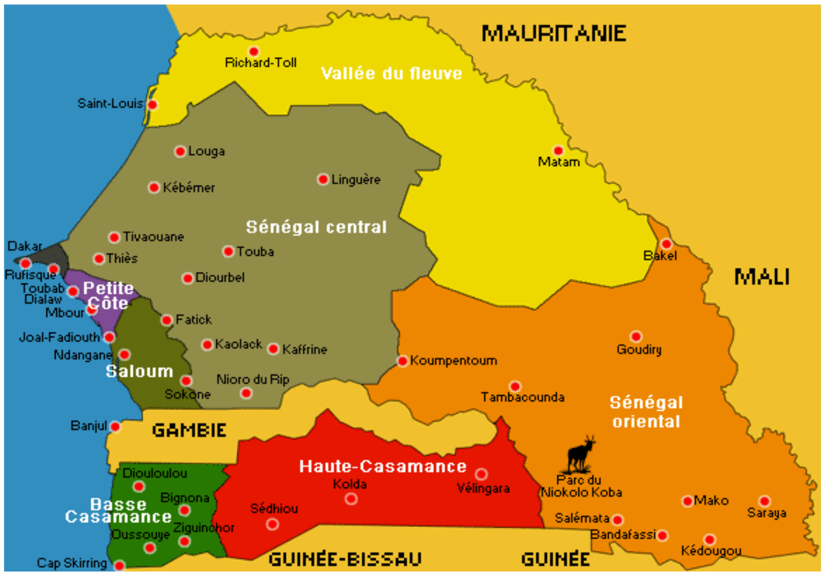

Figure 1. Senegal Map with agroecological zones. Source: Planet Senegal, 2019.

2.1. Adoption Stages

Following Läpple and Van Rensburg (2011) [22] and Barham *et al.* (2004) [13], we defined and classified producers into five categories: non-adopters, laggards/abandoners, late adopters, followers and pioneers/innovators (see Table 1).

It shows that non-adopters represent 47% of producers. Pioneers/innovators constitute 25% of the adopter group and 13.2% of the total sample in the study. The followers' category represents 23% of adopters and 12.2% of the total sample of producers. Late adopters represent the majority of adopters at 28% and 15% of the total sample. Laggards constitute 24% of the adopters and 12.5% of the overall sample.

Table 2 presents the descriptive statistics of rainfed maize producers in Eastern Senegal and High Casamance.

2.2. Producer Characteristics by Adoption Stage

Based on the literature on agricultural technologies adoption, we used the variables summarized in Table A1 in the annex to study the adoption factors by stage. We classified the variables into six groups: sociodemographic and economic characteristics of producers, producer households, access to information, farm characteristics, food security and shocks. In Table 2, we provide statistics of the variables used, while in Table 3, we indicate the results of statistical tests in order to analyse the differences between the groups. Table 2 and Table 3 show the existence of heterogeneity of characteristics among adopting groups that could explain adoption factors at the level of each category.

2.2.1. Sociodemographic and Economic Characteristics

Gender, age, education level, literacy, the fact that the producer is the head of his

Table 1. Description of group producers.

Adopters group	Description
Non-adopters	Maize Producers who don't know or know improved varieties of "*Early Thai*" *and* "*Suwan 1*" maize in 2013, but did not use them in 2013, 2014 and 2015
Laggards/abandoners	Maize producers who have used the improved seeds but ended their use.
Late adopters	Maize producers who adopted late namely at the end of seed dissemination project. They knew improved varieties since 2013 but did not sow them until 2015.
Followers	Maize producers who knew improved varieties but have started using them in 2014 and continued to do so.
Pioneers/Innovators	Maize producers who sowed the improved varieties from the beginning of the project in 2013 and continued to use them until the end of the project in 2015.

Source: Authors, 2019.

household, membership in an organization, benefiting from a development project and production flow constraints are usually reported in the literature as affecting adoption decisions (e.g., [2] [18] [31] and [32]).

In this study, the literacy variable is the ability to read in French, Arabic and one of the national languages of Senegal.

The variable "access to project development" captures three determinants, in this case, access to credit, access to the market and access to inputs. Several studies considered these determinants having positive impact on adoption of improved seeds (e.g., [2] and [18] [33]). The inadequacy of rural infrastructures and isolation of some villages and the difficulties in accessing to agricultural credit and inputs are problems that are very common in Senegalese rural areas as shown [34].

Statistical tests presented in **Table 3** confirm the differences between most sociodemographic and economic variables. At the 5% and 10% levels, the follower and laggard groups and those of late adopters and laggards are different regarding gender. Pioneers and late adopters and pioneers and laggards reveal a significant difference in the average age, at the threshold of 5% and 10%. Producers belonging to the pioneer group are in fact older than are those of the two aforementioned groups, with an average age of 50.78 years compared to 45 years.

Followers and late adopters tend to have a very significant difference at the 1% level for education, literacy and being the head of their household. In fact, the percentage of producers who can read and write in the follower category (60%) is almost double that of late adopters (31%). Low educational attainment and literacy thus appear to be determinants of late adoption or abandonment of improved maize seed varieties.

Table 2. Descriptive statistics of maize producers in Eastern Senegal and High Casamance.

Variables	Pioneers/innovators (n = 40)	Followers (n = 37)	Late adopters (n = 45)	Laggards/abandoners (n = 38)	Non-adopters (n = 144)
	Mean/Proportions	Mean/Proportion	Mean/Proportion	Mean/Proportion	Mean/Proportion
Sociodemographic and economic characteristics of the producer					
Gender	0.9	0.87	0.844	0.97	0.88
Head of household	0.9	0.95	0.82	0.95	0.89
Age	50.78 (13.80)	48.84 (10.13)	45.67 (10.65)	45.15 (10.94)	44.63 (13.19)
Instruction	0.35	0.35	0.18	0.18	0.16
Literacy	0.46	0.60	0.31	0.45	0.26
Production flow constraints	0.40	0.24	0.42	0.37	0.30
Organization	0.30	0.38	0.22	0.34	0.10
Development projects access	0.83	0.54	0.64	0.53	0.14
Awareness, training, information					
Agricultural advisor access frequency	3.18 (2.05)	1.30 (1.29)	1.42 (1.91)	0.66 (1.15)	0.26 (1.04)
Awareness	0.08	0.32	0.09	0.26	0.083
Training	0.03	0.05	0.09	0.05	0.035
Household size	12.83 (6.25)	10.05 (3.94)	10.40 (6.42)	7.42 (8.55)	7.79 (5.22)
Transfers/remittances	0.20	0.19	0.13	0.29	0.15
Female household head	0.15	0.19	0.22	0.79	0.12
Insurance					
Farms characteristics					
Labor force	3.25 (1.71)	1.89 (1.49)	2.09 (1.55)	1.41 (1.07)	1.56 (1.11)
Animal traction	0.65	0.76	0.58	0.61	0.63
Number of maize plots	2.55 (1.04)	2.44 (0.70)	2.05 (0.86)	2.68 (1.38)	2.23 (1.05)
Soil constraints	0.3	0.11	0.24	0.11	0.21
Food security					
Children meals (−5 years old)	3.38 (0.74)	3.43 (0.50)	3.18 (0.88)	3.05 (1.07)	3.17 (1.04)
Adult meals	3.08 (0.47)	2.97 (0.16)	2.09 (1.55)	3 (0)	2.99 (0.08)
Meals number variation	0.35	0.19	0.11	0.32	0.06
Shocks					
Death	0.18	0.08	0.09	0.08	0.035
Disease	0.2	0.11	0.18	0.03	0.13
Losses	0.08	0.16	0.24	0.16	0.04

Source: Authors' calculations based on data from the 2015-2016 CRES survey. Note: Standard Deviations are in parentheses.

DOI: 10.4236/as.2022.1311076

Table 3. Comparison of adopter categories of improved seeds of rainfed maize—statistics of difference of means and proportion tests.

Variables	Pioneers/ innovators	Late adopters	Pioneers/ innovators	Followers	Laggards/ abandoners	Late adopters	All adopters
	Followers	Pioneers/ Innovators	Laggards	Late adopters	Followers	Laggards	Non-adopters
Sociodemographic and economic producer characteristics							
Gender (χ^2)	0.48	−0.76	1.33	−0.26	−1.74*	1.99**	−0.33
Head of household (χ^2)	0.75	−1.03	0.79	−1.70*	0.03	1.75*	−0.32
Age (**t**)	0.70	−1.96*	−1.99**	−1.37	−1.52	−0.23	−2.05**
Instruction	χ^2 0.01	−1.81**	−1.65*	−1.79*	−1.64	0.08	−2.18**
Literacy (χ^2)	1.051	−1.55	−0.25	−2.57***	−1.28	1.28	−3.37***
Production flow constraints (χ^2)	−1.47	0.20	−0.29	1.70*	1.18	1.22	−1.31
Organization (χ^2)	0.73	−0.82	0.40	−1.55	−0.33	1.25	−4.49***
Development project (χ^2)	−2.69***	−1.87*	−2.83***	0.96	−0.12	−1.09	−8.86***
Awareness, training, information							
Awareness (χ^2)	2.76***	0.23	2.23**	−2.68***	−0.58	2.11**	−2.50**
Training (χ^2)	0.66	1.25	0.63	0.60	−0.03	−0.64	−0.89
Agricultural advisor access frequency (**t**)	−4.77***	−4.10***	−6.65***	0.34	−2.27**	−2.16**	−7.822***
Producer's household							
Household size (**t**)	−2.31**	−1.92	−3.19***	0.28	−1.71*	−1.81*	−3.50***
Transfers/remittances (χ^2)	−0.12	−0.83	0.92	−0.69	1.02	1.76*	1.51
Female household head (χ^2)	1.51	1.51	1.51	1.51	1.51	1.51	1.51
Insurance (χ^2)	-	1.35	-	1.30	-	−1.32	−1.35
Farms characteristics							
Labor force (**t**)	−3.69***	−3.45**	−5.64***	0.59	−1.60	−2.28**	−3.82***
Animal traction (χ^2)	1.02	−0.68	−0.41	−1.70	−1.41	0.25	−0.34
Number of maize plots (**t**)	−0.52	−2.64***	0.45	−2.25**	0.89	2.45**	−1.40
Soil constraints (χ^2)	−2.07**	−0.58	−2.13**	1.59	−0.04	−1.64*	0.32
Food security							
Children meals (−5 years old) (**t**)	0.40	−1.31	−1.56	−1.63	−1.97*	−0.60	−0.84
Adult meals (**t**)	−1.24	−1.85*	−0.97	0.14	1.01	0.92	−0.58
Shocks							
Death (χ^2)	−1.23	−1.18	−1.27	0.13	−0.03	−0.16	−2.40**
Disease (χ^2)	−1.11	−0.26	−2.40**	0.89	−1.42	−2.21**	0.37
Losses (χ^2)	1.19	2.10**	1.15	0.92	−0.05	−0.97	−3.43**

Source: Authors' calculations based on data from the 2015-2016 CRES survey. Notes: All adopters = Pioneers/innovators + followers + late adopters +Laggards. T-tests were used for interval variables, while chi-2 tests were used for categorical variables. ***p < 0.01 **p < 0.05 *p < 0.1.

Late adopters are more likely to head their households than abandoners, and the difference is significant. The liquidity constraints variable is not significant among all the groups' adopters, except for the late adopter and follower groups, for which there is a significant difference at the 1% level.

Our results highlight the important effects of belonging to an organization and having access to a development project on the speed of adoption of agricultural technologies, as shown in [2] and [18].

2.2.2. Awareness, Training and Information

We included the variable "access to agricultural advisory services" as advise [3] and [33]. Instead of just looking at whether a producer has access to advisory services or not, we track the frequency and intensity of this contact.

When analyzing the "awareness" variable, it appears that on average, producers belonging to the pioneer group (8%), compared to followers (32%) and laggards (26%), have less access to it. This result is different from what is often found in the literature: that those who adopt early are often referred to as those who have more information as shown [19] and [24]. The mean difference tests between these adopter groups were significant at the 1% and 5% levels. Comparison between the group of followers and laggards shows a significant difference at the 1% level. The abandonment of improved maize seed use could thus be explained by a lack of access to awareness sessions.

It appears that contact with agricultural advisory services is very heterogeneous among the groups. More marked among the pioneers, with a frequency of three (03) visits against one (01) for the late adopters and laggards, this variable seems to be an important determinant of maize seed adoption. A comparison of pioneers, followers and late adopters indicates significant differences at the 1% level. However, this difference is less marked between followers and late adopters, with significance at the 5% level. It is the same for abandoners and late adopters. Thus, as noted in the literature above, access to agricultural advisory services seems to influence strongly the adoption of improved maize seeds or to discourage their abandonment as shown [18] and [35]. This frequency of access also appears to influence how quickly producers adopt improved seeds, with the difference between pioneers and laggards being significant at 1% and lower. Roger (1962) [19] emphasized the ease of access to information and advice as important for pioneers.

2.2.3. Characteristics of the Producer Households

At the producer household level, we used the variables of household size, remittances, insurance and gender of the household head. Due to the high rate of rural exodus and migration in these Senegalese areas, we took into account remittances received from a family member as did [36]. Labour availability [32], household size [37] and gender [38] [39] [40] [41] determined adoption.

We found that household size is on average larger in the pioneer group (12 members) compared to the followers group (10 members), or those of late adopters and laggards (7 members). This difference is significant at the 1% threshold between pioneers and laggards and at 5% between pioneers and followers. There is also a significant difference at the 10% level in this characteristic when comparing the categories of laggards to that of late adopters or followers. The number of members in the household could thus be a potential adoption determinant as found [37]. These results also suggest that producers may delay their adoption or give up when they have a small household size.

Remittances received by households are homogenous except for late adopters and laggards. Producers who have adopted late are less likely to have migrants in their households than are their counterparts and end up abandoning improved maize seeds. This difference is significant at the 10% level. Receiving remittances thus seems to discourage adoption among maize producers.

Regarding gender among producer household heads, statistics show that laggards (79%) and late adopters (22%) tend to be women. This result suggests that being a female household head reduces the likelihood of adopting and is in line with the direction of the results of [3] and [42].

2.2.4. Farm Characteristics

Regarding farm characteristics, we analyzed variables including labour, storage conditions, animal traction, maize plot number and the type of soils as did [17] and [36].

Labour force seems to be more important among pioneers and laggards compared to other groups. Statistical tests indicate a significant difference at the 1% level between pioneers and abandoners. Labour is also significantly more available among pioneers than laggards. Laggards, on the other hand, have less labour on average than late adopters, with a significant difference at the 5% level. Thus, labour force size seems to be a determinant that favours early adoption.

Animal traction is very noticeable among followers and pioneers. Followers are the only category in which around 75% of producers use animal traction. However, the tests did not reveal any significant differences between the groups of adopters.

Statistics show that pioneers and abandoners have more plots than other groups. We found a significant difference at the 1% level between pioneers and late adopters. Producers belonging to the abandoners group are more land-endowed than are late adopters, with a significant difference at the 5% level. This result shows that if having multiple plots encourages adoption by pioneers, it seems to have a contrary effect on the abandoners, followers and late adopters, who, on their side, tend to have significant differences in terms of their number of parcels.

Soil type is heterogeneous among the groups. The farms of the followers (11%) and abandoners (11%) are on average less confronted with pedological problems than are those of the pioneers. On the other hand, this problem seems to be present among late adopters in improved maize seed adoption in Senegal. Soil constraints therefore appear to be negative determinants of adoption across all groups.

2.2.5. Food Security

Following Khonje *et al.* (2015) [3] and [43], we incorporated and considered food security by means of three variables. This includes the number of meals eaten per day by children under five years in the producer household, the number of meals eaten by adults, and the variation in this number.

Statistical analyses of these variables show that children under the age of five in households of all adopters consume a mean of three meals per day. A significant difference at the 10% level appears when comparing followers to laggards. Adults, on the other hand, are less insecure in terms of food availability than are children. In addition, their number of meals eaten per day is heterogeneous among the adopter groups. Food security thus appears to be a factor that hinders or delays seed adoption by maize producers.

2.2.6. Shock

The last category of variables used in this paper is related to shocks as studied [44]. We define shocks as situations where household producers have been the victim of diseases, death or loss of their main production tool.

The statistics show that pioneers are the most confronted with deaths and less confronted with production tool losses. We found a significant difference at the 5% level for diseases between pioneers and abandoners, and abandoners and late adopters. Late adopters seem to be more confronted with loss of their production tools.

Shocks related to illness and death thus appear to be positive factors of adoption, while shocks related to losses delay adoption.

In summary, the results in **Table 2** and **Table 3** confirm the significant heterogeneity of the characteristics among the groups. We thus corroborated the non-homogeneity hypothesis of adopter group characteristics. Although the size of our sample is small, the results of the statistical tests carried out confirm the heterogeneity found in the literature and justify our disaggregation and distinction between the groups of adopters. These results also suggest that determinants of adoption may differ depending on the category to which the rainfed maze producer belongs.

3. Empirical Approach: Multinomial Logit Model to Explain Adoption

3.1. A Model without Unobservable Heterogeneity of Producers and Farm Characteristics

Let us define the variable of "result" by Y_{ij}, $j = 0,1,\cdots,J$, where J is a positive integer less than 0 or equal to 4. For the producer i, we therefore have:

$$Y_{ij} = \begin{cases} 0 \text{ if the producer knows, doesn't know or did not use improved varieties of maze in 2013, 2014 and 2015} \\ 1 \text{ if the farmer knows and used the improved maize varieties in 2013, 2014 and 2015} \\ 2 \text{ if the farmer knows and used the improved maize varieties in 2014 and 2015, but did not seed them in 2013} \\ 3 \text{ if the farmer knows and used the improved maize varieties in 2015, but did not seed them in 2013 and 2014} \\ 4 \text{ if the farmer knows and used the improved maze varieties, but ended up no longer sowing them} \end{cases}$$

$$\text{Or: } Y_{ij} = \begin{cases} 0 & \text{Non-adopters} \\ 1 & \text{Pioneers/Innovators} \\ 2 & \text{Followers} \\ 3 & \text{Late adopters} \\ 4 & \text{Laggards/Abandoners} \end{cases}$$

Since the adoption process is polytomous and individual characteristics may be different across categories, we estimate a dynamic of adoption using a multinomial logit model. According to [22] and [45], this type of model is well adapted when alternatives are different and reveals significant differences between categories of adopters. This model can capture the unique determinants of each category, and adoption factors associated with each category can be compared to those of a reference category as said Barham *et al.* (2004) [13].

In the framework of the model without unobservable heterogeneity, maize farmer *i* makes the decision to belong to one of the groups of adopters listed above *j*. His utility function deriving from the choice of alternatives *j* is represented by the following equation.

$$U_{ij} = X_i' \beta_{ij} + \varepsilon_{ij} \tag{1}$$

U_{ij} represents the utility of the producer *i* deriving from the choice of alternatives *j* (*j* = 0, …, 4); and is the greatest utility among the *J* utilities considered by the producers.

X_i represents vector of individual and observable characteristics of the producer as well as the farm; β_{ij} are the estimated parameters in each alternative and ε_{ij} are the random errors who are statistically distributed independently and identically.

In fact, the probability that the producer *i* will choose the alternative *j* corresponds to the probability that the utility of the choice of the alternative *j* is greater than is those associated with the choices of the other alternatives.

The following equation represents thus the probability of categories *J* for each alternative among non-adopters (=0), pioneers/innovators (=1), followers (=2), late adopters (=3) and laggards/abandoners (=4):

$$\Pr\left(Y_i = j / X_i\right) = \frac{\exp\left(\beta_j X_i\right)}{\sum_{j=1}^{J} \exp\left(\beta_j X_i\right)}, \quad j = 0, \cdots, 4 \tag{2}$$

where *j* is one of the subgroups; $\Pr\left(Y_i = j\right)$ is the probability that the maize producer *i* belongs to the subgroup *j*; X_i represents observable characteristics of the farmer as well as the farm; and ε_{ij} is the error term that is supposed to be independent and identically distributed between the *j* alternatives.

Multinomial logit model identification requires constraint imposition. For estimation purposes, we normalized the coefficients of one of the classes considered as the reference class. As recommended by [46] [47] and [48], we selected $\beta_0 = 0$.

The probabilities of being in a specific category then follow the model below:

$$\Pr\left(Y_i = j / X_i\right) = \frac{\exp\left(\beta_j X_i\right)}{1 + \sum_{j=1}^{J} \exp\left(\beta_j X_i\right)} \quad \text{for } j = 1, 2, 3, 4 \tag{3}$$

$$\Pr\left(Y_i = 0\right) = \frac{1}{\sum_{j=1}^{J} \exp\left(\beta_j X_i\right)} \tag{4}$$

The multinomial logit model is estimated using a maximum likelihood method:

$$L\left(\beta_1, \cdots, \beta_j / Y, X\right) = \prod_{i=1}^{n} \prod_{j=0}^{4} \left(\frac{\exp\left(\beta_j X_i\right)}{\sum_{j=0}^{J} \exp\left(\beta_j X_i\right)} \right)^{Y_i = j} \tag{5}$$

$$\ln L = \prod_{i=1}^{n} \prod_{j=0}^{4} 1\left(y_i = j\right) \ln\left(Y_1 = j / X_i\right) \tag{6}$$

$L\left(\beta_1, \cdots, \beta_j / Y, X\right)$ represents, the maximum likelihood function, $1\left(y_i = j\right)$ is the indicator function of the producer's choice. It takes 1 if $\left(Y_i = j\right)$ and 0 otherwise as in Nguyen-Van *et al.* (2017) [28]. Coefficients are interpreted using relative risk ratios, which is the relative probability of $Y_i = j$ for *j* greater than 0, the basic category, which is the non-adopters group.

$$\frac{P\left(Y = j\right)}{P\left(y = 0\right)} = \exp\left(\beta_j X_i\right) \text{ for } j > 0 \tag{7}$$

3.2. A Model with Unobservable Heterogeneity of Farmers and Farm Characteristics

When estimating a multinomial logit model, there may be unobservable heterogeneity that must be taken into account [28] [49] [50]. The utility of the producer *i* deriving from the choice of alternatives *j* becomes:

$$U_{ij} = X_i' \beta_{ij} + u_i + \varepsilon_{ij} \tag{8}$$

where the new term u_i represents the heterogeneity term assumed to be independent, independent of *X* and to follow the normal density distribution [28]. The probability of being in a specific category is then:

$$\Pr\left(Y_i = j / X_i\right) = \frac{\exp\left(\beta_j X_i + \sigma_j u_i\right)}{1 + \sum_{j=1}^{J} \exp\left(\beta_j X_i + \sigma_i u_i\right)} \quad \text{for } j = 1, \cdots, J \tag{9}$$

$$\Pr\left(Y_i = 0\right) = \frac{1}{\sum_{j=1}^{J} \exp\left(\beta_j X_i + \sigma_j u_i\right)} \tag{10}$$

Since the log-likelihood function depends on individual heterogeneity, it must be integrated prior to maximization using the simulated maximum likelihood method [50]. The log-likelihood function thus becomes:

$$\ln L = \sum_{i}^{n} \ln \left[\frac{1}{H} \sum_{h=1}^{4} P\left(Y_i = j / X_i, u_i^h\right)^{1(y_i = j)} \right] \tag{11}$$

where for each u_i, a number H pseudo random draw u_i^h is generated.

According to [50], it is possible to take an H equal to 50, 100 or 150 during simulations. MacFadden and Train (2000) [51] suggest in turn taking an H equal to 50 for simulations, and we follow them in this regard.

3.3. Endogeneity Test

We ran an endogeneity test of the variable "belonging to an organization". To check this, we used the additional variables test developed by [52] as part of a nonlinear model. This test consisted of two steps. First, an estimation of the determinants of organization membership is made using the following Probit model:

$$\Pr\left(f_i = 1\right) = \Phi\left(Z_i \gamma_i\right)$$

where f_i is the binary variable representing organization membership and Z_i are instruments. Wooldridge (2014) [52] recommends that the instruments encompass all explanatory variables included in the original logit model, as well as other instruments that are not included. We selected the "awareness" variable as external instruments.

In the first part of the test, we calculated a generalized residue (*gr*) according to the following formula: $\hat{g}r_i = f_i \lambda\left(Z_i \hat{\gamma}_i\right) - \left(1 - f_i\right) \lambda\left(-Z_i \hat{\gamma}_i\right)$, where $\lambda(.)$ represents the Inverse Mills Ratio. In the second step of the test, we introduced the residue into the initial estimation of multinomial logit model with an endogenous suspected variable. Subsequently, we did a Wald test to test the null hypothesis that cooperative membership variable coefficients are all equal to zero.

4. Estimation Results

We compared the two models using the likelihood ratio test. The test revealed non-significant differences between the two models. The model with unobservable heterogeneity gave a likelihood ratio equal to $L2 = -271.12$, whereas that of the classical model without unobservable heterogeneity is equal to $L1 = -260.83$. As a result, the statistic test is found to equal $|-20.57|$, which is greater than $Chi(2)4 = 9.49$. We do not reject the null hypothesis. As a result, we reported the results of the multinomial logit model without unobservable heterogeneity of producer characteristics in **Table 4**.

The Hosmer and Lemshow test results show good calibration of the models with a small distance between predicted and observed values at the deciles level, materialized by a $\Pr > Chi(2) = 0.933$ and $Chi(2)10 = 20.952$. Following quality tests of the model, the independence property of irrelevant alternatives (IIA) was verified. A rigorous assumption of a multinomial logit model is IIA [53]

Table 4. Determinants of adoption of improved varieties of rainfed maize.

Variables	Pioneers/innovators	Followers	Late adopters	Laggards/Abandoners
	Coefficients	Coefficients	Coefficients	Coefficients
Sociodemographic and economic characteristics of the producer				
Gender (men)	1.67 (0.90)	17.39 (0.01)	0.66 (0.49)	18.51 (0.01)
Head of household	2.93 (1.45)	19.36 (0.01)	1.11 (0.79)	0.63 (0.00)
Age	0.03 (1.20)	0.04* (2.00)	0.01 (0.42)	0.02 (0.72)
Instruction	0.03 (0.03)	−0.35 (−0.47)	−0.80 (−0.98)	−0.38 (−0.42)
Literacy	0.12 (0.14)	1.60* (2.44)	0.59 (0.85)	0.96 (1.23)
Production flow constraints	−2.46** (−3.22)	−0.42 (−0.61)	−0.49 (−0.81)	0.34 (0.45)
Organization	0.10 (0.12)	−0.21 (−0.31)	−0.85 (−1.30)	−0.56 (−0.70)
Development projects	2.84** (3.02)	3.31*** (3.84)	3.60*** (4.53)	4.51*** (4.72)
Awareness, training, information				
Agricultural advisor access frequency	0.98*** (4.09)	0.42* (1.77)	0.48* (2.18)	0.25 (0.76)
Producer's household				
Household size	0.17** (2.93)	0.14** (2.80)	0.18*** (3.69)	−0.02 (−0.27)
Male household head	−3.06 (−1.33)	−19.78 (−0.01)	−1.37 (−0.80)	−2.33 (−0.00)
Farms characteristics				
Labor force	0.45* (2.18)	0.14 (0.70)	0.24 (1.35)	−0.06 (−0.24)
Animal traction	0.21 (0.35)	0.67 (1.24)	−0.13 (−0.27)	0.13 (0.22)
Number of maize plots	−0.53* (−1.67)	−0.37 (−1.38)	−0.75** (−2.76)	0.16 (0.58)
Regions				
Kolda	17.19 (0.01)	15.65 (0.01)	0.88 (0.78)	−2.84* (−1.90)
Tambacounda	17.17 (0.01)	18.52 (0.01)	2.20* (2.20)	2.36* (1.83)

Continued

Storage				
Room place	0.09	−0.43	1.26*	−0.27
	(0.14)	(−0.70)	(2.45)	(−0.38)
Warehouse	0.38	−0.15	0.52	−0.56
	(0.36)	(−0.16)	(0.53)	(−0.46)
Other types of stock	−20.62	1.51	0.25	−15.23
	(−0.00)	(0.77)	(0.12)	(−0.00)
		Food security		
Children meals (−5 years old)	−1.41***	−0.65*	2.21	−0.57*
	(−3.50)	(−1.76)	(1.13)	(−1.72)
Decrease of meals number	1.46*	1.69*	0.54	4.06***
	(1.81)	(2.10)	(0.66)	(4.72)
		Shocks		
Death	2.33*	2.44*	1.59	2.26*
	(2.07)	(2.31)	(1.59)	(1.87)
Diseases	−3.09***	−1.78*	−1.99**	−1.63
	(−3.62)	(−2.27)	(−2.82)	(−1.49)
Constant	−19.98	−38.76	−2.55	−21.41
	(−0.01)	(−0.01)	(−1.38)	(−0.01)
LR Chi2 (92)=	330.97			
Pseudo R^2	0.388			
N=	303			

Source: Authors' calculations based on data from the 2015-2016 CRES survey. Notes: Standard errors are in parentheses. ***p < 0.01 **p < 0.05 *p < 0.1.

[54] [55]. This assumption states that the inclusion or exclusion of categories does not affect relative risks associated with explanatory variables at the level of remaining categories. We used the Hausman and MacFadden (1986) [53] approach to test the validity of this restriction by comparing the initial model with four alternatives. The tests[3] concluded that we could not reject the IIA Hypothesis for all four alternatives. Thus the results of the [53] test seem to justify the reliability of our results despite the small size of our sample.

With respect to the endogeneity test results[4] of the "organizational membership" variable, we could not reject the null hypothesis of non-endogeneity in our model. Indeed, the Wald test proved to be robust and indicated a statistic cor-

[3]The statistic of the test is calculated on the basis of this following formula: $\chi^2 = \left(\hat{\beta}_s - \hat{\beta}_E\right)\left[\hat{V}_s - \hat{V}_E\right]^{-1}\left(\hat{\beta}_s - \hat{\beta}_E\right)$ where the index S indicates the estimators based on the restricted sub groups of choices, the index E indicates those based on the set of possible choices whereas $\hat{V}_s$ and $\hat{V}_E$ are the respective estimates of the asymptotic covariance matrices. The statistic is distributed according to a χ^2 law with k degrees of freedom [53] [56].

[4]Regarding the endogeneity test results of the variable "membership organization", it was found that awareness, access to development projects, flow constraints and having a storage warehouse increase the probability of belonging to an organization among maize producers in Senegal (see **Appendix Table A2**).

responding to $Chi2(4)$. This test result indicates a statistic equal to 4.232 with a p-value of 0.376, which is above the level of 5%.

Table 4 presents the factors of adoption of improved seed maize in Eastern Senegal and High Casamance for each category of adopter. The adoption determinants analysis between adopter groups suggests similarities and dissimilarities.

4.1. Pioneers/Innovators Adoption Factors

The pioneers/innovators analysis showed that improved maize seed adoption is positively influenced by the frequency of access to agricultural advice, access to a development project, household size, availability of workforce and shock occurrence, such as deaths. These results are in line with those of Moser and Barret [14] and [57] regarding access to counselling services and those of Uaiene (2011) [33] regarding development projects that provide credits. The results also suggest that complementary input components are a promising way to promote adoption in Senegal. This finding is consistent with Adegbola *et al.* (2011) [58] study regarding household size. It also agrees with those of Ryan and Gross (1950) [24], according to which pioneers are more likely to adopt because of the availability of their labour force. This may suggest that these three groups of producers are adopting improved maize seeds not only to ensure their household food security but also because they have more labour.

However, maize plot number, the presence of shocks such as illnesses and the number of meals eaten per day by children under 5 years reduce the pioneers' probability of adoption. Finally, flow constraints were found to be an important determinant of non-adoption among pioneers/innovators. This result raises the importance of developing projects and programs that can facilitate the flow of production to maize producers in Eastern Senegal and High Casamance.

4.2. Follower Adoption Factors

Compared to other groups, we found that age and literacy are specific determinants of adoption among followers. This result differs from that of Ryan and Gross (1950) [24], who showed that pioneers are the most literate. In terms of age, the results also invalidate those of [13], who found that the probability of adoption decreases with age in the category of late adopters. It also invalidates those of Lapple and Van Rensburg (2011) [22] in which the pioneers are older.

These first results may thus suggest that older maize producers are more risk averse and tend to wait for improved seed adoption advantages by younger producers before considering using them. This raises the importance of awareness projects and encourages older producers to understand the importance of new agricultural technologies usage. Among followers, adoption is also positively influenced by the frequency of access to agricultural advice and being the victim of shocks such as loss of family members. This finding is consistent with the study of Dercon and Christiansen (2011) [44] and [59] who point out that, to mitigate the risks of shocks, farmers adopt agricultural technologies.

4.3. Late Adopter Adoption Factors

As in the case of the pioneers and followers, the probability of adoption of improved maize seeds in the late adopter producer group increases with their frequency of access to agricultural advice, access to development projects and their household size. These results are in line with those of Moser and Barrett (2006) [26], Lambrecht *et al.* (2014) [18] and Barham *et al.* (2018) [57], who showed the importance of access to information for adoption. In particular, the provision of storage infrastructure and being located in the Tambacounda region improve the probability of adoption in this group. This result corroborates those of [58] study, according to which the adoption of storage innovations is important in Africa. However, the high number of their maize plots, diseases and production flow constraints reduce their probability of adoption. This conclusion is not surprising in the literature, since improved maize seeds are often used to solve performance issues rather than for area extension. Some studies such as Adeoti *et al.* (2003) [5] and Diederen *et al.* (2003) [23] even showed that a large area size might serve as a barrier to the adoption of agricultural technologies because of the need for related inputs.

4.4. Laggard-Abandoner Adoption Factors

The fact that the household head is a woman increases the probability of adoption in the laggard group but is not significant. The results are the same when we compare abandoners with other groups. These conclusions differ from those of [40], who show that female household heads are less likely to adopt agricultural technologies than male household heads. In addition, even if the frequency of access to agricultural advisory services was found to be a positive and common determinant of adoption among pioneers, followers and late adopters, this variable was non-significant among laggards. This suggests that to ensure sustainability and adoption of improved maize seeds and their impact, producers must have equitable access to their local agricultural advisory services.

Food insecurity in terms of availability also encourages adoption among abandoners. This means that improved maize seed adoption has a significant impact on food security [60]. In addition, the location of the farm in the region of Tambacounda increases the likelihood of adoption by abandoners, while residing in Kolda decreases the likelihood of adoption by abandoners. Land availability in Tambacounda could explain this difference. Finally, if shocks such as death increase the probability of adopting among pioneers and followers, they are a source of abandonment in this category of producers.

5. Conclusions

In this paper, we analyzed the dynamics and adoption factors of improved rainfed maze varieties distributed in Senegal within the framework of the West

Africa Agricultural Productivity Program in Eastern Senegal and High Casamance zones. The data came from a survey of 336 maize producers conducted by the Consortium for Economic and Social Research in collaboration with the World Bank.

The initial hypotheses tested in this research were as follows. First, improved maize seed adoption is not necessarily dichotomous; it is a process that takes place in several groups of adopters in Senegal. Second, the characteristics of different groups of adopters can be heterogeneous and influence individual factors in the adoption of improved maize seeds in Senegal.

To test our hypotheses, we grouped adopters into four groups (pioneers/innovators, followers, late adopters and laggards), performed statistical tests and estimated a multinomial logit model with and without unobservable heterogeneity.

Statistical test results revealed significant differences between the adopter groups, thus corroborating the first hypothesis tested. The results show that the frequency of access to agricultural advisory services, access to development projects, labour availability and shocks positively affect the pioneers group. However, liquidity constraints and a high number of plots decrease their likelihood of adopting maize seeds. Producers belonging to the follower category tend to be older and more literate than those in other categories are. However, food security and shocks such as diseases hamper their adoption. Among late adopters, the size of their household and the availability of storage facilities such as inhabited rooms explain adoption. However, plot number and shocks reduce their probability of adopting. Finally, the laggards group tends to face shocks and have food security.

In terms of policy implications, it is important that innovations be diffused in practice first, taking into account the heterogeneity of the characteristics of farmer groups. Our results also suggest that agricultural technological innovation diffusion programs in Senegal should incorporate several strategies: distribution of complementary inputs such as credit, agricultural advice, storage infrastructure, equitable dissemination of information, and training sessions for better adoption should accompany the distribution of improved seeds.

Indeed, in the context of developing countries such as Senegal, farmers often do not have sufficient access to agricultural production resources. As a result, it will be difficult for them to adopt or adopt continually technological innovations. Thereby, successful improvement of agricultural productivity requires improvement of several contributing factors other than simply improved seeds.

Finally, given the youthful nature of most adopters groups, significant efforts to raise awareness should be made among older farmers. Women farmers should also be encouraged to adopt improved maize seeds.

Regarding the limitations of this paper, because of the small size of our sample, we could not include another possible category of adopters, namely, those who partially give up and come back. It would be interesting to include them in other WAAPP evaluation studies.

Acknowledgements

The authors would like to express their profound thanks to the Consortium for Economic and Social Research (CRES) in Senegal, who kindly provided the data used in this paper.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. Variables description

Variables	Description
Sociodemographic and economic characteristics of the producer	
Gender	If producer is a man = 1 if producer is a woman = 0
Head of household	Producer is the head of his household = 1, = 0 otherwise
Age	Age of the producer in the past year
Instruction	Producer went to school = 1, producer never went to school = 0
Literacy	If the producer can read and write in at least one of the languages (French, Arabic, national language other languages) = 1, = 0 otherwise
Production flow constraints	Producer has flow constraints of his production = 1, = 0 otherwise
Organization	Producer is a member of an association = 1, = 0 otherwise
Development project	Producer benefits from at least one of the development projects (credit, input, access to the market) = 1, = 0 otherwise
Awareness, training, information	
Awareness	Producer has access to information on improved seed varieties = 1, 0 otherwise
Training	Producer has been trained in the use of varieties = 1, 0 otherwise
Technical sheet	Producer has an improved maize seed technical data sheet = 1, 0 otherwise
Agricultural advisor access	The number of times the producer has received agricultural advice
Producer household	
Household size	Number of household members of the producer
Transfers	Producer receives transfers from one family member = 1, = 0 otherwise
Female household head	The producer's head of household is a woman = 0, = 1 otherwise
Insurance	The producer's household subscribed to agricultural insurance = 1, 0 otherwise
Farms Characteristics	
Storage	If the producer has storage means 1 = loft, 2 = inhabited room, 3 = storage warehouse, 4 = other
Animal traction	Producer uses animal traction = 1, 0 otherwise
Labor force	Number of people working on the farm
Region	The farm is located in the region of Tambacounda or Kolda
Number of maize plots	The number of maize plots in farm
Soil constraints	The farmer's farm is at least confronted with one of the constraints (silting, steep slope, water stagnation, parasitic plants, water erosion, wind erosion, 7 Grass cover, animal straying) = 1, 0 Otherwise
Food security	
Children meals (−5 years old)	The number of meals taken per day by children under 5 years in producer household
Adult meals	Number of meals taken per day by adults over 5 years of the producer's household
Food insecurity	If the number of meals taken per day per child and adult varies (1 = down, 0 = up or constant)
Shocks	
Disease	The producer's household members are ill in recent months = 1, = 0 otherwise
Death	Producer's household member is the victim of death in the last months 1, = 0 otherwise
Losses	The producer' has lost its main production tool in the last months 1, = 0 otherwise

Source: Authors, 2020.

Table A2. Determinants of organizational membership.

Variables	Coefficients	Z
Gender (Man)	0.334	0.84
Awareness	0.329*	1.81
Training on technical itinerary		
Age	0.013	1.42
Instruction	−0.102	−0.32
Literacy	0.443	1.56
Agricultural advisor access frequency	0.005	0.08
Production flow constraints	0.528*	2.30
Development projects	0.960***	3.68
Storage		
Room place	0.514*	2.10
Warehouse	1.010**	2.91
Other types of stock	1.920**	2.70
Household size	−0.004	−0.22
Labor force		
Animal traction	0.157	0.67
Number of maize plots	0.008	0.08
Children meals (−5 years old)		
Adults meals		
Food insecurity(decease)	−0.364	−1.30
Death	−0.117	−0.31
Disease	0.440	1.57
Losses	−0.424	−1.27
Constant	−3.10***	−4.54
LR Chi2 (19) = 103.77		
Pseudo R^2 = 0.329		
N = 303		

Source: Authors' calculations based on CRES survey data (2015-2016).