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Abstract

Maize occupies a prominent place in Benin's agricultural sector in that it is widely consumed and represents a potential source of foreign exchange for the country. The objective here is therefore to analyse the effects of adopting improved seed varieties on productivity in Benin. More specifically, it aims to (1) identify the factors that influence farmers' decisions to adopt improved maize varieties, and
(2) estimate the impact of adopting improved seeds on maize yields. The data used are secondary and extracted from the database of the Agricultural Policy Analysis Programme of the National Institute for Agricultural Research of Benin (PAPA/INRAB) and cover a random sample of 356 maize producers. Using the regime-switching regression model to control for potential selection bias and unobserved heterogeneity issues, it is shown that access to credit, the amount of fertiliser used, technical support and membership of a farmers' organisation are among the factors that determine the adoption of improved maize varieties by farmers. Furthermore, the results clearly show that the adoption of improved maize seed varieties is associated with improved productivity among adopters, suggesting that efforts to disseminate improved varieties to non-adopters should be continued to maximise the benefits inherent in this innovation.

Keywords: Adoption, maize, improved seeds, endogenous partition model, Benin

JEL codes:

1. Introduction

Agriculture plays a major role in Benin's economy. It contributes around 28% to GDP and employs over 70% of the working population. The agricultural sector is mainly focused on cotton and food crops. Maize accounts for approximately 14.1% of food production and, in 2018, represented 76% of total cereal production in Benin, although this proportion fell to 73% in 2019 (DSA, 2020). However, the yields achieved are still below the country's potential. For example, while the reforms set a target of 1.91 tonnes per hectare in 2019, the level achieved was around 1.08 tonnes per hectare. There are several factors that explain this low level of productivity.

The literature distinguishes between exogenous factors that are beyond farmers' control, such as floods, irregular rainfall, insect damage, etc., and endogenous factors that depend in part on farmers' decisions (Assouto et al., 2020). Among the endogenous factors is the use of technologies aimed at improving yields. In this vein, high-yielding seed varieties are considered necessary to increase productivity in the agricultural sector. Numerous studies suggest that the use of improved seeds not only stimulates the transition to high yields (Just and Zilberman, 1988; Nata et al., 2014; Ghimire et al., 2015) but also contributes to improving the livelihoods of smallholder farmers (Afolami et al., 2015, Asfaw et al., 2012). Tufa et al. (2019) confirm the gains from adopting improved seed varieties in terms of both productivity and income. Despite the positive effects of improved seeds clearly highlighted in the literature, the adoption of such seeds remains low.

The low uptake of seeds reflects the inherent difficulties facing the agricultural sector in developing countries in general. In Benin, for example, only 7.7% of farmers use improved seeds (WFP, 2017). Most farmers, 66.5%, use seeds from their own harvest to plant new crops. Traditional maize varieties are still widely cultivated. Improved varieties account for only 47% of maize land (MAEP, 2016). The low levels of adoption of improved seed varieties have been the subject of numerous studies (Nguyen, 2019; Mdemu et al., 2017; Mabah Tene et al., 2015). Most of these studies point to education levels, access to credit, non-agricultural income, land tenure and the availability of improved seeds as the main barriers to the adoption of innovative technologies. While there is a wealth of literature on the determinants of improved seed variety adoption, very few studies simultaneously address the impact in terms of productivity.

However, growing demand for maize and declining productivity could lead to a threefold increase in imports of this product in developing countries by 2050 [Food and Agriculture Organisation (FAO), 2016]. A policy aimed at improving maize productivity is therefore necessary to make up for this shortfall. In this regard, another body of literature argues that improving productivity has implications for the economy (Douillet and Girard, 2013; Thirtle et al., 2003). Douillet and Girard (2013) postulate that increased productivity can boost both producers' incomes and consumers' purchasing power by lowering unit production costs. It also stimulates production and consumption and is therefore a major driver of economic growth and rising living standards in the medium term, especially in developing countries. According to Thirtle et al. (2003), a 1% increase in agricultural productivity by 1% reduces poverty by 0.6%, and a 1% increase in production reduces the number of people living on less than a dollar a day by 6 million in Africa.

Studies examining the link between the adoption of improved seeds and well-being are based on the strong assumption that the adoption of innovation, as measured by the use of improved seeds, leads to increased productivity, which in turn has a positive impact on well-being. However, it is unlikely that the adoption of improved seed varieties will lead to increased productivity if certain conditions are not met. These include, for example, access to certified fertilisers and technical support, which are factors that can determine the effectiveness of the technology. This article attempts to understand the productivity gains from adopting seed varieties by controlling for these factors. Furthermore, the few studies that examine the relationship between the adoption of improved seeds and productivity focus either on a specific region (see, e.g., Khonje et al., 2015) or on crops other than maize (Tuffa et al., 2019). However, maize is a crop that plays a central role in Benin's agricultural sector.

Maize is indeed the most widely grown crop in Benin. Eighty-five per cent of farmers in Benin produce maize, which is currently the leading food product, far ahead of rice and sorghum [World Food Programme (WFP), 2014]. Maize is also the only crop for which Benin is self-sufficient and produces a surplus. Maize cultivation is one of the priority sectors identified in Benin's Strategic Plan for Agricultural Development (PSDSA) to promote and guarantee food security and poverty reduction (MAEP, 2018). Maize is consumed in all regions of Benin. More than 70% of the population in southern and central Benin eat maize on a daily basis, with an estimated average annual per capita consumption of 69 kg (MAEP, 2018). It is gradually becoming a cash crop and is even seen as a crop that could generate significant foreign exchange for the country. This research therefore aims to fill the gap in the literature by simultaneously examining the determinants and impact in terms of productivity of the adoption of improved maize seed varieties based on a nationally representative sample of producers in Benin's agricultural sector.

It answers two main research questions: What factors influence the decision to adopt improved maize varieties? What is the impact of adopting improved seeds on maize yields? The overall objective of this research is to analyse the effects of adopting improved seed varieties on productivity in Benin. Specifically, it aims to (i) determine the factors explaining the adoption of improved maize seed varieties by producers in Benin and (ii) to estimate the impact of the adoption of improved varieties on maize productivity in Benin.

The rest of the article is organised as follows. Section 2 describes Benin's agricultural sector, highlighting the importance of maize. Section 3 summarises previous work on the determinants of the adoption of improved maize varieties and their impact in terms of productivity. Section 4 outlines the methodological approach, while section 5 presents and discusses the results obtained. A final section concludes and presents the main policy implications.

2. The agricultural sector and the maize industry in Benin

The agricultural sector plays an important role in Benin's economy. It employs at least 70% of the working population, contributes nearly 36% of GDP and provides approximately 88% of Benin's export earnings (Ministry of Agriculture, Livestock and Fisheries (MAEP), 2018). However, production remains dominated by small farms with an average area of 1.7 ha, on which an average of 7 people live. Approximately 34% of farms cover less than one hectare. Only 5% of farms in southern Benin and 20% in northern Benin cover more than 5 ha. Of the 11 million hectares of gross available land, just under 60% is suitable for agriculture (MAEP, 2011). The main food crops in Benin are maize, sorghum, yams, cassava, millet, rice and beans. Cotton and cashews are the main cash crops. Cereals occupy the largest cultivated area. Over the period 2003-2013, they accounted for an average of 49.5% of the area under cultivation. Next come roots and tubers (20.3%), legumes (15.5%), industrial crops (11.5%) and finally market garden crops (3.2%) in terms of area under cultivation

Cereal production rose from 1,027,884 tonnes in the 2003–2004 season to 1,691,863 tonnes in the 2013–2014 season, representing an average annual increase of 6.5%, which is higher than the estimated population growth of 3.5% (INSAE, 2015). Total maize production accounted for 77% and 76% of total cereal production in the 2012-2013 and 2016-2017 agricultural seasons, respectively. Maize thus contributes significantly to food security in Benin. Maize production is intended for domestic consumption and sale in urban and peri-urban markets. It is also used in animal feed (particularly poultry farming) and brewing. Part of the production is exported to neighbouring countries such as Nigeria, Niger and Togo. It should be noted that maize is used to make porridge, a common breakfast food for people of all ages and backgrounds. Maize is also used in the production of weaning foods for children and is used to make popular local beverages. It is also consumed as fresh maize, grilled maize, pasta, flatbread, etc., which provides a good marketing channel for maize.

However, it is important to note that domestic maize production far exceeded domestic consumption in 2014, resulting in a substantial surplus. During the 2014-2015 agricultural season, total maize production was 1,286,060 tonnes, while total consumption was 441,000 tonnes. This surplus declined in 2016 due to growing demand for maize on the market and very low maize yields. Following the 2008 global food crisis, the country now has a maize surplus because of the government's production stimulus measures. However, these various policies have had limited impact, as maize yields remain low compared to other countries in the sub-region such as Burkina Faso, Ghana and Nigeria (FAO Stat, 2016)[1]. The average maize yield in Nigeria is 1,661 kg/ha, in Burkina Faso it is 1,645 kg/ha, in Ghana it is 1,624 kg/ha and in Benin it is 1,184 kg/ha over the entire period. These statistics show that maize yields in Benin are still far below those of other countries in the sub-region, which explains the low productivity of maize in Benin. The real situation of production is revealed in its long-term analysis in Benin. The highest yields are achieved for improved maize (see Table 1). This shows the importance of using improved seeds to increase maize productivity.

Table 1: Evolution of local and improved maize yields in Benin in kg/ha

Year	2012	2013	2014	2015	2016
Improved maize	1,261	1746	1668	1547	1677
Local corn	1238	991	1169	1004	1048
Total maize	1251	1346	1399	1281	1376

Source: Author, based on data from the 2017 DSA.

[1]Table 6 in the Appendix shows the evolution of maize yield (in kg/ha) in Benin compared to that of countries in the sub-region (Burkina Faso, Ghana and Nigeria) between 2000 and 2014.

The West Africa Agricultural Productivity Programme (WAAPP) supports the maize sector through specific actions. Several agricultural technologies have been developed by the WAAPP's national agricultural research system. Seeds and planting materials for improved maize varieties have been developed by the National Institute for Agricultural Research of Benin (INRAB) and the Regional Agricultural Centres for Rural Development (CARDER), which have become Territorial Agricultural Development Agencies (ATDA). There are also improved varieties such as 2000 SYN-EE (75-day growing cycle), DMR (90 days) and TZPB-SR (120 days). An assessment of agricultural extension mechanisms reveals the existence of a National Agricultural Extension System (SNVA) whose missions include defining and implementing national agricultural extension policy and implementing a Village-Level Participatory Approach (APNV) to identify the individual and collective concerns of the community.

Since independence, Benin has tried out a bunch of different ways to help farmers and rural folks (MAEP, 2007). Some of the approaches they have tried in recent years to add to the existing system are the Family Farming Council (CEF), the Farmer's Field School, and the demand-driven approach. The extension systems in use according to agro-ecological zones are CARDER, CEF and PMA (Multi-Stakeholder Platform). The former SONAPRA was the only potential customer. Seed marketing is carried out through two channels: Seed Producer – SONAPRA – CARDER – Producers and Seed Producer – Producers. In the first channel, after producing the seed, the producer sells it to SONAPRA, which in turn makes it available to the CARDER in each locality at a subsidised price. Producers of maize for consumption obtain their supplies from the CARDER to produce maize for consumption. In the second channel, seed producers sometimes sell small quantities directly to producers. The main reason for the existence of this channel is the scarcity of seed experienced by maize producers at certain times of the year. This leads maize producers to draw on their stocks for production.

3. Literature review

This section provides a summary of the available literature on the determinants of farmers' adoption of improved seed varieties and the impact of improved seed adoption on productivity, and then reviews the empirical work carried out in Benin on this topic.

3.1 Determinants of the adoption of improved seed varieties

Numerous studies have examined the factors that influence decisions to adopt improved seeds in agriculture. These determinants can be classified into two categories: technical factors and economic factors.

3.1.1 Technical determinants of the adoption of improved seed varieties

The literature explains the low levels of adoption of improved seed varieties in the agricultural sector by technical constraints that make producers reluctant to use new seed varieties. Improved seed varieties are considered an innovation in agriculture, the adoption of which depends on the level of information available to farmers. Derwisch et al. (2016) estimate that farmers may not have access to the knowledge and technical skills related to innovation to increase their production. Chambers (1994) argues that farmers first seek to learn about the new technology, its features, advantages and disadvantages, and then form their own opinion before making a decision. Only farmers who have gathered all the relevant information about the seeds would then be ready to adopt them and express their willingness to do so. This leads Janvry et al (1991) and Feder et al (1985) to say that access to relevant information and access to seeds are important factors in determining the demand for the adoption of improved varieties.

In addition, farmers may be skeptical and resistant to change or simply unable to bear the risk associated with new technologies. Sánchez-Toledano *et al*. (2018) show that despite the productivity gains they generate, improved seed varieties may be less preferred by farmers. The explanation for this is that local varieties offer certain advantages, such as adaptation to local climatic conditions and stability in the face of climate variability. Timu *et al*. (2014) confirm the importance that producers attach to resistance to climate variability by opting for traditional seed varieties. Similarly, the preference for traditional varieties is greater in isolated production areas where soils are poor. Amare *et al*. (2012) and Ali *et al*. (2014) identified seed attributes as one of the factors affecting the demand for improved seed adoption.

Kopainsky *et al*. (2012) argue that the criteria for selecting a maize variety would be, in order of importance, yield potential and early maturity, followed by drought resistance. Ghimire *et al*. (2015) showed that technology-specific variables (yield potential and acceptability) are important in explaining adoption behaviour. The authors assert that perceptions that determine expectations regarding seed quality are dynamic and depend on environmental conditions.

Other equally relevant technical factors that can influence farmers' decisions to adopt technologies include farm structure and management (Hazell and Wood, 2008), sources of information (Abebaw and Belay, 2001) and availability of machinery (Feder et al, 1985).

3.1.2 Socio-economic determinants of the adoption of improved seed varieties

The literature on socio-economic factors influencing the adoption of agricultural technologies highlights the important role played by factors such as age, level of education, household size, experience, farm size, market access, extension services, membership of a farmers' association, income and access to credit (Nkonya et al., 1997; Mugisha and Diro, 2010; Amare et al., 2012; Kabunga et al., 2012; Mabah Tene et al., 2015; Ali et al., 2014). For example, Amare et al. (2012) point to yield and expected net profitability as factors explaining the adoption of improved seeds.

According to Ali *et al*. (2014), farmers only adopt improved seeds if they are convinced of the benefits or gains they can derive from them. This is consistent with the theory of expected utility and economic rationality, which states that individuals' choices are determined solely by their own interests. Mabah Tene *et al*. (2015) explain the low rate of adoption of technical innovations in Cameroon by the inadequacy of the technology package for the local production context and farmers' needs. Ouma and De Groote (2011) have shown that credit is an important factor in adoption. Indeed, access to credit enables producers to purchase agricultural inputs in real time (Mdemu *et al*., 2017).

Farmer income and fertiliser use are strongly and positively associated with the use of improved maize seeds (Kuti, 2015). Alene *et al*. (2000) shows that education level, family labour, farm size, extension services, farmer income.

The availability of improved seeds significantly influences the adoption of improved maize varieties. Survey results from farming households in Ethiopia show that the main barriers to the adoption of drought-tolerant maize by smallholder farmers are seed prices, insufficient resources, lack of information and seed unavailability (FAO, 2016). Barry (2016) notes that the variables influencing adoption are age, land area, membership of a farmers' organisation, number of cattle, distance from the market, contact with the agricultural agent, market value and good taste. Bezu *et al*. (2013) in Malawi use the instrumental variables model to control for endogeneity and selection bias due to factors affecting the decision to adopt improved maize varieties. The results show that the adoption of improved maize varieties is positively correlated with the producer's household consumption, income and assets. More recently, Nguyen (2019) highlights the important role played by land rights in the adoption of improved rice varieties by households in Vietnam.

3.2 Effects of adopting improved seed varieties on productivity

Previous studies have shown that the adoption of improved seeds is positively associated with overall productivity gains (Abdul-Rahaman *et al*., 2021; Bello *et al*., 2020; Donkor and Owusu, 2019; Dontsop Nguezet *et al*., 2012). Focusing on rice farmers in Nigeria, Bello *et al.* (2020) and Dontsop Nguezet *et al*. (2012) demonstrate the positive effects of adopting improved seed varieties. Mugisha and Diro (2010), in a study of maize farmers in Uganda, conclude that the adoption of improved varieties leads to increased yields. Abdul-Rahaman et al (2021), analysing the impact of the adoption of improved rice seeds in Ghana, found that farmers who adopt these seeds show higher efficiency and productivity levels.

However, the extent of productivity gains varies depending on the studies and the crops considered. For example, while Dontsop Nguezet *et al*. (2012) reported that farmers adopting NERICA and other improved rice varieties in Nigeria produced approximately 217 and 210 kg/ha more rice grain than non-adopters, Bello *et al*. (2020) estimate the productivity gain at 452 kg/ha for the same country. The difference in the two results for the same country reflects inconsistencies over time. For their part, Donkor and Owusu (2019) obtained a productivity gain of approximately 211-390 kg/ha in northern Ghana, representing an increase of 27-52%. In contrast, Abdul-Rahaman (2021) deduce a higher productivity gain of around 76% compared to non-adoption for the whole of Ghana. In Uganda, the productivity of farmers using improved maize varieties is significantly higher than that of producers using local varieties (Mugisha and Diro, 2010). The increase in productivity measured in kg/ha, induced by the adoption of improved maize varieties, is around 73.64%. Abdoulaye *et al.* (2018) found that, for the same crop in Nigeria, the adoption of improved maize varieties increased yields by 574 kg/ha.

Numerous other studies argue that the adoption of improved seed varieties is associated with improved well-being, based on the strong assumption that it leads to increased productivity. Thus, based on a bivariate probit model, Idrissa *et al*. (2012) found that the adoption of improved maize varieties significantly reduces food insecurity in rural Nigeria by improving yields. These results are confirmed by Audu and Aye (2014), who use a linear regression model to show that the adoption of improved seeds in Nigeria leads to improved producer welfare and, consequently, poverty reduction. Similar results were found by Becerril (2010), who uses the propensity score matching method and finds that the adoption of improved maize varieties contributes to an increase in per capita household expenditure on Mexico. Adoption also reduces the probability of poverty by 19–31%. The mean comparison analysis in the study by Issoufou et al. (2017) shows a positive difference of 211.74 kg/ha in yield between farmers who use improved millet varieties and their counterparts who do not. Khonje et al. (2015) used two different econometric approaches in the impact analysis of improved maize varieties for Zambia, namely endogenous regression with regime switching (ESR) and propensity score matching (PSM) models. The results revealed that improved maize varieties have a significant impact on poverty reduction in eastern Zambia. Similarly, the study by Shiferaw et al. (2014) in Ethiopia and that of Kassie et al (2014) in Tanzania use the propensity score matching method and show that the adoption of new varieties increases the food security of farming households.

3.3. Adoption of innovations by Beninese farmers

In Benin, several studies are available in the literature. The study conducted by the APRM (2015) on the impact of seed supply strategies on the adoption of improved maize varieties shows that the three main problems encountered by producers are the inaccessibility and unavailability of inputs, the unavailability of labour, and the fertiliser requirements of improved maize varieties. These various findings show that there is a strong correlation between the adoption of improved seeds and inorganic fertilisers. They also indicate that farmers' decisions to adopt these technologies are simultaneous. Furthermore, an analysis by Tokoudagba (2014) of the economics of maize production based on data collected for the 2012-2013 agricultural season showed that the purchase of mineral fertilisers and the depreciation of agricultural equipment were the most significant items of expenditure, accounting for 45% of the total costs incurred to produce one hectare of maize. Mahussi *et al*. (2017) showed that the variables influencing the intensity of improved maize seed use are the quantity of seed used, specific training received on the use of improved seeds, number of years of experience in production, and the proportion of annual agricultural income derived from maize production. Baco *et al*. (2011) show that around 11% of farmers purchased improved maize seeds during the 2007-2008 agricultural season, and there are several reasons for this low percentage. One of these is the low purchasing power of most farmers, and another is the poor coverage of the national territory by the structures responsible for supplying seeds to producers.

Boubacar et al. (2017) use the matching method to minimise selection biases induced by observable characteristics. The results showed that food expenditure increased by approximately 105,500 CFA francs per year with the adoption of certified seeds of improved varieties. The adoption of certified improved seeds reduces the poverty rate by 3.6%. Finally, a recent study conducted by the West and Central African Council for Agricultural Research and Development (CORAF/WECARD) provides a regional report on the impact of the adoption of improved maize varieties on the well-being of maize farmers in Benin, Burkina Faso, Côte d'Ivoire, and Mali (CORAF/WECARD, 2018). The results show that the adoption of improved maize varieties increases school enrolment expenditure by 13% and 10% for the coastal sub-zone (Benin and Côte d'Ivoire, respectively). In the Sahelian sub-zone, it is 4% and 7% (Burkina Faso and Mali, respectively). The results also indicate that the impact of adopting at least one of the improved maize varieties on profit is 47% and 34% for the coastal sub-zone (Benin and Côte d'Ivoire, respectively). In the Sahelian sub-zone, it is 13% and 29% (Burkina Faso and Mali, respectively). Finally, the results reveal that the adoption of improved maize varieties has reduced the incidence and intensity of poverty in all sub-zones. More recently, Houeninvo *et al.* (2018) highlight the importance of adopting improved maize varieties in increasing agricultural incomes.

The available literature shows that most past studies have focused either on the determinants of the adoption of improved seed varieties or on the impact on productivity. In addition, a body of literature deals more with the effects of adoption from the perspective of food security and well-being. There are few studies that link the adoption of improved seed varieties to maize productivity in Benin. Studies conducted in countries in the sub-region focus on rice (Abdul-Rahaman, 2021; Bello et al, 2020) or millet/sorghum (see Tufa et al, 2019). This article therefore makes a significant contribution to the literature by examining the impact on productivity of adopting improved maize seeds in a context where speculation plays a strategic role in the political priorities of public authorities.

4. Study methodology

4.1. Data source and sampling technique

The data used in this study are secondary and come from the database of the Agricultural Policy Analysis Programme of the National Institute for Agricultural Research of Benin (PAPA/INRAB). They cover 49 of Benin's 77 municipalities. The selected municipalities belong to different agro-ecological zones in Benin, particularly regions with natural conditions favourable to maize production. These choices were made considering the municipalities where maize seed multipliers and the extension system are located. Data collection was carried out in 2016. Ten (10) maize producers were randomly selected in each of the municipalities covered by the study. A total of 490 maize producers were surveyed, including 356 producers of maize for consumption.

The stakeholders who were the subject of focus groups were basic seed multipliers and maize producers. The stakeholders surveyed were those in the selected municipalities in the agro-ecological zones. Before arriving in each commune, the Rural Development Managers (RDRs) and packaging agents are contacted by telephone. A summary of the study is given to them, and they are then asked to mobilise the actors to be surveyed. Once on site, the focus group is conducted with the actors who responded to the call from the RDR and the packaging agent.

Data collection was carried out using interview guides. Two (02) guides were used. One was intended for certified seed multipliers and the other was used during focus group discussions with maize producers. Focus groups were facilitated with each of the stakeholders in the selected municipalities. Content analysis was used. The data collected each day in the municipalities during the interviews was transcribed. This step made it possible to assess the progress of the work to estimate what was being done each day and identify what needed to be focused on the following day. The data entered was then analysed and restructured for use.

4.2. Theoretical framework for analysis

According to neoclassical theory, farmers adopt new technologies if they bring them net economic benefits (Scherr 2000; Kabunga 2012). Thus, following the work of Kemeze *et al*. (2018), the adoption of improved maize varieties can be analysed within the framework of utility maximisation theory utility maximisation theory. Let U_{i1} be the utility derived from adopting improved maize varieties and U_{i0} the utility derived from non-adoption. The difference in utility between adoption and non-adoption is denoted *by* U_i. Farmer i will decide to adopt improved maize varieties when this provides him with greater utility than non-adoption. Mathematically, we have:

$$U_i = U_{i1} - U_{i0} > 0 \quad (1)$$

Since its benefits are not observable, this preference of the farmer can be represented by the latent variable A^*_i for the adoption of improved maize seeds:

$$A_i^* = \partial Z_i + \mu_i \quad (2)$$

$$A_i = \begin{cases} 1 \text{ if } A_i^* > 0 \\ 0 \text{ if } A_i^* < 0 \end{cases}$$

where A_i is the adoption variable, which takes the value 1 for adopters and 0 for non-adopters, Z_i is a vector of producer characteristics assumed to influence the decision to adopt improved varieties, and μ_i is the error term.

The model of the impact of improved variety adoption on maize yield is presented as follows:

$$Y_i = \alpha_i X_i + \beta_i A_i + v_i \tag{3}$$

where Y_i is the maize yield, α and β are the parameters to be estimated, and v_i is the error term.

4.3. Method of analysis

The models frequently used in adoption studies are: Heckman's selection model, propensity score matching (PSM), instrumental variable models (IV) and the *endogenous switching regression* (ESR) model. These models make it possible to control for the selection bias problem often encountered in impact evaluation studies. The decision to adopt maize varieties is not random. Each producer makes the decision to adopt voluntarily, and some producers are better placed than others to adopt improved seed varieties. For example, producers who benefit from technical support are likely to have a better understanding of the advantages of using improved seed varieties.

In this case, there may be observable or unobservable factors that influence the decision to adopt, creating selection bias. When this bias is due to unobservable factors (motivation, skills, etc.), the PSM and Heckman models do not allow for control of the endogeneity bias thus created. In this case, regime-switching models are more appropriate (Lokshin and Sajaia, 2004; Asfaw *et al*., 2012). Specifically, the ESR model is an econometric model that specifies a decision-making process and the regression models associated with each decision option. The advantage of the regime-switching model is that it allows simultaneous estimation of the adoption decision and the impact model when there is a non-random allocation of individuals to treatment and non-treatment groups. Thus, this model can be used to perform counterfactual analyses, i.e., to determine what the yield of the producer who used improved maize varieties would have been if he had not adopted them. Conversely, what would have been the yield of non-adopters if they had adopted the improved varieties? The use of the regime switch model (ESR) is therefore preferred in the following to obtain unbiased estimates.

The regime switch model involves separate estimates for the two groups of producers. Consequently, the adoption of improved varieties becomes the selection criterion indicating the regime (adoption or non-adoption) to which producers belong. A producer is adopting improved seed varieties if he or she uses only improved seeds for production purposes.

Following equation (2), maize yields are observed for both groups of producers (Maddala, 1983; Asfaw *et al.,* 2012).

$$\text{Regime 1:} Y_{1i} = \alpha_1 X_{1i} + v_{1i} \text{ (adopters)} \tag{4}$$

$$\text{Regime 2:} Y_{2i} = \alpha_2 X_{2i} + v_{2i} \text{ (non-adopters)} \tag{5}$$

where Y_i is maize production per hectare, X_i is a vector of exogenous variables affecting maize yield, and v_i is residues.

It is likely that the error term in the adoption Equation (2) and the error terms in the outcome Equations (4) and (5) are correlated. To resolve this issue, equations (2), (4), and (5) will be estimated simultaneously using the full information maximum likelihood method, which remains the most effective approach (Lokshin and Sajaia, 2004).

$\mu_i v_{1i}$ and v_{2i} are assumed to have a trivariate normal distribution with zero mean vector and a covariance matrix of the form:

$$COV(\mu_i, v_{1i}, v_{2i}) = \begin{bmatrix} \sigma^2_\mu & \sigma_{1\mu} & \sigma_{2\mu} \\ \sigma_{1\mu} & \sigma^2_1 & \vdots \\ \sigma_{2\mu} & \cdots & \sigma^2_2 \end{bmatrix}$$

where σ^2 is a variance of the error term in the selection equation, and σ_1^2 and σ_2^2 are the variances of the error terms in the continuous equations. $\sigma_{1\mu}$ is a covariance of μ_i and v_{1i}, and $\sigma_{2\mu}$ is a covariance of μ_i and v_{2i}. The covariance between v_{1i} and v_{2i} is not defined, because Y_{1i} and Y_{2i} are never observed simultaneously. We can assume that $\sigma^2_\mu = 1$ (∂ is only estimable up to a scalar factor). The model is identified by construction through non-linearities.

Following previous studies (Carter and Milon, 2005; Di Falco *et al.,* 2011; Asfaw *et al.,* 2012), the regime-switching regression model is used to compare maize yields of adopters of improved varieties with those of non-adopters and to estimate expected yields in the counterfactual case where non-adopters adopted. These measures are important for explaining the yield differences between the two groups and for providing possible responses to changes in seed policy. The conditional expectations for maize yield are presented in Table 2.

Table 2: Conditional expectations and treatment effects

	Decision stages		Average treatment effect (ATE)	Gain (in %)
	Adopters	Non-adopters		
Adopters	(a) $K(y_{1i}\|A_i = 1)$	(b) $K(y_{2i}\|A_i = 1)$	(a)-(b) $K(y_{1i}\|A_i = 1) - E(y_{2i}\|A_i = 1)$	$((a) - (b))/(b)$

Note: (a) indicates actual expectations, while expectations in the counterfactual case are presented in (b).
Source: Author based on literature

The effect of adopting improved varieties on adopters is expressed by equation (6). It is the "treatment effect on the treated" (TT), which is the difference between cases (a) and (b) (Heckman *et al.,* 2001; Asfaw *et al.,* 2012).

$$TT = K(y_{1i}|A_i = 1) - K(y_{2i}|A_i = 1) \quad (6)$$

4.4. Study variables

This section presents the main variables used in the econometric estimation.

Yield (kg/ha): Yield is the dependent variable in productivity models. It is measured by the ratio of production (kg) to area planted (in ha). When the level of yield recorded after using a technology is high, households are more willing to intensify the level of adoption in order to hope for even better yields.

Access to credit: One of the main obstacles facing actors in the agricultural sector is the lack of access to credit for short-term working capital and medium-term capital investment. Banks are generally reluctant to take the risks involved in lending to agricultural businesses. When banks and other formal financial institutions do engage in agricultural lending, it is only to registered producer groups and well-established agribusinesses, and under conditions of very high over-collateralisation involving title deeds or, if title deeds are not available, a lien on equipment and insurance for perishable crops, a personal guarantee and/or a substantial bank deposit. Most farmers have low purchasing power, which affects the continued use of improved seeds. They provide their own human and physical capital inputs. The study by Ouma and De Groote (2011) shows that access to credit has a positive effect on the continued use of improved maize seeds. Access to credit is a binary variable that takes the value 1 if the respondent has access to credit and 0 otherwise.

Technical support: Indirect actors such as INRAB, CERPA and other agricultural extension services play an important role, as they are responsible for providing improved seeds to producers. Demand for improved seeds is low in Benin due to the prevalence of farming practices that involve using seeds from the previous season's harvest. However, these services must be in constant contact with producers to provide them with training and information on new technologies to adopt in order to improve yields. This reinforces the continued use of improved seeds. It is also a binary variable that takes the value 1 if yes and 0 if no.

Age: Older farmers may adopt new technology in order to increase their production and thus limit the risks inherent in farming. Sall (2000) showed that older farmers can easily adopt and maintain the use of technology more readily than younger farmers because they have accumulated capital, have access to land, or have large families. On the other hand, young farmers may have a longer planning horizon and be more willing to take risks (Zegeye et al 2001). However, other studies have highlighted the ambiguous effect of age on the adoption of improved seed varieties (Barry, 2016). This is a continuous variable expressed in number of years. It also captures the effect of experience, especially since correlation tests have shown that there is a strong correlation between age and producer experience.

Gender: Smale *et al*. (1991) showed that female-headed households are less likely to adopt technologies than male-headed households because women are generally risk-averse. The variable "gender" can be either positively or negatively related to the adoption and continued use of improved seeds, taking men as the reference. The Gender is a binary variable with female as the reference, i.e. it takes the value 1 if the farmer is male and 0 if the farmer is female.

Education: Education, which includes skills and training, affects the expected gains from adopting modern technologies. These human capital assets reflect the unobservable productive characteristics of the decision-maker, in this case the producer (Uduji and Okolo-Obasi, 2018). Education increases farmers' ability to obtain, process and use information relevant to technologies.

Family and hired labour: Labour is a classic and decisive input in explaining the level of production. Here, it is broken down into family labour and hired labour measured in man-days. The breakdown is inspired by the work of Asfaw *et al*. (2012).

Membership of a farmers' organisation: The organisation of producers into groups or structures plays a decisive role in reducing transaction costs. Producer groups can also be seen as frameworks for training, exchange and replication of farming practices.

Use of fertilisers: Inputs, in this case fertilisers, are a component of the technological package used in agriculture. The use of these fertilisers makes plants more resistant to disease and thus improves production.

Table 3 below presents a description of the variables used and the expected signs.

Table 3: Description of variables used in the endogenous partition model

Models	Descriptions	Measures	Expected signs	
			(1)	(2)
Production variables Production	Yield	Kg/ha	Dependent variable	
	Area sown	In ha	−	+
	Fertiliser quantity	kg/ha	+	+
	Seed quantity	Kg/ha	+	
	Family labour	Man-days	+	
	Salaried labour	Man-day	−	
	Producer's income	Fcfa	+	
Producer characteristics	Adoption of improved seeds	1= Yes and 0 = No	Dependent variable	
	Age	In years		+/−
	Gender	1= male and 0= female		+
	Member of a farmers' organisation	1 = Yes and 0 = No	+	+
	Agricultural training	1 = Yes and 0 = No	+	
Institutional variables Institutional	Access to credit	1= Yes and 0 = No		+
	Education	1= Yes and 0 = No		+
	Technical support	1 = Yes and 0 = No		+
	Farmers' organisation	1= Yes and 0 = No	+	+
	Agriculture as primary main	1= Yes and 0 = No		+

Note: Columns (1) and (2) show the expected signs for the productivity model and the adoption model, respectively.

Source: Author

5. Data description

The adoption of improved maize varieties remains relatively low in Benin (Table 4). Overall, 57% of maize producers reported that they use improved varieties. Analysis by region shows that 75% of producers in northern Benin used improved seeds, compared to 42% in the centre and only 29% in southern Benin. This trend can be explained by the fact that northern Benin remains the largest maize-producing area in Benin. It therefore receives more attention in terms of agricultural intervention policies. These disparities between areas can also be explained by the fact that producers in the north, who have long been involved in cotton production, are increasingly interested in growing maize, which is considered a cash crop by most producers in the region. Maize has become a cash crop for these producers as a means of improving their financial situation. The climate in the north is more characterised by drought, so improved varieties with a short growing cycle are favourable for this area. In addition, maize is grown more in the northern part of Benin, which acts as the country's breadbasket and where producers are more focused on marketing. In contrast, in the south, where maize is part of the diet, producers consume all or part of their production. However, in terms of the organoleptic characteristics of fresh maize, consumers prefer local maize to improved varieties.

Table 4: Distribution of improved maize seed adoption in Benin

	Benin	Region		
		North	Centre	South
Adopters (%)	57	75	42	29
Non-adopters (%)	43	25	58	71

Source: Author based on survey data, 2016 PAPA/INRAB

Table 5 presents descriptive statistics and tests of equality of means for continuous variables, as well as tests of equality of proportions for binary variables between adopters and non-adopters.

Table 5: Socio-economic characteristics of respondents

Variables	Overall	Adopters	Non-adopters	t-test/Chi-square
Yield	1283.38	1381.79	1151.304	-2.854***
Age	52.05	51.51	52.76	1.11
Gender	96.62	97.54	95.39	1.24
Education	50.28	47.05	54.6	1.98
Area sown	2.38	2.51	2.21	-3.32***
Experiment	30.29	29.53	31.32	1.45
Technical supervision	44.94	51.47	36.18	-2.894***
Farmers' organisation	33.71	40.68	24.34	-3.266***
Access to credit	16.29	21.08	9.87	-2.857***
Fertiliser	198.83	220.2	170.14	-4.70***
Agricultural training	51.69	47.06	57.89	2.030

Note: ***, **, * significant at 1%, 5%, 10% respectively

Source: Author based on survey data, 2016 PAPA/INRAB

Maize producers have an average age of 52 and are predominantly (97%) men (Table 5). They have an average of 30 years' experience in maize production. Approximately 50% have primary education level. The price of improved seed is 194.35 CFA francs. No significant differences were observed between adopters and non-adopters of improved maize varieties in terms of age, gender, education, production experience and input prices.

Very few producers (16%) have access to credit, and there is a significant difference between the two groups. Adopters (21%) have greater access to credit than non-adopters (10%). Adopters (51%) of improved seeds have greater access to technical support services than non-adopters (36%). Less than half (34%) of producers belong to farmer organisations (FOs). However, the difference is significant for both groups. A significantly higher number of adopters belong to FOs. These results indicate that access to institutional services such as credit, extension services and membership of a PO would encourage the adoption of improved maize seeds. The average area sown tends towards 2.4 ha, and adopters have a significantly larger area (2.51 ha) than non-adopters (2.21 ha). Similarly, adopters have higher yields (1381.79 kg/ha) than non-adopters (1151.304 kg/ha), with an average production of 1283.38 kg/ha. The results of the descriptive statistics clearly show that the adoption of improved maize seeds is positively associated with socio-economic variables such as area sown, fertiliser use, agricultural training, yield, etc.

Furthermore, the adoption of improved maize seeds is also positively influenced by institutional variables, including access to extension services, membership of a farmers' organisation (FO) and access to credit. One of the main obstacles faced by actors in the agricultural sector is the lack of access to credit for short-term working capital and medium-term capital investment. Most farmers have low purchasing power, which affects the continued use of improved seeds. They provide their own human and physical capital inputs. Ouma and De Groote (2011) have shown that credit is an important factor in adoption. Indeed, access to credit enables producers to purchase agricultural inputs in real time (Mdemu *et al*., 2017). POs are frameworks for the exchange and replication of farming practices. Barry (2016) also showed that membership of a farmers' organisation influences adoption. Alene *et al*. (2000) showed that extension services significantly influence the adoption of improved maize varieties. The role of indirect actors such as INRAB, CERPA and other agricultural extension services is very important because they are responsible for providing improved seeds to producers. Demand for improved seeds is low in Benin due to the predominance of farming practices that involve using seeds extracted from the previous season's harvest. However, these services must be in constant contact with producers to provide them with training and information on new technologies to adopt to improve yields. This reinforces the continued use of improved maize seeds.

Analysis of the results shows that the adoption of improved maize seeds is positively influenced by institutional and socio-economic variables. It is noted that non-adopters lose out in terms of information, i.e. adopters have greater access to extension services and OP. Agricultural intervention policies must work to bring those who are not in the system into the system.

6. Results and discussions

The results of the regression model estimation are shown in Table 6. The log-likelihood test indicates that the model is globally significant. Thus, the model specification is good, and the variables selected effectively explain the adoption of improved seeds and determine the impact in terms of productivity of the use of improved seeds. The results presented in Table 6 concern, on the one hand, the determinants of the adoption of improved maize varieties among Beninese farmers (see column 1) and, on the other hand, the determinants of productivity among both adopters and non-adopters (see columns 2 and 3).

Table 6: Maximum likelihood results of the regime change model

Variables	Selection equation	Maize yield (kg/ha)	
		Non-adopters	Adopters
Log income	-0.003	0.013	0.010***
	(0.017)	(0.008)	(0.004)
Member of a farmers' organisation (1=Yes)	0.290	0.211	-0.016
	(0.167)	(0.085)	(0.041)
Log Quantity of fertiliser per hectare	0.129	0.075	0.056
	(0.057)	(0.020)	(0.033)
Log Area sown (in ha)	-0.413***	-0.361	-0.451
	(0.133)	(0.062)	(0.055)
Log Family labour per hectare		0.057	0.043
		(0.029)	(0.025)
Log Salaried labour per hectare		0.042	-0.037
		(0.035)	(0.031)
Log Quantity of seeds per hectare		-0.025	0.012
		(0.059)	(0.038)
Agricultural training		0.078	0.112
		(0.053)	(0.042)
Production region (Ref.= *South*)			
Centre	0.979	0.188	-0.222
	(0.237)	(0.120)	(0.138)
North	-0.106	-0.084	-0.133
	(0.235)	(0.075)	(0.123)
Formal education (1=Yes)	0.119		
	(0.131)		
Age	0.086		
	(0.056)		
Age*Age	-0.001		
	(0.000)		
Gender	0.032		
	(0.313)		
Access to credit (1=Yes)	0.353		
	(0.172)		
Technical support (1=Yes)	0.355		
	(0.142)		
Agriculture as main activity (1=Yes)	0.396		
	(0.198)		
Constant	-3.291**	6.587***	7.134***
	(1.604)	(0.237)	(0.218)
N	356	152	204
σ_i		-0.812***	-1.192***
		(0.156)	(0.079)
ρ_i		1.221	-0.021
		(0.359)	(0.379)
Wald statistic χ^2		87.74	
Log likelihood		-298.341	
LR test of independence of equations $\chi^2(2)$		11.69	

Note: Robust errors are shown in brackets. * p<0.1; ** p<0.05; *** p<0.01

Source: Author, PAPA/INRAB data (2016).

The results show that the parameterρ_0 which measures the correlation between the error term of the adoption equation and the productivity equation of non-adopters is significantly different from zero. This implies that if non-adopters choose to adopt improved seeds, the effect may not be like the effect on adopters because there are systematic differences between adopters and non-adopters. In other words, there is self-selection in the adoption of improved seeds. Self-selection in the treatment exists if ρ_0 or ρ_1 is significantly different from zero (see Lokshin and Sajaia, 2004). Given that ρ_0 is positive and significantly different from zero, the model suggests that farmers who have not adopted improved maize seeds have lower yields than farmers randomly selected from the sample.

6.1 Determinants of the adoption of improved varieties and maize productivity in Benin

The results presented in Table 6 show that access to credit, the amount of fertiliser used, technical support, membership of a farmers' organisation, the area under cultivation and agriculture as the main activity, as well as the production region, are the main factors determining farmers' adoption of improved maize varieties. In concrete terms, access to credit has a positive influence on the decision to adopt improved seed varieties, confirming the predictions of Bello et al (2020) and those of Uduji and Okolo-Obasi (2018). Bello *et al*. (2020) warned against credit access constraints that could affect the adoption of improved rice seed varieties in Nigeria due to the financing problems faced by smallholders. Access to credit encourages farmers to purchase adequate quantities of inputs necessary for agricultural operations (Oladeji *et al*. 2015).

Improved seed varieties are very demanding in terms of certified fertilisers and therefore require significant financing. It is therefore not surprising that the amount of fertiliser has a positive influence on the adoption of improved seed varieties. Kuti (2015) shows that fertiliser use is strongly and positively associated with the use of improved maize seeds. Indeed, improved varieties require intensive fertiliser use to achieve better results.

Technical support has proven to be a determining factor in the adoption of improved seed varieties. This result is consistent with that of Mahoussi *et al*. (2017), who showed that specific advice on the use of improved seeds influences the intensity of their use. The support provided by the technical services of the Beninese Ministry of Agriculture enables producers to become better informed about the issues involved in adopting these varieties. While highlighting the benefits of improved maize seed varieties, the support provided to producers also serves as a means of equipping them with the tools they need to adopt new practices associated with the use of these varieties. Producers, whose objective is to maximise profit, see any process that enables them to increase their production as an opportunity to be seized. From this point of view, producers who receive training are more inclined to adopt improved seed varieties.

Farmers' organisations (FOs) also provide a forum for farmers to share their experiences on their different farms. Membership in such organisations therefore allows producers to benefit from positive externalities. Similarly, producers who are members of farmers' organisations have greater access to extension agents, as the latter find it more comfortable to work with umbrella organisations than with individual farmers (Bello *et al.*, 2020). Abdul-Rahaman *et al*. (2021) also assert that membership of a farmers' group plays an important role in the adoption of varieties.

arguing that group members can benefit from social capital to access improved seed varieties, chemicals and fertilisers, as well as essential services such as credit and extension services. Barry (2016) adds that POs are frameworks for the exchange and replication of farming practices. Similar results were obtained by Yahaya *et al*. (2019) and Khonje *et al*. (2015).

The area under cultivation is negatively correlated with the decision to adopt improved maize varieties. In other words, the larger the area under cultivation, the less likely farmers are to adopt improved seed varieties. Such results, *which may seem* counterintuitive *at first glance*, can be explained by producers' aversion to risk. In fact, farmers in Benin prefer to increase the area under cultivation to boost their production. Furthermore, increasing the area under cultivation implicitly increases the necessary input costs, forcing producers to draw on their previous harvest for the seeds needed to start the new production cycle. However, farmers who derive most of their income from agricultural activities are more inclined to adopt improved varieties. Undoubtedly, motivated by the desire to increase their agricultural income, they see these improved seeds as an opportunity to achieve their goals.

Furthermore, it appears that the decision to adopt varies according to the different production regions. The dummy variable for the "Centre" region included in the model proves to be statistically very significant, with the "South" region being the reference region. This indicates that farmers located in the centre of the country are more likely to adopt improved maize seeds than those in the south. One explanation for this is that the Central region is constrained by climate. Like the Northern region, this region has one production season per year, unlike the South, which has two seasons. Producers therefore use improved maize varieties to increase their production and thus overcome the difficulties associated with scarce rainfall. The results obtained confirm the conclusions of Asfaw et al (2012), which show that in Ethiopia, the decision to adopt improved varieties was highest in the district located on the main inter-state road, which is also a meeting place for farmers.

The estimated parameters of the productivity model for producers who did not adopt improved maize seed varieties and those who did are shown in the second and third columns, respectively. The results indicate that the coefficient for family labour is significant and positive for both farmers who have not adopted improved seed varieties and those who have. This result suggests that the use of family labour increases farmers' productivity. This result can be explained by the type of agriculture practised by farmers in sub-Saharan African countries, who rely more on family labour. This type of agriculture is essentially subsistence-based and uses unpaid labour based on a rotating mutual aid mechanism. Asfaw et al (2012) also highlight the importance of family labour in the cultivation of new chickpea varieties. Moral hazard associated with hired labour is put forward as a plausible justification. Such hazard makes hiring labour costly for households with a small family workforce. It is also possible that the new varieties require more work. They may require improved agronomic practices such as weeding and ploughing, and more work for harvesting or threshing.

In addition, the variable "quantity of fertiliser used" also shows a significant and positive coefficient in both productivity models. This result unsurprisingly confirms the importance of fertilisers in improving productivity, regardless of whether the producer has adopted improved seed varieties. On the other hand, membership of a farmers' organisation only affects only the productivity of farmers who have not adopted improved seed varieties, confirming the positive externalities they enjoy by participating in exchange meetings. Furthermore, the variables "income" and "agricultural training" show positive coefficients only in the productivity model for adopters. It follows that the availability of capital enables producers to meet working capital needs at the farm level by promoting the use of hired labour and the purchase of various inputs.

6.2 Effects on productivity of adopting improved maize varieties in Benin

Table 7: Observed and counterfactual maize yields for adopters.

	Observed	Counterfactual	ATT	Gain (in %)
Maize yield (kg/ha)	1304.775	1090.539	214,236	19.64
	(45,794)	(23,614)	(56,847)	

Note: Standard errors are shown in parentheses. ATT refers to the average treatment effect.
Source: Author, based on estimation results.

Table 7 presents the results of estimates of productivity gains resulting from the use of improved maize varieties. In light of the results presented in Table 7, the adoption of improved seed varieties has a positive and significant impact on yield in that it enables producers to increase their productivity. The average treatment effect on the treated (ATT) is positive, reflecting the existence of a productivity gain linked to the adoption of improved seed varieties. This gain is estimated at 214.236 kg per hectare, representing an increase of around 19.64%. This result, which is consistent with several theoretical predictions, nevertheless differs in terms of the magnitude of the productivity gain. Indeed, Abdoulaye *et al*. (2018) showed that the adoption of improved maize varieties increased maize yields by 32.6% in Nigeria. Similarly, Issoufou et al. (2017) showed that improved millet varieties increased millet yields by 406.93 kg/ha in Niger, representing a 42.25% increase. Tufa *et al*. (2019) also showed that the adoption of improved soybean varieties is associated with an average yield gain of 61%.

Overall, the results clearly show that the adoption of improved maize seed varieties is associated with improved productivity among adopters. Therefore, it will be essential to continue efforts to disseminate improved varieties to non-adopters to maximise the benefits inherent in this innovation, as a significant number of farmers have still not adopted these improved seeds. Indeed, currently only 57% of farmers use improved varieties.

7. Conclusion and policy implications

This study provides answers to the following questions: What factors influence the decision to adopt improved maize varieties? What is the impact of adopting improved seeds on maize yields? Despite the existence of numerous studies in Benin on the adoption of improved maize seeds, the link with agricultural performance variables has been little explored. The objective here is therefore to analyse the effects of adopting improved seed varieties on productivity in Benin.

The results show that access to credit, the amount of fertiliser used, technical support, membership of a farmers' organisation, the area under cultivation and agriculture as the main activity, as well as the production region, are the main factors determining farmers' adoption of improved maize varieties. About the estimated parameters of the productivity model, the results indicate that the amount of family labour and the amount of fertiliser used are sources of productivity improvement for farmers. In addition, the coefficient related to farmers' organisations is significant and positive only for producers who have not adopted improved maize seed varieties, reflecting the importance of positive externalities from exchange meetings in increasing productivity. On the other hand, income and agricultural training have a positive influence on the productivity of farmers who have adopted improved seed varieties.

It has also been established that the adoption of improved seed varieties generates clearly positive effects compared to the use of local seeds. Maize producers who have adopted improved seeds increase their yield by 19.64% compared to non-adopters.

The results of this study provide additional empirical evidence for the idea that the adoption of improved seed varieties is essential for increasing maize productivity in Benin. The results obtained can serve as a guide for the development of policy strategies aimed at increasing maize productivity in Benin. Firstly, it is necessary to strengthen the sector's financing mechanisms by removing the financial constraints on farms. Secondly, technical support services for producers must be strengthened through a paradigm shift from conventional means of supporting producers, where agents visit farmers, to modern techniques using ICT and media systems. For example, extension services could be provided through mobile technology or media platforms made available to producer organisations, as results have shown that farmers benefit significantly from exchange meetings organised by their umbrella organisations.

Finally, efforts must be made to establish an efficient distribution chain for inputs such as fertilisers and seeds to producers to facilitate their access. This could be achieved by encouraging a productive relationship between farmers' organisations and seed companies. To this end, seeds could, for example, be supplied to farmers through farmers' organisations.

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Appendix:

Table A1: Comparative evolution of maize yields in Benin and countries in the sub-region

	Benin	Burkina Faso	Ghana	Nigeria
2000	1148	1754	1458	1300
2001	1100	1816	1315	1400
2002	883	1738	1490	1490
2003	1190	1528	1627	1500
2004	1180	1267	1579	1600
2005	1145	1806	1561	1660
2006	1132	1944	1499	1818
2007	989	1174	1544	1705
2008	1251	1666	1737	1957
2009	1246	1529	1697	2196
2010	1103	1434	1887	1850
2011	1422	1536	1646	1627
2012	1262	1839	1871	1512
2013	1308	1735	1724	1462
2014	1399	1911	1729	1845
Average	1184	1645	1624	1661

Source: Author based on data from FAO Stat, 2016

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To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

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